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Review of sufficiency and effectiveness of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012

Report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012

Submitted by the Gothenburg Protocol review group

Summary

Following the entry into force of the 2012 amendment to the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) on 7 October 2019, and pursuant to article 10 of the Protocol, as amended, the Executive Body initiated the review of the Protocol at its thirty-ninth session (Geneva, 9–13 December 2019).

The present final report on the review is submitted by the Gothenburg Protocol review group at the request of the Working Group on Strategies and Review[a] based on the draft version the Working Group considered at its sixtieth session (Geneva, 11–14 April 2022). The report is accompanied by the documents entitled "Scientific information for the review of the Gothenburg Protocol" (ECE/EB.AIR/2022/4, unofficially referred to as annex I to the present report) and "Technical information for the review of the Gothenburg Protocol" (ECE/EB.AIR/2022/5, unofficially referred to as annex II to the present report).

The Executive Body is invited to adopt the final report on the review of the Protocol.

[a] ECE/EB.AIR/WG.5/128, para. 16, advance version.

I. Introduction

1. Following the entry into force of the 2012 amendment[1] to the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) on 7 October 2019, the Executive Body initiated the review of the Protocol at its thirty-ninth session (Geneva, 9–13 December 2019) (ECE/EB.AIR/144/Add.1, decision 2019/4) pursuant to article 10 of the Protocol. The 2016 scientific assessment of the Convention on Long-range Transboundary Air Pollution (Air Convention),[2] its policy response (ECE/EB.AIR/WG.5/2017/3 and Corr.1) and the Long-term strategy for the Convention for 2020–2030 and beyond (decision 2018/5, annex)[3] form the basis of the key elements taken into consideration for the review.

2. At its fortieth session (Geneva, 18 December 2020), the Executive Body decided that the scope of the review should remain broad and that the review should focus on information-gathering, scientific and technical inputs and assessing the information collected.[4]

II. Legal requirements for the review

3. Article 2 (1) of the Protocol sets out the treaty's objective, which is to control and reduce emissions of specific pollutants that are caused by anthropogenic activities and that are likely to cause adverse effects on human health and the environment, natural ecosystems, materials, crops and the climate in the short and long term. Article 2 (2) specifies that Parties should, in implementing measures to achieve their national targets for particulate matter (PM), give priority, to the extent considered appropriate, to emission reduction measures that also significantly reduce black carbon (BC).

4. Article 10 (2) requires that Parties keep under review and assess the obligations of the Protocol, which are meant to achieve the objectives set out in article 2. Article 10 also broadly specifies the modalities of such reviews.

5. The broader elements to be included in the review are those assessing the obligations of Parties in relation to their calculated and internationally optimized allocations of emission reductions; as well as the adequacy of the obligations and whether sufficient and efficient progress has been made towards the achievement of the objectives of the Protocol. The review includes an evaluation of the emission reduction commitments for 2020, not the fixed emission ceilings in the original Protocol for 2010.

6. Article 10 (3) and (4) refer to specific elements that must be included in the review. These elements include an evaluation of mitigation measures for BC emissions and an evaluation of ammonia (NH_3) control measures and consideration of the need to revise annex IX to the Protocol. In accordance with Executive Body decision 2020/2, these evaluations have been subsumed by the broader review of the Protocol. This report and its accompanying documents (annexes) include the main review findings on BC and NH_3, as well as references to newly drafted documents that contain the requested information on the evaluation of mitigation measures for BC and NH_3.

7. The review addresses the best available scientific information on the effects of acidification, eutrophication and photochemical pollution, including assessments of all relevant human health effects, climate co-benefits, critical levels and loads, the development and refinement of integrated assessment models, technological developments, changing economic conditions, progress made on the databases on emissions and abatement

[1] The amendment of the text of and annexes II–IX to the Protocol and the addition of new annexes X–XI, adopted by Executive Body decision 2012/2.

[2] See Rob Maas and Peringe Grennfelt, eds., *Towards Cleaner Air: Scientific Assessment Report 2016* (Oslo, United Nations Economic Commission for Europe (ECE), 2016); and United States Environmental Protection Agency and Environment and Climate Change Canada, "Towards Cleaner Air: Scientific Assessment Report 2016 – North America" (2016).

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

[4] Executive Body decision 2020/2, para. 1.

techniques, especially related to PM, NH_3 and volatile organic compounds (VOCs), and the fulfilment of the obligations on emission levels was taken into consideration.

III. Emission, concentration and deposition trends

Emission trends

8. Over the past 20 years, stricter emission standards have led to decreased emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x) and $PM_{2.5}$ (see table 1 below). Moreover, emission reductions were realized due to fuel switching from coal to natural gas fuels, particularly in the residential sector. The impact of reduced use of coal in electricity generation is ongoing and is accentuated by the increased use of renewables. By contrast, modest NH_3 emission reductions over the past 20 years have primarily been driven by targeted emissions reduction policies regarding, for example, covered manure storage, low emission spreading of manure and emission standards for large stables.

Table 1
Trends in emission reductions by region officially reported to the Centre on Emission Inventories and Projections
(Percentage)

Pollutant	*Europe (European Union 27+United Kingdom+EFTA) 2000–2019*	*EECCA 2000–2019*	*Canada-United States 2005–2019*
SO_2	-82	-22	Canada: -66 United States: -86
NO_x	-48	-1	Canada: -29 United States: -57
NH_3	-12	+10	Canada: -3 United States: +5
VOCs	-43	+11	Canada: -27 United States: -23
$PM_{2.5}$	-35	-15	Canada: -29 United States: -18

Abbreviations: EECCA, Eastern Europe, the Caucasus and Central Asia; EFTA, European Free Trade Association.

Note: The latest available data provided by the Parties have been used. Table 1 is based on an emission data set gap-filled by the Centre on Emission Inventories and Projection. Documentation on gap-filling methods is available at www.ceip.at/ceip-reports.

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

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

11. Reported emissions entail uncertainty margins of 10 per cent to over 100 per cent. In general, the trend in emissions is less uncertain than the absolute levels. The trend in

emissions is comparable to the trend in measured concentrations, although, in some cases, there are unexplained divergences (see table 2 below).

12. BC emissions are reported on a voluntary basis, with 40 Parties providing BC emission estimates. Significant inconsistencies exist between estimates, suggesting that the accuracy and completeness of submissions need to be improved. Emission trends are expected to be more reliable, and data for the 27 European Union member States show emissions halving from 1990 to 2018 and for Canada they have decreased by 22 per cent since 2013. For the United States of America, they decreased by 48 per cent from 2011 to 2017. Some of the reductions in Europe, the United States of America and Canada have come from reductions from diesel vehicles. The residential sector is also a source of BC emissions. For Europe, the residential sector is becoming the main source. For the United States of America, around 8 per cent of emissions are from residential solid wood burning.

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

Concentration and deposition trends

14. Pollutant concentration trends generally followed the decreasing emission trends in the extended EMEP region, which includes Eastern Europe, the Caucasus and Central Asia, the Western Balkans and Türkiye. Between 2000 and 2019, wet deposition of oxidized sulfur declined by 77 per cent in the United States of America Pollutant Emission Management Area region and by 68 per cent in the eastern half of Canada. Oxidized nitrogen deposition declined by 35 per cent in the Pollutant Emission Management Area region and by 50 per cent in Canada. NH_3 and particulate ammonium increased in the north-central region of the United States of America.

Table 2

Trends in average annual concentrations and depositions at Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe monitoring sites

(Percentage)

Average annual concentrations/depositions	*2000–2019*
SO_2 concentrations	-74
NO_2 concentrations	-24
Total nitrate concentrations (nitric acid plus particulate nitrate)	-38
Reduced N concentrations (NH_3 and particulate ammonium)	-28
$PM_{2.5}$ concentrations	-46
Particulate sulfate concentrations	-61
Particulate nitrate concentrations	-38
Particulate ammonium concentrations	-49

Average annual concentrations/depositions	*2000–2019*
Wet deposition of oxidized sulfur	-60
Oxidized nitrogen deposition	-26
Wet deposition of ammonium	-6

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

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

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

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

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

20. The influence of transcontinental transport of PM on sulfur and nitrogen concentrations and deposition in Europe, Canada and the United States of America is relatively minor, though not insignificant. Wildfires and wind-blown dust originating outside Europe substantially influence concentration levels during episodes (typically a few times a year).

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

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

22. Updated WHO air quality guideline values, relative risk factors, as well as no-effect/counterfactual values, became available in late 2021. These will form the basis for new assessments of mortality and morbidity risks for $PM_{2.5}$, NO_2 and O_3 in the EMEP region. Preliminary EMEP assessments show a relatively high population exposure to $PM_{2.5}$ in large cities and in industrial areas, in particular in countries of Eastern Europe, the Caucasus and Central Asia. Health risks of $PM_{2.5}$ will include exposure to secondary inorganic particles, as well as secondary organic particles caused by emissions of NH_3 and VOCs.

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

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

25. Both acidification and eutrophication are dominated by NH_3 emissions from agricultural sources. NO_x emissions are expected to decline further as a result of climate and energy measures and the adoption of zero-emission vehicles. Additional emission reductions, especially of NH_3, are necessary to allow ecosystems to recover and to prevent, inter alia, effects on nutrient imbalances in trees, on surface water and groundwater quality, on biodiversity, as well as on the resilience of forests to stress factors such as drought or insect infestation.

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

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

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

29. Model results suggest that the phytotoxic O_3 dose for deciduous forests declined over the period 2000–2016 by approximately 0.7 per cent per year at EMEP O_3 stations. The phytotoxic O_3 dose for crops shows no significant decline for the majority of sites. Based on current knowledge, O_3 pollution was responsible for a reduced wheat grain yield of, on average, 9.9 per cent in the northern hemisphere in the period 2010–2012.[5] Projections based on current climate and energy policies (Representative Concentration Pathway 4.5) show that O_3 risks to biodiversity will still occur by 2050, as O_3 exposure will remain similar to that in 2000.[6] Similarly, projections show that there will still be a potential risk of a significant effect of O_3 on the biomass increment of trees.

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

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

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

in corrosion became more modest; currently a constant level seems to have been reached.[7] Carbon steel and copper corrosion decreased more pronouncedly in urban areas even after 1997. For soiling, there is no decreasing trend after 1997 and, consequently, many areas in Europe are above acceptable levels. The main pollutant responsible for soiling of materials is PM.

V. Emission reduction commitments for Parties

A. Status of meeting emission reduction commitments for 2020 and beyond

31. Tables 2–6 of annex II to the amended Protocol set out the emission reduction commitments for SO_2, NO_X, NH_3, VOCs and $PM_{2.5}$ for 2020 and beyond, expressed as percentage reductions from the 2005 emission level. In all, thirty-four Parties are currently listed in tables 2–6 (twenty-seven European Union member States, the European Union, the United Kingdom of Great Britain and Northern Ireland, Canada, the United States of America, Norway, Switzerland and Belarus), of which 26 have already accepted the amendment to the Gothenburg Protocol (status as of July 2022). Belarus and seven European Union member States are still in the process of ratification and may soon join. Other Parties currently not yet listed in tables 2–6 of annex II to the Protocol may also be considering ratification.

32. An assessment of the current status of efforts to meet the 2020 emission reduction commitments of the amended Protocol based on a comparison with reported emissions (2019) and projections (2020–2030) by Parties (reporting year 2021), provides the following key findings:

(a) The collective efforts of all 34 Parties resulted in combined emission reductions between 2005 and 2019 that already exceed the combined emission reductions envisaged by the Parties' emission reduction commitments for 2020, except for $PM_{2.5}$. However, for individual Parties, there is a significant difference in the progress made towards meeting the emission reduction commitments;

(b) The majority of the 34 Parties did not meet their 2020 emission reduction commitments for one or more pollutants in 2019. The latest reported emission projections based on current legislation ("with measures" projections) for the period 2020–2030 show that, in 2030, 15 out of 34 Parties will still not meet their 2020 emission reduction commitments for one or more pollutants, in particular for NH_3. Emission levels corresponding to the 2020 relative targets for NH_3, VOC, NO_X and $PM_{2.5}$ will still be exceeded in 2030 by up to 30 per cent for several Parties according to these reported "with measures" projections. Additional policies and measures will be required for NH_3 and, to a lesser extent, VOC, NO_X and $PM_{2.5}$, in order for Parties to make faster progress towards meeting all their emission reduction commitments in 2020 and beyond;

(c) The main reasons for not meeting the reduction commitments include lack of or delayed implementation of policies and measures, higher activity levels than foreseen at the time when the emission reduction commitments were set, and slower replacement of old equipment/installations. Additional action is needed by several Parties in the agricultural sector (NH_3), the energy sector (NO_X), road transport (NO_X and VOCs), shipping (NO_X), solvent use (VOCs), domestic wood burning ($PM_{2.5}$ and VOCs) and agricultural residue burning ($PM_{2.5}$) to meet the 2020 emission reduction commitments. The necessary additional action is sometimes hampered by a lack of political will, especially to address sensitive activities or sectors such as agriculture (NH_3) and domestic wood burning ($PM_{2.5}$). There is possibly a lack of enforcement in some Parties/sectors.

33. Other Parties that have not yet ratified the amended Protocol and for which no emission reduction commitments are proposed in tables 2–6 of annex II to the amended

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

Protocol show mixed emission trends for the main pollutants between 2005 and 2019. For some of these Parties, and for one or more pollutants, emissions have increased.

34. The emissions for 2020, reported in 2022, are on average lower for all pollutants compared to emissions for 2019, reported in 2021, especially for NO_x. Due to reductions in economic activity in 2020 related to the coronavirus disease (COVID-19) pandemic, the emissions reported in 2022 for the year 2020 show more progress in meeting reduction commitments than expected. While, in 2019, 10 Parties did not meet their 2020 emission reduction commitments for NO_X, in 2020 this dropped to 3 Parties. However, the year 2020 should not be considered representative of real or systematic progress to date. The transport sector was one of the activities strongly affected by the COVID-19 lockdowns, resulting in reduced NO_X emissions from this activity.

35. The new Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) baseline scenarios developed to support the review of the amended Protocol show significantly higher total emission reductions for all pollutants by 2030 than the most recently reported national projections referred to in paragraph 32 above, except for NH_3. While both the GAINS baseline and national projections are based on current legislation, the GAINS baseline was also developed using energy and agricultural scenarios that take into account recently agreed new targets (e.g., the European Union Green Deal). According to the GAINS baseline scenarios, 12 Parties would still not meet their 2020 emission reduction commitments for NH_3 by 2030. For the other pollutants, only a few potential non-compliance cases would remain.

B. Update of the base year 2005 emission estimates

36. A comparison of the most up-to-date 2005 emission estimates, as reported by Parties in 2021, to the 2005 estimates listed in tables 2–6 of annex II to the amended Protocol indicates that:

(a) There are many significant changes in the reported 2005 emission estimates between 2012 and 2021, especially for $PM_{2.5}$ and VOCs, and less so for NO_X and SO_2. Most changes remain within the range of +50 per cent and -50 per cent compared to the 2005 emission estimates listed in tables 2–6 of annex II to the amended Protocol, but with some outliers to over 100 per cent change. Similar conclusions can be drawn for the more recently reported 2005 emission figures in 2022;

(b) A comparison of the 2005 emission estimates reported in 2012 with the reported updates for the year 2005 in 2021 shows that the basis for setting the 2020 emission reduction commitments significantly changed between 2012 and 2021. It underlines the importance and usefulness of moving from fixed (2010 ceilings) to relative targets (2020 emission reduction commitments);

(c) Relative targets are able to absorb many, but not all, of the effects of inventory developments and improvements. The transition from the 2010 fixed targets to the 2020 relative targets will therefore most likely also reduce, but not eliminate, the need for and use of the emission inventory adjustment procedure from 2022 onwards (see para. 38 below).

C. Use of the inventory adjustment procedure

37. An analysis of the approved emission inventory adjustment applications related to the 2010 fixed emission ceilings provides the following key messages:

(a) A total of 11 Parties submitted eligible adjustment applications in the period 2014–2021 for one or more pollutants. Adjustments of national emission inventories were submitted for NH3, NO_X and VOCs, and concern adjustments to account for new emission source categories, as well as significant changes in emission factors or methodologies used. The majority of the adjustment applications were submitted for the following categories: road transport, agricultural soils, manure management and cultivated crops;

(b) The approved adjusted emission totals represent 2–20 per cent of the unadjusted national emission totals for NH_3, 10–30 per cent of the unadjusted national emission totals for NO_X, and 10–40 per cent of the unadjusted national emission totals for VOCs;

(c) All adjustment applications approved so far relate to adjustments to emission inventories for the purpose of assessing compliance with the 2010 fixed ceilings (provisional application since 2014). Approved adjustments so far will not be applicable for use with respect to the 2020 emission reduction commitments.

38. New applications and reviews (based on a new reference point and including adjustments for the base year 2005) will be required for the post-2020 scheme. In all, four Parties submitted adjustment applications in spring 2022 with respect to assessing compliance with the 2020 emission reduction commitments; three of these applications were for NMVOC emissions from agriculture. The review of these adjustment applications has not been finalized.

D. Inclusion of condensables in reporting particulate matter emissions for residential heating

39. The inclusion of condensables in reporting particulate matter emissions allows for a more representative explanation of the population exposure to $PM_{2.5}$ and could better define the effectiveness of measures for health protection. This could shift the optimal policy strategy towards addressing residential solid fuel burning.

40. At the time when the 2020 emission reduction commitments were set (2012), many Parties had not yet included condensables in their PM reporting for residential (wood) heating. To date, this remains the case for:

(a) Some Parties, including condensables could prove to be problematic as, even with adjustment of their 2005 emission data, they would not be able to deliver the national emission reduction commitment for $PM_{2.5}$, without additional measures for residential heating or for other sectors/activities;

(b) Other Parties, including condensables could undermine the set emission reduction commitment for $PM_{2.5.}$ This would be the case if the use of wood for residential heating had not significantly increased between 2005 and 2020 and the share of old stoves/fireplaces had decreased during this period. The inclusion of condensables for this specific situation would inflate PM emissions in the base year 2005 much more than in 2020 (given that the share of the condensables in PM from old stoves with poorer combustion conditions is much higher than for new stoves).

41. Work on the inclusion of condensable particles in future PM emission reporting needs to continue after the completion of this review. This should include an assessment of the policy implications of including condensable particles. Meanwhile, more Parties have begun reporting whether residential $PM_{2.5}$ emissions include condensable particles.

E. Adequacy of 2020 emission reduction commitments

42. The collective projected emission reductions will overachieve the original overall goal of the amended Protocol in terms of targeted emission reductions from 2020 onwards through the implementation of the 2020 emission reduction commitments. However, current commitments and legislation will not be sufficient to achieve the long-term objectives (no exceedance of critical loads and levels).

VI. Emission limit values, technical annexes and related guidance documents of the Protocol (with priority given to black carbon and ammonia measures)

43. The technical annexes to the amended Protocol include emission limit values (ELVs) for installations, vehicles and products based on best available techniques (BATs), available at the time the revised Protocol was agreed (2012). More recent BAT are presented in new or updated guidance documents from the Task Force on Techno-economic Issues (TFTEI) and the Task Force on Reactive Nitrogen (TFRN). The emission levels associated with the use of these BATs show a higher reduction potential than the current ELVs contained in the technical annexes.

44. TFTEI conducted an in-depth analysis of annexes IV–VI, VIII and X–XI to the amended Protocol, and their associated guidance documents, to identify the ELVs, and other technical requirements in the technical annexes that could potentially be updated due to advancements in technology since 2012. The key finding is that potential new ELVs have been identified as technically feasible and consistent with the new and upgraded techniques, now available, which would allow significant emission reductions, including for black carbon, in many of the emission source categories analysed.[8] New data and information exist for the technical annexes that could be used to update, simplify or extend them with activities not currently included, with the exception of annex XI. Summary conclusions of the analysis carried out by TFTEI are included in its report to the Working Group on Strategy and Review (ECE/EB.AIR/WG.5/2022/1). A more extensive report, containing detailed information on the TFTEI review, is available as an informal document for agenda item 4 of the sixtieth session of the Working Group on Strategies and Review (Geneva, 11–14 April 2022).[9]

45. Gaps, complexity and the demands of the requirements in the technical annexes have been examined in collaboration with the Coordinating Group on the promotion of actions toward implementation of the Convention in Eastern Europe, the Caucasus and Central Asia. Possible adaptation of the annexes to better address key sectors in South-Eastern Europe, Eastern Europe, the Caucasus, Central Asia and Türkiye is related to the flexibility mechanisms of the Protocol.[10] TFTEI has developed the case study "Technological Pathway toward ratification of the current ELVs in the amended Gothenburg Protocol". This case study describes how the ELVs in the technical annexes for some countries of the Eastern Europe, the Caucasus and Central Asia region could be implemented (see the document entitled "Technical information for the review of the Gothenburg Protocol" (ECE/EB.AIR/2022/5), further referred to as annex II to the present report).

46. The United States of America and Canada, like the European Union, have rigorous air quality management systems. The regulatory programme of the United States of America under the Clean Air Act includes national ambient air quality standards for SO_2, NO_2, PM and O_3. Under the Clean Air Act, State and local governments implement programmes to significantly reduce these pollutants by specific deadlines. New and existing sources are regulated through new source performance standards and maximum available control technology regulations. The air quality programme of Canada is its Air Quality Management System – a collaborative effort implemented by federal, provincial and territorial governments. It includes ambient standards and emissions requirements for industrial sectors, as well as emission reduction measures for transportation and consumer and commercial products; along with monitoring, modelling and data collection. The United States of America and Canada implement their commitments under the applicable technical annexes through emission reduction measures that are part of their respective air quality programmes.

8 Informal document, agenda item 4 : Review of annexes IV–VI, X, XI to the Gothenburg Protocol by TFTEI, p. 159. Available at https://unece.org/environmental-policy/events/working-group-strategies-and-review-sixtieth-session.

9 ibid.

10 Agenda item 4 (d) informal document, Report of the Chair of the Eastern Europe, the Caucasus and Central Asia Coordinating Group to the Executive Body at its forty-first session, available at https://unece.org/environmental-policy/events/executive-body-forty-first-session.

47. Many options to update annex IX were discussed in the 2012 process to amend the Protocol[11] and its review was prioritized for the present review via article 10 (4) of the amended Protocol. Annex IX is over 20 years old and can no longer be considered state-of-the-art; even so, many Parties have not fully implemented its requirements. Its implementation is not technically demanding, as has been demonstrated by actions taken by a few Parties. Considering substantial progress in technical capability, availability of cost-effective measures, and recognition that measures are needed to meet NH_3 emission reduction commitments, a key conclusion is that a comprehensive revision of annex IX is overdue and it is recommended to take into account sustainable management practices in the context of the wider N cycle.

48. The following guidance and other documents related to NH_3 and the wider N cycle need to be kept up-to-date as follows, with details provided in the informal document:[12]

(a) The Guidance document on preventing and abating ammonia emissions from agricultural sources (ECE/EB.AIR/120);

(b) The United Nations Economic Commission for Europe Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions (ECE/EB.AIR/129);

(c) The Guidance document on national nitrogen budgets (ECE/EB.AIR/119);

(d) The Guidance document on integrated sustainable nitrogen management (ECE/EB.AIR/149);

(e) The Assessment report on ammonia (ECE/EB.AIR/2021/7).

VII. Specific sector approaches (such as residential solid fuel, agriculture, shipping)

49. There are key sectors that require specific attention in further reducing their emissions of pollutants under the Protocol and their impacts on human health and the environment. It is focused on the following pollutants: PM and BC (residential solid fuel burning), NH_3, CH_4, NO_x, VOCs (agriculture) and NO_x (shipping).

50. A number of background technical documents developed by TFTEI[13] identify key sources/sectors, including shipping, and measures to address them, in relation to the pollutants indicated in paragraph 49 above. Sectors, for which specific guidance documents have been developed by TFTEI, are indicated below.

51. Agricultural residue burning and residential solid fuel burning remain major issues, and efforts are still needed to reduce emissions, in particular those of $PM_{2.5}$, BC and PAHs. The guidance document on reduction of emissions from agricultural residue burning (ECE/EB.AIR/2021/5) provides alternative methods, practices and techniques to eliminate or reduce agricultural residue burning and its negative effects. The code of good practice for wood-burning and small combustion installations (ECE/EB.AIR/2019/5) may help end users to implement more efficient uses of appliances.

52. Non-exhaust emissions from the transport sector need more attention because of PM resuspension and emissions from tyres and brakes, which are becoming dominant as compared to exhaust gas emissions in the transport sector, and are also a source of BC. In the international shipping sector, potential further reductions in NO_x emissions are possible with

[11] See agenda item 5 informal document entitled "Supplementary information for the review of the Gothenburg Protocol", para. 87, footnote 26, containing the list of documents related to revision of annex IX, available at https://unece.org/environmental-policy/events/executive-body-forty-first-session.

[12] ibid., paras. 93, 101 and 154.

[13] Informal documents for the fifty-eighth session of the Working Group on Strategies and Review, available at https://unece.org/environmental-policy/events/working-group-strategies-and-review-fifty-eighth-session.

the new/upgraded technologies, as highlighted by analyses carried out by the Task Force on Hemispheric Transport of Air Pollution, on the basis of parameters provided by TFTEI.

53. Gas flaring from the oil and gas industry is an important source of BC emissions, particularly in areas surrounding the Arctic. Steam-assisted flares are clearly the most efficient measure in terms of soot emission reductions. However, high pressure-assisted flares can also be an efficient technique if water is not available on site.

54. CH_4 emissions from waste landfills are the most significant non-agricultural source of CH_4 emissions in Europe and are responsible for around 20 per cent of overall emissions. In most other parts of the world, this share varies somewhere between 15 and 25 per cent.

55. The main barrier to NH_3 reduction by Parties and non-Parties appears to be a lack of political will. However, this will has improved recently as Parties realize that implementation of measures is needed to meet emission reduction commitments and to reduce the impact of NH_3 on N-sensitive ecosystems. In addition, confidence in measures to control NH_3 emissions has increased greatly since these were first discussed by the Convention in the 1990s, with control of NH_3 emissions now seen as part of a wider strategy to reduce large amounts of otherwise-wasted valuable reactive N resources.[14] Implementation of such cost-beneficial measures would be accelerated by strengthening investments in modern agricultural equipment.

56. TFRN has identified the following "Top five" cost-effective and reliable measures for NH_3 emission abatement (ECE/EB.AIR/WG.5/2011/16), which are still considered to represent the leading measures:

(a) Low emission application of manures and fertilizers to land;

(b) Animal feeding strategies to reduce N excretion;

(c) Low emission techniques for all new stores for cattle and pig slurries and poultry manure;

(d) Strategies to improve N use efficiencies and reduce N surpluses;

(e) Low emission techniques in new and largely rebuilt pig and poultry housing.[15]

57. The importance of linking across the nitrogen cycle for multiple co-benefits has been recognized in new Guidance document on integrated sustainable nitrogen management. In addition, a new way to address N is reporting of national nitrogen budgets, as this provides an opportunity to optimize for multiple benefits in relation to environment, climate, health and economy. However, nitrogen budgets have been only used by a few Parties (the main barriers appear to be the lack of any mandatory requirement of the Protocol as amended in 2012, resources to provide national budgets, and resources for awareness-raising on the benefits of such an approach).

VIII. Non-technical measures

58. Implementation of ELVs (based on BATs) for installations and products is not always sufficient to meet national emission reduction obligations or air quality targets. Additional actions in the form of "non-technical" measures could be considered at the national or local level. This could include encouraging faster substitution of old and polluting technologies by new and cleaner technologies, facilitating use of cleaner fuels or feedstocks, or stimulating greener consumer behaviour. Often, such measures prove to be more efficient and less costly than implementing stricter ELVs. The common feature of structural and behavioural changes

[14] Activities linked to the International Nitrogen Management System have drawn attention to a global loss of reactive nitrogen worth $200 billion per year, pointing to the opportunity to "halve nitrogen waste" by 2030, saving $100 billion per year globally, as embraced as part of national action plans under the Colombo Declaration on Sustainable Nitrogen Management.

[15] A more comprehensive list of ammonia and nitrogen mitigation options is listed in the informal document accompanying the present one, available at https://unece.org/info/Environmental-Policy/Air-Pollution/events/350953, subsection entitled "Which elements of annex IX and guidance documents need to be updated?"

is that they cannot easily be implemented via permitting of specific activities. They often require a combination of actions by producers and consumers and a wider set of policy instruments, including financial incentives, infrastructural investments and awareness-raising.[16] A guidance document on best practices will be developed in 2023.

59. "Prioritizing reductions of particulate matter from sources that are also significant sources of black carbon – analysis and guidance" (ECE/EB.AIR/2021/6) report identifies "non-technical" measures as the main measures that would reduce PM-emissions and also significantly reduce BC (and PAH) emissions: (a) reduction of residential burning of coal and wood; (b) reduction of open field (agricultural) residue burning; and (c) scrapping of old diesel vehicles and old, non-road mobile machinery.

IX. Flexibility provisions to facilitate ratification and implementation

60. The amended Protocol contains a wide range of flexibility provisions, some of which are addressed to all Parties in order to facilitate full implementation of all requirements and some of which are specifically intended to facilitate ratification by countries of Eastern Europe, the Caucasus and Central Asia and other countries that have not yet ratified the Protocol. The flexibility provisions vary in type, scope and impact.

61. Some flexibility provisions were already available in the 1999 Gothenburg Protocol. Several new flexibility provisions were added to the Protocol, as amended in 2012, including flexibility provisions to specifically accelerate/encourage ratification by non-Parties.

62. There is an overall lack of reporting on the use of some of the flexibility provisions, impeding proper monitoring and enforcement.

63. The following is a list of key conclusions:

(a) To date, the current flexibility provisions have not proven adequate and/or effective in facilitating further ratifications. In particular, the additional flexibility mechanisms introduced in the amended Protocol to increase the number of ratifications (arts. 3 bis and 7 (6) and annex VII (4)) have not met expectations (not been used so far);

(b) For the time being, a cautious approach should be taken to drawing firm conclusions on the usefulness and effectiveness of the current flexibility provisions, as the amended Protocol only entered into force in October 2019, and, given the global COVID-19 pandemic that occurred in the interim, insufficient information on their use is available;

(c) A primary reason for the persistent non-ratification of the amended Protocol by some of the current non-Parties is that the Protocol and its 11 technical annexes are too complicated and demanding for them. The two non-Parties that responded to the questionnaire circulated in 2021 in support of the review of the flexibilities indicated the technical complexity of the Protocol as a major barrier. A review of previous workshops and exchanges on this topic confirms that the complexity of the Protocol, combined with a lack of financial resources, is a major barrier to ratification.

64. The following is a list of possible options for consideration:

(a) Increase the effectiveness of the Protocol and facilitate ratification and implementation by considering and implementing improvements to the current flexibility provisions that could be pursued under the 2012 amended Protocol;

(b) Consider and discuss new options and/or additional/different flexibilities for a potential revision of the Protocol, as amended in 2012, that could help non-Parties overcome barriers and move towards ratification and implementation. Use the outcome of the thematic session on barriers to ratification and implementation of the Gothenburg Protocol and solutions to overcome them, scheduled as part of the forty-second session of the Executive Body (Geneva, 12–16 December 2022), to reflect on next steps.

[16] See "Informal document on non-technical and structural measures", available at https://unece.org/fileadmin/DAM/env/documents/2020/AIR/WGSR/Note_on_non-technical_and_structural_measures_-201120.pdf.

65. More information on the review of the flexibility provisions to facilitate ratification and implementation can be found in document ECE/EB.AIR/2022/6 entitled “Review of the flexibility provisions to facilitate ratification and implementation”, as well as in the informal document on barriers to ratification and implementation and solutions to be made available for the forty-second session of the Executive Body.

X. Convention Parties that are not Parties to the Protocol

66. Only 26 of the 51 Parties to the Convention ratified the 2012 amended Gothenburg Protocol (29 Parties ratified the 1999 Gothenburg Protocol). The fundamental principles of the Convention assume that a Party will protect human health and the environment from air pollution through development of national policies and strategies. Implementation of the Protocol’s requirements by the Parties is strongly linked to national systems. Awareness of policymakers of the need to improve air quality and to implement best available techniques and emission limit values is a prerequisite for action. The technical aspects should be introduced at the national level under the Party’s own legislation.

67. Air pollution monitoring, allowing observed ambient concentrations to be compared to the (new) WHO air quality guidelines, is also a key element in improving awareness, both for Parties and non-Parties to the Protocol. This task requires significant efforts from various national stakeholders. To ensure ratification and implementation of the Protocol, identification and development of policies and measures for key sectors to improve air quality is recommended. It is also imperative for national Governments to work with stakeholders, including the business community. A key conclusion is to encourage Parties to contribute to efforts within the ECE region specifically on developing policies and measures for implementation consistent with the amended Protocol that will provide greater benefits to human health and the environment. In post-review discussions on options to increase the effectiveness of the Protocol to facilitate both ratification and implementation, a stronger focus on implementation of such policies and measures in countries not Parties to the Protocol is recommended.

XI. Canada and the United States of America

68. Canada and the United States of America are also bilaterally addressing cross-border air pollution under the Canada-United States Air Quality Agreement (AQA), which includes commitments by both countries to reduce emissions of SO_2, NO_x and VOCs. Although not covered by the AQA, NH_3 is also of concern to both countries. Additional assessments are needed to quantify the impacts. In the context of the Protocol review, neither country is currently incorporated into the provisions of annex IX (under art. 3 (8) of the Protocol).

69. In early 2021, both countries initiated work on a joint review and assessment of the AQA, examining whether it is meeting its environmental objectives as well as its sufficiency in addressing transboundary air pollution. The key conclusions of the review and assessment are scheduled for completion in late 2022. The review and assessment focus on pollutants that cause acid rain and O_3 formation, as well as their transboundary impacts. The review also examines pollutants/issues not currently addressed by the AQA, such as $PM_{2.5}$, including concentrations and trends, as well as transboundary flows and impacts.

70. Preliminary findings of the AQA review indicate that, although emission levels of pollutants that cause acid rain and form O_3 have decreased significantly since the Agreement was established in 1991, transboundary air pollution continues to be a problem. As noted in the Joint *Canada-United States Air Quality Agreement: Progress Report 2018,* despite the results achieved under the AQA, the pollutants covered by the Agreement (SO_2, NOx, VOCs and O_3) continue to have significant impacts on human health and the environment in both countries and remain a concern. In addition, although $PM_{2.5}$ is not covered under the Agreement, it continues to pose a significant risk to the health of the citizens and environment in both countries, even at low levels. Both countries should continue their effective bilateral cooperation to address the remaining health and environmental issues related to transboundary air pollution. These efforts will help to ensure that transboundary air pollution

does not affect each country's ability to attain and maintain its national ambient air quality standards for pollutants such as O_3 and $PM_{2.5}$, or to protect the health and environment of its citizens.[17]

XII. Hemispheric transport

71. Although the ECE region covers most of the northern hemisphere, O_3 and PM levels in the ECE region are made up of precursor emissions within the region, as well as O_3 and PM transported from distant sources on hemispheric and global scales, which has impacts on human health, ecosystems and biodiversity.

72. Specifically, the intercontinental contribution to ground-level O_3 is larger than the intercontinental contribution to PM or its components due to the longer atmospheric lifetime of O_3. Since 1990, decreases in precursor emissions within the ECE region have increased the share of background O_3, which includes O_3 from intercontinental transport to O_3 concentrations in the ECE region, especially in Europe. Further reductions of O_3 precursors, including methane, outside the ECE region would be needed to reduce the background concentration and health and ecosystem impacts of long-term exposure to O_3. However, reduction of NO_x and VOC emissions within the region remains important to reduce peak concentrations and health and ecosystem impacts of short-term exposure to high levels of O_3.

73. Evidence shows that, for PM, the contribution of anthropogenic emission sources from outside the ECE region to associated impacts within the ECE region is small compared with the impact of anthropogenic sources within the ECE region, but not insignificant. Non-anthropogenic sources such as wildfires and wind-blown dust outside the ECE region, however, do influence PM levels and deposition in the ECE region and are sensitive to changes in climate.

74. The absolute contribution of NO_x and VOC emissions outside the ECE region to annual average ground-level O_3 in Europe and Canada-the United States of America is not expected to change significantly under a current legislation scenario to 2050. In addition, without new measures, expected increases in global methane emissions are expected to more than offset projected reductions of NOx and VOC emissions in Europe and at least partially offset reductions of NOx and VOC emissions in Canada-the United States of America.

75. If NOx and VOC emissions outside Europe were to be reduced by the same percentage as implied by the Protocol for the European region, the emission reductions outside of Europe would have a bigger impact on annual average European O_3 levels than the emission reductions within Europe. In Canada-the United States of America, such a scenario would contribute significantly to decreases of O_3 in North America, but not more than the percentage emission reductions in Canada-the United States of America itself.

76. Various projected trends in anthropogenic CH_4 emissions span a very wide range, between a factor of two smaller or a factor of two larger than present-day emissions by the end of the century, depending on assumptions made about economic development, behavioural changes and the use of emission control technology.

77. The expected increase in global methane concentrations offsets the decreases in surface O_3 due to NO_x and NMVOC controls within Europe and North America. Model studies consistently show that decreasing methane concentrations leads to lower levels of ground-level O_3, independent of other emission controls. In addition, decreasing methane concentrations has a larger impact on local O_3 concentrations in VOC-limited areas where NOx emissions are high.

78. Even with full implementation of the Protocol, background levels of O_3 in the ECE region are expected to continue to increase due to methane, NOx and VOC emissions outside the ECE region. Further reductions of O_3 precursor emissions within the ECE region are technically feasible and can decrease O_3 concentrations and impacts within the region. In addition, cooperation with other countries, organizations and forums outside of the ECE region to enable and motivate emissions reductions outside the ECE region will also be

[17] Gatineau, Canada, Environment and Climate Change Canada, 2020, p. 31.

needed. Options should be explored for how this cooperation could be realized, including through the work of the Forum for International Cooperation on Air Pollution.[18]

XIII. Integrated multi-pollutant, multi-effect approach and interactions with other policy areas

79. The robust science and technical base within the Convention lays the groundwork for the continued support of a comprehensive multi-pollutant, multi-effect approach to managing air quality. An integrated multi-pollutant approach is more cost effective than the original flat rate emission reduction agreements for individual pollutants; it increases the synergies in policy measures, makes the most efficient use of available resources, and increases the benefits associated with air quality management, such as reducing risk to public health.

80. A primary goal of multi-pollutant planning is to identify and evaluate control strategies targeting acidification, eutrophication, O_3 and $PM_{2.5}$ and their precursors. However, a multi-pollutant definition is far broader and can also incorporate other pollutants and environmental concerns such as climate change, biodiversity loss, energy, transport, agricultural and nitrogen management policies. Centre for Integrated Assessment Modelling (CIAM) calculations indicate that full implementation of policies and measures in these other areas could offer substantial, cost-effective emission reductions of air pollutants covered by the Protocol. Such measures would make attainment of air quality targets more likely.

81. To limit negative effects of air pollution on climate change, more focus is needed on reducing emissions of air pollutants that have a warming effect, such as BC and O_3 precursors. CH_4 reduction plays a key role in reaching synergetic effects, as CH_4 is both a greenhouse gas and an increasing determinant of O_3 formation.

82. The main anthropogenic sources of CH_4 emissions are agriculture (with cattle dominating in the ECE region), fossil fuel production and waste treatment. Cost-effective technical solutions are available to reduce CH_4 emissions from waste treatment and oil and gas production.[19] In order to reduce CH_4 emissions from cattle, fewer technological options are available. Here, behavioural change leading to less (over)consumption of meat and dairy could offer synergetic benefits on health, climate, O_3 formation and N pollution.

83. A number of options are available for addressing CH_4 as an O_3 precursor under the Convention. The methane contribution to transboundary O_3 is significant enough to warrant considering potential policy action under the Air Convention (see annex II to the present report for additional information).

84. BC has multiple environmental effects. It contributes to health effects associated with $PM_{2.5}$ and absorbs light and heats the atmosphere, contributing to global warming. When deposited onto ice and snow, it accelerates melting – a significant issue regarding the Arctic and mountain glaciers. Emission scenarios that stabilize global warming at 1.5°C include global BC emission reductions of 40–60 per cent by 2030. BC is co-emitted with other particles that reflect light and contribute to cooling. Because BC is emitted in population centres, it contributes to highly localized air quality issues. BC concentrations are, on average, 2.5 times higher in populated areas compared to remote locations.

85. NH_3 emissions are hardly influenced by energy policy measures, although some side effects may occur; for example, NH_3 emissions could increase due to increased production of biofuels. A wider agricultural and integrated nutrient management approach could play an important role in meeting N deposition targets and halting biodiversity loss, while tackling other forms of N pollution, such as nitrate leaching and emissions of nitrous oxide, as well as reducing CH_4 emissions.

[18] The mandate of the Task Force for International Cooperation on Air Pollution was adopted by the Executive Body through decision 2021/5.

[19] See, e.g., Lean Höglund-Isaksson and others, "Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model", *Environmental Research Communications*, vol. 2, No. 2 (February 2020).

86. The Convention's tools and technical expertise have the potential to support cities in developing multi-pollutant air quality management plans that reduce air pollution and improve public health and the environment. One way to achieve this is to continue capacity-building efforts with a focus on identifying emission reduction measures that address multiple pollutants and take into account the linkages with other policy areas.

XIV. Objectives and key articles of the Protocol

A. Progress towards achieving the objectives of the Protocol

87. In order to assess whether the Protocol obligations, if fully implemented, would lead to the desired results in reducing emissions of S, NO_x, NH_3, VOCs and PM, including BC, and their effects on human health and the environment, in view of the latest best available scientific knowledge, CIAM developed a series of scenarios, calculating emissions, concentrations, depositions and effects up to 2050. These include baseline scenarios based on current legislation, maximum technical feasible reduction scenarios based on the application of BAT and "low" scenarios including climate change policies and some structural changes. The details and results of these CIAM scenarios are included in annex II to the present report. The main conclusion of the scenario analysis is that, although there are technical and non-technical options available to further improve air quality and reduce harmful effects beyond what is achievable with the amended Protocol and current national reduction plans, the long-term targets of the Air Convention to protect health and ecosystems will remain a challenge. Even the most optimistic scenario for 2050 still shows that 30 per cent of the population in the EMEP domain will be exposed to $PM_{2.5}$ concentrations above the 2021 WHO guideline level and that, in the European Union, in 30 per cent of the ecosystem area, the nitrogen critical load will be exceeded. For non-European Union countries this figure will be 15 per cent.

B. Adequacy of other key articles of the Protocol

88. Other key articles such as definitions, objectives, exchange of information, public awareness, strategies and measures, reporting (not covered above), research and development, reviews by the Parties, adjustments and amendments (amongst others), overall continue to be relevant as many of these provide the basis for the day-to-day work of the Convention. However, given that they were developed over 10 years ago, some articles may no longer be fully adequate and, in order to remain relevant and useful, merit further consideration of updates to reflect current evidence and advances in science and integrated policymaking, and to address international cooperation. More information on the other key articles can be found in annex II to the present report.

XV. Conclusions

89. The following are the main conclusions on the adequacy of the obligations and the progress made towards the achievement of the objectives of the amended Gothenburg Protocol:

(a) Collective projected emission reductions will exceed the original overall emission reduction goal of the amended Protocol in terms of targeted emission reductions through the implementation of the 2020 emission reduction commitments. Emissions of air pollutants have decreased considerably over the last 20 years, although less so for NH_3 and generally much less so for the Western Balkans and Eastern Europe, the Caucasus and Central Asia;

(b) Emission reporting has generally improved, although there are still differences in the quality and completeness of the emission inventories reported by the Parties. Policies and measures may be misrepresented in reported emissions, resulting in differences between reported and actual emissions. Further effective reductions will depend on the decrease in actual emissions and on the reconciliation of reported and actual emissions;

(c) Despite the emission reductions achieved so far, with a generally similar downward trend in pollutant concentrations and depositions, adverse effects on human health, ecosystems and materials continue to occur. Reducing these effects is one of the stated objectives of the amended Protocol;

(d) Current legislation (baseline), including commitments contained in annex II to the Protocol as amended, will not be sufficient to achieve the long-term objectives of article 2 thereof (i.e., no exceedance of critical loads and levels). Although current legislation will further deliver significant emission reductions in the short and longer term, exceedances of critical loads and levels will still occur to some extent throughout the ECE region by 2050: for example, only one third of the population will meet the 2021 WHO air quality guideline for $PM_{2.5}$ in the ECE region; in 65 per cent of the ecosystem area in the European Union the nitrogen critical load will still be exceeded; the phytotoxic O_3 dose for forests has decreased, but not much, if at all, for crops, with an average loss of 8 per cent of wheat yields in the northern hemisphere by 2050 under current legislation; and PM soiling of materials will continue;

(e) In scenarios with full implementation of available technical reduction measures (“maximum technically feasible reduction” scenario) and with additional changes in the energy system and agriculture (“low” scenario) further emission reductions by 2050 are possible, although still modest, by 2030 due to the short time available for new measures to become fully effective by 2030. Technical emission reduction potentials are still particularly large for Eastern Europe, the Caucasus and Central Asia, inter alia, for coal burning, transport and waste treatment. The “low” scenario provides for significant additional reductions of NH_3 and CH_4 in agriculture. However, the additional emission reductions in both the more optimistic scenarios will still not be sufficient to meet the long-term objectives of the amended Protocol. There will still be exceedances of critical loads and levels (eutrophication, O_3, $PM_{2.5}$ exposure above WHO air quality guideline), even with full implementation of all available technical measures and additional changes that were considered in the energy sector (intensified climate policy) and the agricultural sector (healthy food policy);

(f) To increase the effectiveness of the amended Protocol, more Parties will have to ratify and implement emission reduction commitments. This will require new flexibilities or other solutions to overcome the barriers to ratification faced by current non-Parties. Some of the technical annexes are considered too complex and demanding by some current non-Parties;

(g) To achieve the long-term objectives of the amended Protocol before or by 2050, it will not be sufficient to rely only on available technical measures. Due to technological developments in the last decade, new and updated BATs show higher reduction potentials than the current emission limit values in the technical annexes, but non-technical and structural measures, synergies of climate and energy policies, as well as additional efforts outside the ECE region (e.g., in international shipping), will also be needed. The achievement of the long-term objectives of the amended Protocol to protect health and ecosystems will remain a challenge and the implementation of technical BATs alone will not be fully sufficient/adequate to achieve them;

(h) In particular, additional action is needed in the agricultural sector (NH_3 and CH_4), the energy sector (NO_X), road transport (NO_X, VOCs, BC and non-exhaust PM), (international) shipping (NO_X), solvent use (VOCs), domestic wood burning ($PM_{2.5}$, BC and VOCs), agricultural residue burning ($PM_{2.5}$ and BC), gas flaring (BC and CH_4) and landfills (CH_4). Future efforts should focus on activities and sectors that were only partially or not all covered in the 2012 revision. Non-technical measures (e.g., encouraging renewal of installations and vehicles, switching to cleaner fuels and greener consumer behaviour) often prove to be more efficient and cheaper and have a high reduction potential;

(i) Global CH_4 reduction (in addition to CH_4 and NO_X/VOC control in the ECE region) will be needed to reduce ground level O_3 in the ECE region;

(j) Annex IX on NH_3 control measures is over 20 years old and can no longer be considered state-of-the-art. Additional emission reductions of NH_3 beyond the current annex IX requirements are necessary to allow further ecosystem recovery.

90. According to the 2022–2023 workplan,[20] the Working Group on Strategies and Review will consider the main conclusions of this review and implications for next steps and deliver its recommendations to the Executive Body. The following are suggestions for next steps and further work:

(a) Take further steps towards meeting the long-term objectives of the amended Protocol. Carefully consider different options for making further progress towards these targets, taking due account of the barriers to ratification faced by the current non-Parties;

(b) Continue to work on removing barriers to the ratification of the amended Protocol and to the implementation of abatement measures; Encourage Parties to contribute to efforts within the ECE region for developing policies and measures for implementation consistent with the amended Protocol;

(c) Apply a multi-pollutant/multi-effect approach when preparing the next emission reduction steps, including synergies and interactions with other areas (such as climate change) and including non-technical measures (to increase the overall cost-effectiveness and coherence of policies in different areas). Optimize future scenarios for new interim impact targets for 2030/2035/2040;

(d) Note that further reductions of exceedances of the 2021 WHO air quality guidelines and critical loads will require increased efforts at all levels: international (Convention and beyond), national and local. Cooperation with other international forums needs to be strengthened, in particular for CH_4. The tools and technical expertise of the Convention can be shared to help cities and relevant agencies develop multi-pollutant air quality management plans that reduce air pollution emissions and improve public health;

(e) Consider additional action on NOx, SO_2, $PM_{2.5}$ (BC), VOCs and in particular NH_3;

(f) Continue scientific work and policy discussions on CH_4 and consider potential action on the appropriate policy mechanism to achieve methane reductions to reduce O_3;

(g) Continue scientific and policy work on setting metrics for BC and inclusion of condensable particles in PM reporting; and consider appropriate action;

(h) An update of the technical annexes should take into account current barriers to implementation;

(i) Continue to update the EMEP/EEA Air Pollutant Emission Inventory Guidebook as the reference for preparing the emission inventories, in line with improvements in scientific and technical knowledge;

(j) Develop a comprehensive guidance document on non-technical and structural measures.

[20] ECE/EB.AIR/2021/2, table 2, activity 2.1.2.