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

Technical information for the review of the Gothenburg Protocol

Submitted by the Gothenburg Protocol review group

Summary

The present document was compiled by the Gothenburg Protocol review group based on information provided by the task forces reporting to the Working Group on Strategies and Review. It supplements the report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012 (ECE/EB.AIR/2022/3) with additional policy-relevant information and is unofficially referred to as its “annex II”.

The Executive Body is invited to take note of the information contained in the present document.

I. Introduction

1. The present document was compiled by the Gothenburg Protocol review group based on the information provided by the task forces[1] reporting to the Working Group on Strategies and Review, as part of the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol), as amended in 2012, initiated by the Executive Body with its decision 2019/4.[2] The present document provides additional policy-relevant technical information to supplement the report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (ECE/EB.AIR/2022/3).

2. The document describes policy scenarios up to 2050, case studies on the technological pathways chosen in selected countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia, barriers to implementation, adequacy of key articles of the Gothenburg Protocol, options to address nitrogen, options to address methane (CH_4) and international cooperation on air pollution.

II. Policy scenarios

3. The scenarios were developed by the Centre for Integrated Assessment Modelling (CIAM) based on projections by Parties and international organizations, such as the International Energy Agency and the European Commission Joint Research Centre. Results for future concentrations and deposition levels were calculated by CIAM in cooperation with the Meteorological Synthesizing Centre-West (MSC-W). Health impacts were based on exposure-response relationships developed by the World Health Organization (WHO). Effects on materials and on ecosystems, including lakes and crops, were calculated by the programme centres of the international cooperative programmes of the Working Group on Effects.

Current reduction plans

4. Current reduction plans in Europe show relatively small decreases for NH_3 (NH_3) compared to the projected emission reductions of sulfur dioxide (SO_2), nitrogen oxides (NO_x) and primary particulate matter (PM). The regional deposition rates of sulfur and nitrogen are projected to change similarly to regional emissions of SO_x, NO_x and NH_3. Reductions of primary PM emissions, together with precursors of the secondary inorganic aerosols, are projected to lead to reduced $PM_{2.5}$ concentrations by 2030. Even so, the 2021 WHO air quality guideline interim target 3 for $PM_{2.5}$ (i.e., 10 µg/m^3) is still expected to be exceeded in some areas (north Italy, areas in the Western Balkans and Eastern Europe, the Caucasus and Central Asia). In the longer term, some processes may lead to increasing PM levels again, for example, higher temperatures may increase biogenic volatile organic compound (VOC) emissions (and hence formation of secondary organic aerosols) and increasing NOx and NH_3 emissions from soils might also increase secondary PM formation. Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model calculations show that the 2021 annual WHO air quality guideline value for $PM_{2.5}$ will be exceeded in large areas by 2030 in the scenario assuming implementation and enforcement of current environmental legislation.

Additional reduction options

5. Within the United Nations Economic Commission for Europe (ECE) region, further technical reductions in NH_3 emissions from agriculture, fine particulate matter ($PM_{2.5}$) and non-CH_4 volatile organic compounds (NMVOCs) emissions from residential solid fuel burning and agricultural waste burning, and CH_4 emissions from municipal waste treatment, the fossil fuel sector and agriculture are also possible. Beyond these technical abatement

[1] The Task Force on Techno-economic Issues, the Task Force on Reactive Nitrogen, the Task Force for International Cooperation on Air Pollution and the Task Force on Integrated Assessment Modelling

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

options, emission reductions can result from structural changes in energy, transport and food systems.

6. In countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia, further emission reductions are possible using best available technologies, inter alia, in coal power plants, solvent use, transport and waste management. Further emission reductions are considered possible in international shipping; for example, via the International Maritime Organization agreements on emission control areas,[3] or initiatives by port authorities to encourage clean ships and to provide shore-to-ship electricity access.

Greenhouse Gas and Air Pollution Interactions and Synergies model improvements by the Centre for Integrated Assessment Modelling

7. The GAINS modelling domain is extended and includes all countries of Eastern Europe, the Caucasus and Central Asia. NOx emissions from soil are included and consistent with the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)/European Environment Agency (EEA) *EMEP/EEA air pollutant emission inventory guidebook 2019*[4] and national reporting. NMVOC emissions from livestock manures, crops and grasslands are implemented in GAINS applying the EMEP/EEA guidebook methodology. Slurry acidification is added as NH_3 mitigation option. The waste management sector model has been revised and includes consistently multi-pollutant impacts of control options (including CH_4 emissions). The critical load 2021 database is implemented in GAINS jointly with the Coordination Centre for Effects (CCE). Health impacts assessment methods are discussed with the Task Force on Health. New global scenarios will follow in summer-autumn 2022. New source receptor coefficients were developed jointly with MSC-W and include urban-rural interactions. Draft results, including an internally consistent representation of the condensable fraction of PM are available.[5] Please see figure 1 below for a summary of emission scenarios.

Greenhouse Gas and Air Pollution Interactions and Synergies scenarios

8. The baseline includes air pollutants (SO_2, NO_X, $PM_{2.5}$, BC, NH_3, VOC) and CH_4 emissions up to 2050 and assumes effective implementation of current legislation. Historical data were updated and validated with nationally reported emissions in 2021 jointly with the EMEP Centre on Emission Inventories and Projections. For $PM_{2.5}$, the baseline scenarios still give a mixed picture with respect to inclusion of condensable PM for residential heating. Recent policies and measures and national implementation progress and plans were included. For the European Union, energy and agriculture policies follow the 55 per cent greenhouse gas reduction target for 2030 and net-zero carbon in 2050. Note that this assumption gives a more optimistic picture than the nationally reported emission projections for 2030 (see section V. A of the report on the review). For the Western Balkans, the Republic of Moldova, Georgia, and Ukraine, new energy and agricultural scenarios were developed. For countries of the European Free Trade Association (EFTA), Türkiye and countries of Eastern Europe, the Caucasus and Central Asia, activity projections were derived from the International Atomic Energy Agency World Energy Outlook[6] and the Food and Agriculture Organization of the United Nations. Recent developments in the ECE region have not been considered, and the scenarios were run before the invasion of Ukraine by the Russian Federation.

9. The baseline scenario shows strong reductions of air pollutants (SO_2: -80 per cent between 2005 and 2030, NO_x: -50–-80 per cent, $PM_{2.5}$: -25–-70 per cent) in the European Union, North America, and also in countries of the Western Balkans, owing to the Energy Community agreements[7] that include commitments to strong reduction of emissions from stationary sources in the coming decades. Countries of Eastern Europe, the Caucasus and

[3] See International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, and as further amended by the Protocol of 1997, annex VI.

[4] Available at www.eea.europa.eu/publications/emep-eea-guidebook-2019.

[5] New global scenarios will follow in autumn 2022.

[6] See www.iea.org/topics/world-energy-outlook.

[7] See www.energy-community.org/legal/treaty.html.

Central Asia will still have increasing fossil fuel use, but even here, due to ongoing technical progress, emissions of SO_2 and NO_x are expected to be reduced over time, by about 40 per cent and 20 per cent respectively between 2005 and 2030.

10. CH_4 declines in the baseline only in the European Union (Green Deal scenario). In North America, an increase is associated with the oil and gas sector. GAINS assumes higher (documented) emission factors for unconventional gas exploration than the United States Environmental Protection Agency.

11. The maximum technically feasible reduction (MTFR) scenario uses the same activity data (energy and agriculture scenario) as the baseline scenario and explores the potential for further mitigation applying best available techniques (BATs) globally. These techniques are characterized with lowest emission factors attainable with reduction technologies for which experience exists. These include highly efficient end-of-pipe technologies in industry (filters, scrubbers, primary measures), the transport sector, residential combustion (clean burning stoves, pellet stoves and boilers), measures in agriculture (including new low emission animal houses (such as cleaning ventilation air where applicable), covered storage of manures, immediate or efficient application of manure on land and urea use with inhibitors), solvent substitution, control of leaks on oil and gas production and distribution systems, to name some of the key measures. Note that this scenario does not include any cost constraint or lack of necessary resources to fund respective investments. It focuses on the technical mitigation potential. However, the scenario includes constraints due to the applicability of technology in particular sectors and uses information about the age structure of installations. No early shutdown or scrapping of cars or boilers is assumed. Consequently, it is clear that the mitigation potential increases towards 2050.

12. For SO_2 (apart from Eastern Europe, the Caucasus and Central Asia), most of the further mitigation potential is already committed in the baseline scenario. Assuring enforcement is essential here. For NO_x, some further mitigation measures are available. Remote sensing data (and N deposition measurements) indicate that emission inventories have overestimated the decline in emissions in the last decade. The effective reduction potential will depend on the decline in real-life emissions.

13. Current abatement policies are very modest for NH_3. Further reduction options exist across all regions (with the exception of single countries where policies are more advanced). However, overall, the technical mitigation potential for NH_3 is less than for other air pollutants.

14. For primary $PM_{2.5}$, with the exception of the European Union+EFTA, a large abatement potential exists, especially in industry and residential heating in countries of Eastern Europe, the Caucasus and Central Asia and the Western Balkans. Residential heating dominates in many cities of Eastern Europe, the Caucasus and Central Asia, while the power sector is an important regional source for local background concentrations.

15. The "low" scenario includes changes in activity data due to global climate mitigation policy, including a significant transformation in the agricultural sector leading to strong reduction of livestock numbers, especially cattle and pigs, which are associated with changes in human diet. This brings significant additional reductions of ammonia (NH_3) and CH_4. Compared to the MTFR scenario, an additional 20–40 per cent reduction is estimated. The "low" scenario assumes for all regions climate policies with strong reduction of fossil fuel use and a simultaneous increase in use of biofuels and renewable energy (wind, solar, etc.). The trajectories for fossil fuel use, as well as the structure of energy use in general, differs across the regions. For the European Union, the baseline already includes a strong reduction of fossil fuel use and therefore this energy projection for the European Union is also used in the "low" scenario.

16. For SO_2 and NO_x, most regions have significant reductions in the baseline (although less so in Eastern Europe, the Caucasus and Central Asia) and therefore the further mitigation potential is limited. However, in relative terms, emissions in the "low" scenario can be 50 per cent lower than in the MTFR scenario. For NH_3, the picture is different in that the baseline shows no significant reduction, but for all regions the structural and behavioural changes in the "low" scenario provide a significant additional abatement potential and will also bring CH_4 co-benefits.

Result[8]

17. Calculations with the GAINS model show that mean annual $PM_{2.5}$ concentrations in 2015 were above the 2005 WHO guideline (10 µg/m^3) in several regions. Most of the population in the EMEP domain (the ECE region excluding North America) lives in areas where $PM_{2.5}$ is above the current WHO annual mean guideline value of 5 µg/m^3. The "baseline" scenario brings declining concentrations, and the current European Union limit value (25 µg/m^3) will be met in 2030 in the European Union. Even so, elevated concentrations persist in the countries of the Western Balkans, Eastern Europe, the Caucasus and Central Asia (see figure 2). Overall levels in large parts of the EMEP domain remain above the WHO guideline in 2030. The MTFR scenario for 2030 brings little improvement in the number of people exposed to exceedances of the WHO guideline, although the concentrations and associated health impacts drop. Both MTFR and "low" are not yet fully effective in 2030 due to the short time available for full introduction of abatement measures or transformations embedded in the "low" scenario.

18. The baseline for 2050 shows further improvements, but the WHO guideline level would only be attained for one third of the population. MTFR brings large-scale improvements, also across the Western Balkans, as there is enough time to introduce further technical measures. Lastly, the "low" scenario gives even lower concentrations. More than 60 per cent of the population in the EMEP domain would be exposed to $PM_{2.5}$ levels below the 2021 WHO guideline by 2050 (over 80 per cent in the European Union+EFTA+ the United Kingdom of Great Britain and Northern Ireland, but only 30 per cent in Eastern Europe, the Caucasus and Central Asia + Türkiye, where nearly 30 per cent is also exposed to more than 10 µg/m^3) (see figure 3 below).

Health impacts

19. Exposure to $PM_{2.5}$ levels above the 2021 WHO-guideline value is estimated to have caused about 128,500 cases of premature death in the European Union-27 in 2020. This is lower than the EEA estimate of 307,000 cases, which also includes impacts of exposure below the WHO-guideline value.[9] Exposure to NO_2 caused about 21,200 cases. EEA estimates that the number of cases due to ozone-exposure above 70 micrograms (Sum of Ozone Means Over 35 parts per billion (ppb)) was 16,800 in 2019; this is similar to the estimates of the GAINS model for 2015 of about 21,000 cases, declining to about 16,250 cases in the baseline scenario in 2030. It should be noted that $PM_{2.5}$ and NO_2 numbers cannot be added because of double counting.

20. GAINS-estimates for the European Union-27 show that, between 2020 and 2030, the baseline scenario will already give a decrease in premature mortality due to (excess) $PM_{2.5}$ exposure by about 55 per cent.[10] Premature mortality due to (excess) NO_2-exposure is expected to decrease by more than 80 per cent. The MTFR scenario for 2030 would lead to premature mortality reductions of 80 per cent for $PM_{2.5}$ and 85 per cent for NO_2. In 2050, MTFR would give 90 per cent less cases of premature mortality due to $PM_{2.5}$ compared to 2020 and 97 per cent less due to NO_2-exposure.

Air pollution in cities

21. The GAINS model has been further developed to address contribution of local and regional sources of pollution to air pollutant concentration in cities. Existing measurement data, albeit sparse outside the European Union, confirm the results of the GAINS model that

[8] Supplementary information with tables on emissions, share of the population per country exposed to air pollution levels above World Health Organization air quality guidelines, life years lost, premature death from ozone, share of ecosystems with exceedance of acidification and of nitrogen critical loads for 2015, 2030 and 2050 "baseline", 2030 and 2050 MTFR and 2030 and 2050 "low" scenarios will be made available as an informal document on the web page of the session: https://unece.org/info/Environmental-Policy/Air-Pollution/events/367824.

[9] See www.eea.europa.eu/publications/air-quality-in-europe-2021/health-impacts-of-air-pollution.

[10] European Commission, Directorate-General for Environment, "Second Clean Air Outlook report: Full implementation of clean air measures could reduce premature deaths due to air pollution by 55 per cent in 2030", 8 January 2021.

many of the cities in the region face $PM_{2.5}$ concentrations well above the national and current European Union standards. Analysis done so far for the Western Balkans, Eastern Europe, the Caucasus and Central Asia shows that the local contribution of residential combustion is important or dominant in many cities (in the Western Balkans, local residential heating sources might cause 50 per cent or more of the concentrations), with the power sector being an important regional source. It is important to highlight that residential combustion is also a relevant regional source, while its contribution obviously varies across the cities depending on the role of district heating. Especially in parts of Central and Eastern Europe, the Caucasus and Central Asia, district heating needs to be better reflected in the model. For several cities, the levels of pollution remain high and would require further policies based on assessments of the local, regional and transboundary contribution. Even in cases where the "baseline" scenario brings reductions, the future levels of pollution remain well above the WHO guidelines. This points to the need to develop further mitigation strategies that address both local, regional and transboundary sources to achieve significant reductions of the impact of air pollution in cities in the future.

Black and organic carbon

22. On average, about 10–15 per cent of the $PM_{2.5}$ emissions consists of elemental carbon (EC) and about 40–50 per cent is attributed to the sum of EC and organic carbon (OC). Abatement of $PM_{2.5}$ emissions would, in general, also reduce these carbonaceous emissions. The contribution of carbonaceous particles varies strongly across sources and regions, for example, diesel engines, agricultural residue burning and wood burning are notorious for their high share of EC and OC in PM emissions. This offers opportunities to focus $PM_{2.5}$ emission reduction on these sectors in order to maximize the reduction of carbonaceous aerosols and potentially also to obtain climate co-benefits. Additionally, VOCs, which are also emitted from incomplete combustion, condensate to particles when the flue gas cools down. This so-called condensable fraction of PM significantly increases total $PM_{2.5}$ emissions, especially for low efficient wood burning residential installations, and has not been consistently considered in past emission inventories. First estimates have been made for residential wood combustion, applying a harmonized set of emission factors including condensable fraction. Initial results show that for some countries, for example, Austria and Germany, this may contribute to an increase of total $PM_{2.5}$ emissions of up to around 40 per cent, and the estimated number of people exposed to more than 10 ug/m^3 $PM_{2.5}$ in these countries would rise by 10–20 per cent.

Ecosystem protection

23. For the European Union, exceedance of the critical loads for acidification will be reduced in the "baseline" scenario from about 9 per cent of all ecosystems in 2015, to 3 per cent in 2030 and 2 per cent in 2050. In the "low" scenario, exceedance in the European Union could drop to below 1 per cent of the ecosystems by 2050. For non-European Union countries in the EMEP domain, exceedance will decline from about 4 per cent of the ecosystems in 2015, to 2 per cent in the 2050 "baseline" and less than 0.5 per cent in the "low" scenario (see figures 4 and 5 below).

24. Exceedance of the critical loads for eutrophication in the European Union will be reduced in the "baseline" scenario from 80 per cent of all ecosystems in 2015, to 70 per cent in 2030 and 65 per cent in 2050. In the "low" scenario, 35 per cent of the ecosystems in the European Union will remain with an exceedance even in 2050. For non-European Union countries in the EMEP domain, exceedance will decline from 50 per cent of the ecosystems in 2015, to around 43 per cent in the 2050 baseline and 15 per cent in the "low" scenario (see figure 6 below).

Lakes

25. Based on MSC-W calculations, deposition of sulfur and nitrogen at all International Cooperative Programme for Assessment and Monitoring of the Effects of Air Pollution on Rivers and Lakes (ICP Waters) sites will decline, but more slowly than in the period 2000–2020. ICP Waters estimates that sulfate and nitrate concentrations will likely continue to decline up to 2030 and 2050 but will not reach assumed pre-acidification levels in affected

regions. At sensitive sites, only part of the acid deposition is neutralized by ion exchange with base cations in catchment soils, and acid neutralizing capacity (ANC) will remain lower than pre-acidification levels. Climate change and annual variability in climate are having a greater effect on ANC as acid deposition is declining, a tendency likely to continue with unknown consequences for biological recovery.

Baltic Sea

26. Atmospheric inputs of nitrogen to different regions of the Baltic Sea contribute to the exceedance of the maximum allowable input as defined by the Baltic Marine Environment Protection Commission to guarantee a good ecological status in terms of clearness of the water, natural levels of nutrient and oxygen concentrations, natural occurrence of plants, including algae, and animals. CCE calculated the average accumulated exceedance (AAE) of the critical atmospheric input of the Baltic subbasins using deposition projections from MSC-W. The overall AAE on basin level in general seems not very high compared to the AAE of the terrestrial ecosystems. The highest exceedance is indicated for the south-western part of the Baltic. The deposition in the 2030 "baseline" scenario, will reduce the AAE in the subbasins with the highest exceedances by 60 per cent. In the MTFR scenario, the reduction in these basins will be 80 per cent compared to the 2019 situation. Still, it has to be stressed that the exceedance in some parts of the basins is higher, in particular along the coastlines.

Ozone

27. The GAINS baseline (and MTFR) scenario assumes a further increase in global CH_4 emissions between 2005 and 2050. Only in the European Union (+EFTA+United Kingdom of Great Britain and Northern Ireland) are CH_4 emissions expected to decrease (by more than 40 per cent) due to measures in the energy and waste sector. CH_4 emissions in Eastern Europe, the Caucasus and Central Asia region and the Western Balkans are expected to remain constant. CH_4 emissions in Canada and the United States of America are expected to increase. They are associated with unconventional gas exploration. There are documented differences in emission factors used in the GAINS model and by the the United States Environmental Protection Agency (GAINS assumes higher losses). The increase in global CH_4 emissions is expected to offset the decreases in surface ozone due to NO_x and NMVOC controls within Europe and North America (see informal document "Synergies and interactions with other policy areas").[11]

28. The "low" scenario achieves reductions of CH_4 emissions in North America, Eastern Europe, the Caucasus and Central Asia and the Western Balkans consistent with the 30 per cent reduction target in 2030 for countries that joined the Global Methane Pledge.[12] Together with the regional policies in Europe and North America to reduce other ozone precursors (NO_x and NMVOC), and a reduction of NO_x-emissions from marine shipping, this could result in decreasing summer ozone concentrations by up to 5 ppb in Europe in 2030 and give benefits for health, crop production and ecosystem protection. This will also reduce temperature increase. The continuing decline of CH_4 emissions beyond 2030 in the "low" scenario will result in even lower ozone concentrations in 2050.[13]

29. The International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) expects that the average wheat yield loss in Europe due to ozone (using the phytotoxic ozone dose (POD3IAM) metric) will decrease from 9.3 per cent in 2015 to 7.8 per cent in 2050 in the "baseline" scenario. In the "low" scenario (with maximum technical abatement measures, climate and energy policies and dietary change) the average yield loss will be further reduced to 6.7 per cent in 2050. For deciduous forests, the average per cent biomass loss in the 25 European countries with the greatest deciduous forest cover is expected to decrease from 18.6 per cent in 2015 to 16.5 per cent in 2050 in the "baseline" scenario and to 14.7 per cent in the "low" scenario (see figure 7 below).

[11] Available at:https://unece.org/sites/default/files/2022-09/Synergies%20and%20interactions%20with%20other%20policy%20areas_13%20Aug%20final.pdf.

[12] See www.globalmethanepledge.org/.

[13] The MSC-W results will become available after the submission of the present document.

30. In 2015, estimated total wheat production losses for Europe due to ozone were 23.8 million tons, greater than the annual production of Ukraine (21.8 million tons). By 2050, total losses for Europe are predicted to have reduced by 7 million ton for the "low" scenario, equivalent to the current wheat production of Poland. However, overall, results show that significant production losses of wheat will still occur even under the most stringent of the scenarios, with an estimated 16.8 million tons loss for Europe under the 2050 "low" scenario.

Damage to materials

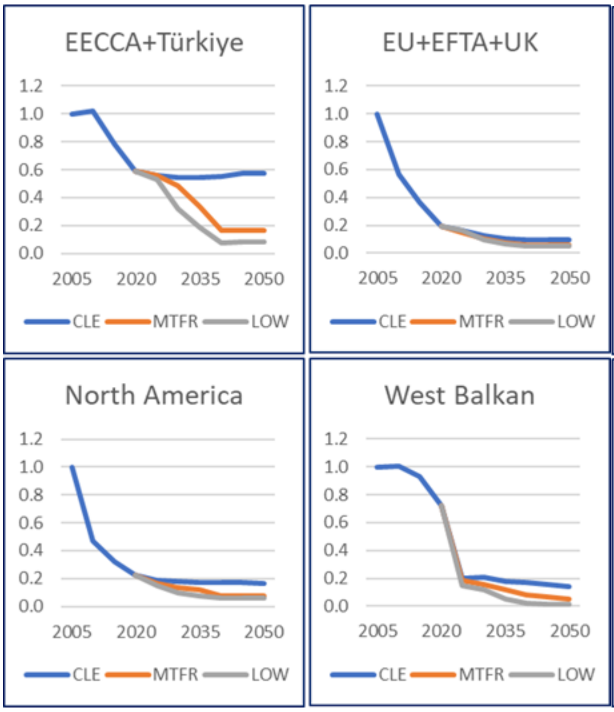
31. All scenarios show that, by 2030, air quality targets will be reached that prevent carbon steel corrosion and limestone recession. For soiling of modern glass, the target is reached for almost all sites to protect modern technical constructions but the target for cultural heritage is not reached for about 30 per cent of the 23 investigated sites. The largest contribution to soiling is from particulate matter. Even though the modelled data show that most of the targets are reached, it is noted that decreasing trends are not always confirmed by measured data. Therefore, it is important to improve dose-response functions that show the largest discrepancy to increase confidence that the protection targets will be reached.

Conclusion

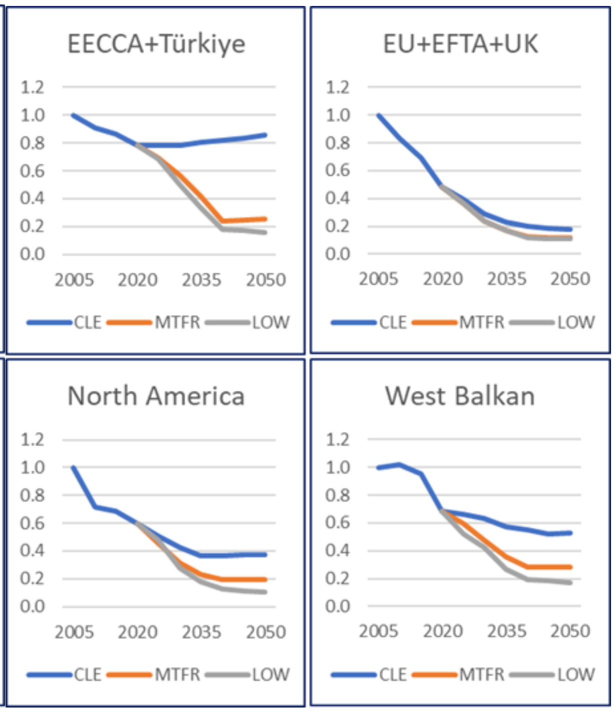
32. Current reduction plans will, in the coming decades, improve air quality and lead to less acidification and eutrophication than with the current emission reduction obligations for 2020 and beyond in the Gothenburg Protocol. At the same time, the scenario analysis shows that there are technical and non-technical options for further improvement. However, the Convention's long-term targets to protect health and ecosystems will remain a challenge. Even the most optimistic scenario for 2050, assuming rather radical region-wide structural and behavioural transformations, still shows that 30 per cent of the EMEP domain population would be exposed to $PM_{2.5}$ concentrations above the 2021 WHO guideline level and that in 25 per cent of ecosystem area the nitrogen critical load will still be exceeded.

Figure 1
Emission trends in "baseline", maximum technically feasible reduction and "low" scenarios[14]

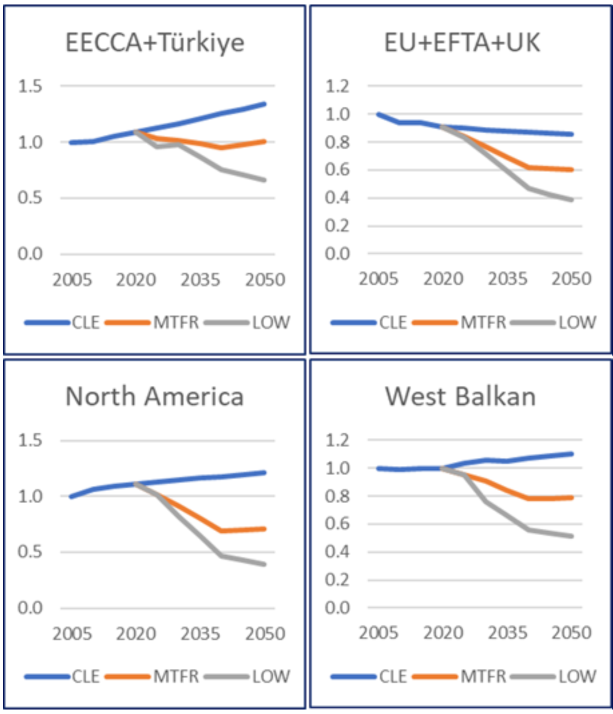
SO_2



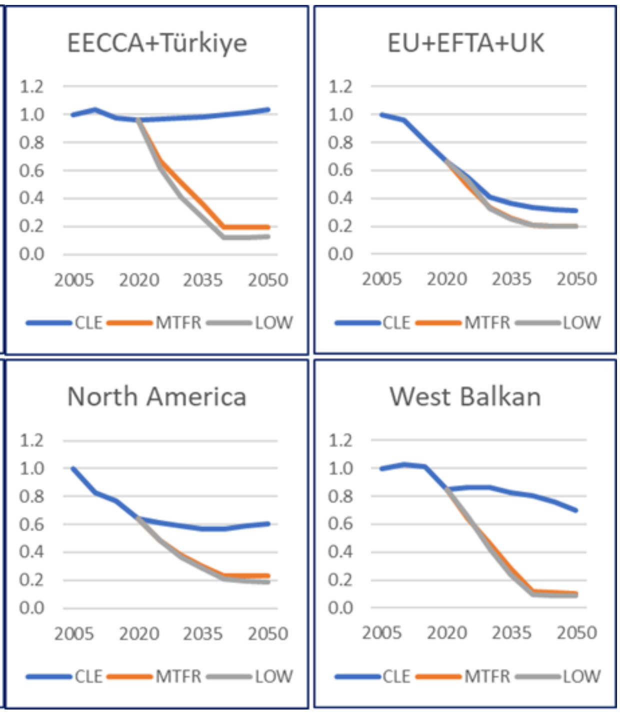
NO_x



NH_3



$PM_{2.5}$



[14] Figures 1–6 in present document were produced by CIAM based on GAINS model.

Figure 2
PM2.5 concentrations in 2015, 2030–2050 "baseline" and 2050 "low" scenario

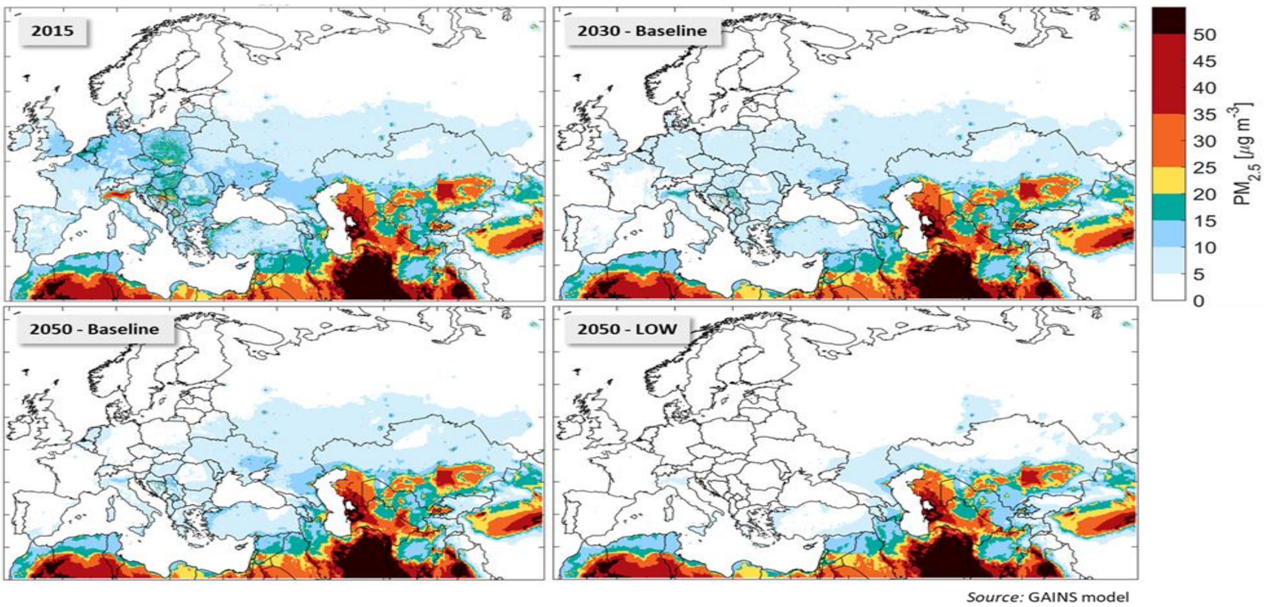


Figure 3
Population exposure in United Nations Economic Commission for Europe domain, excluding North America

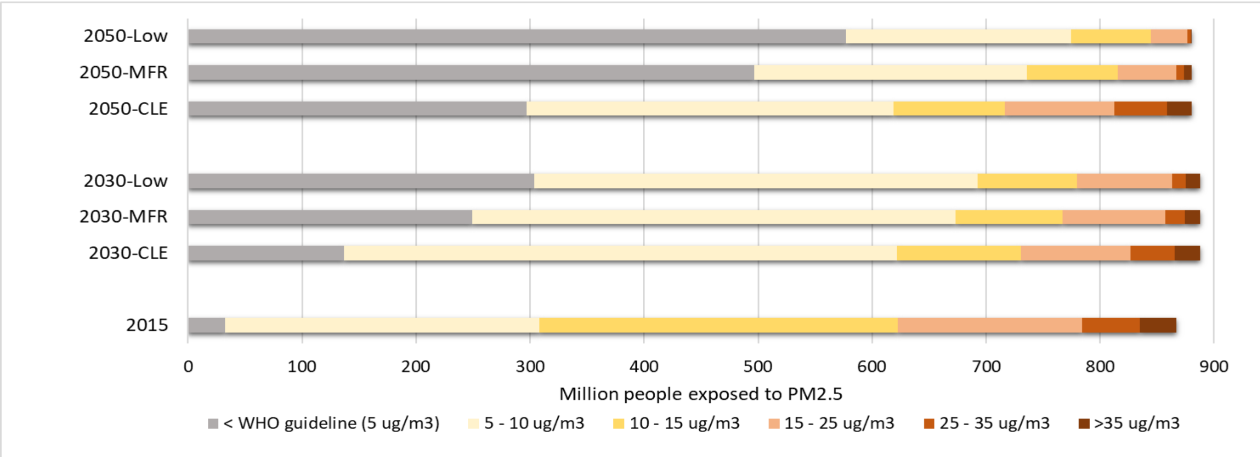


Figure 4
Exceedance of critical loads for acidification and eutrophication in Europe

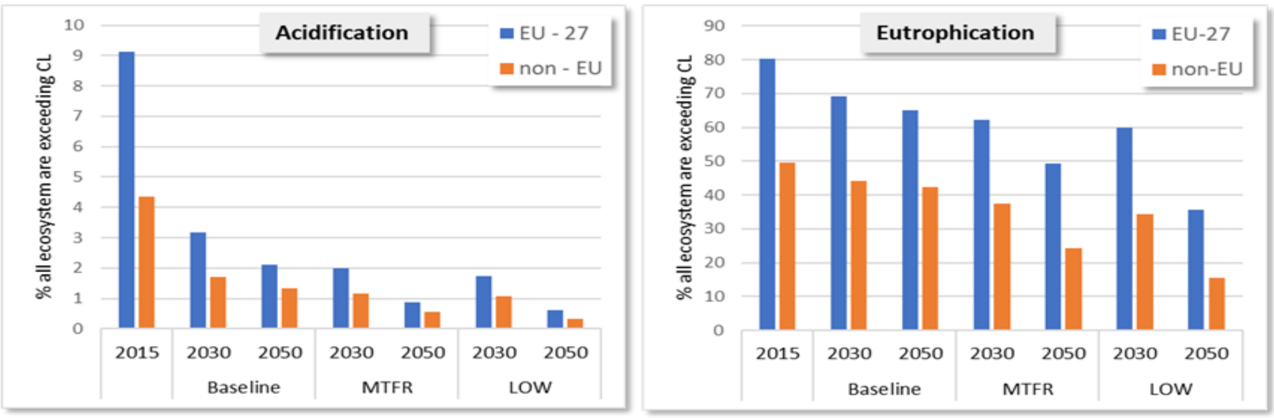
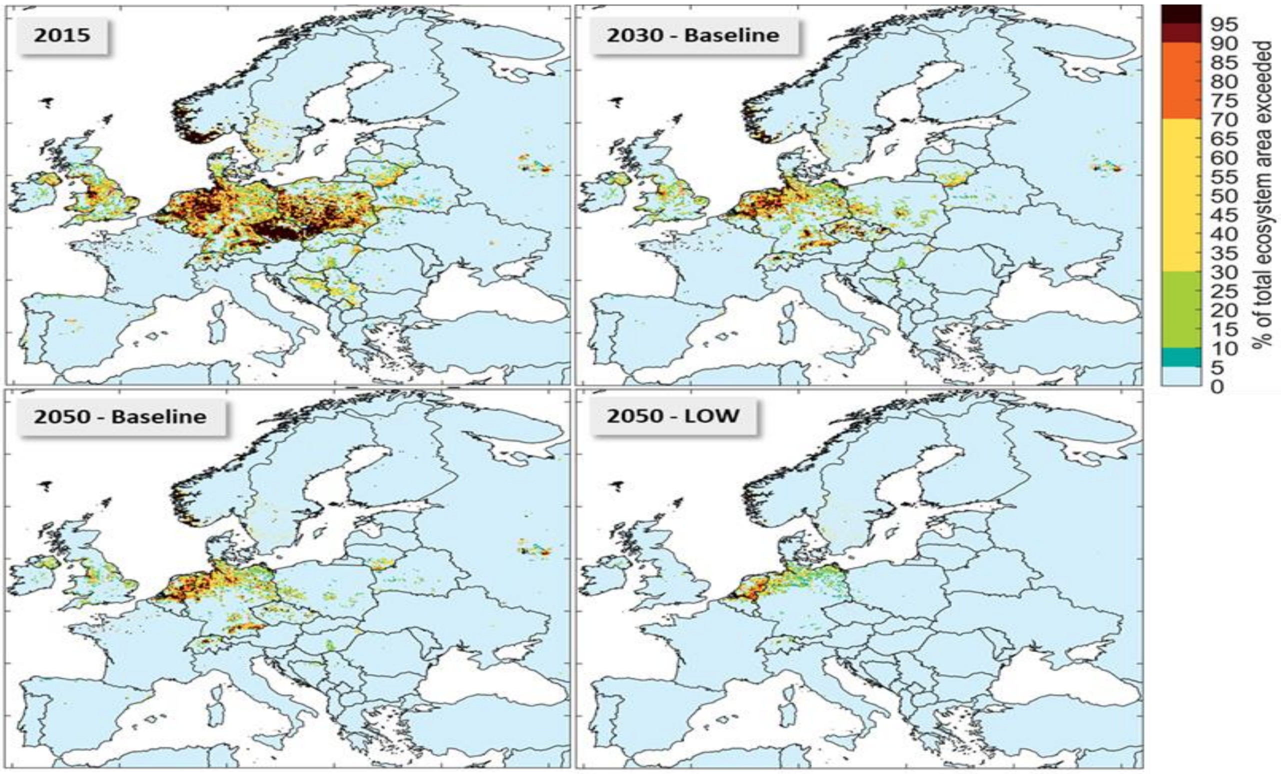
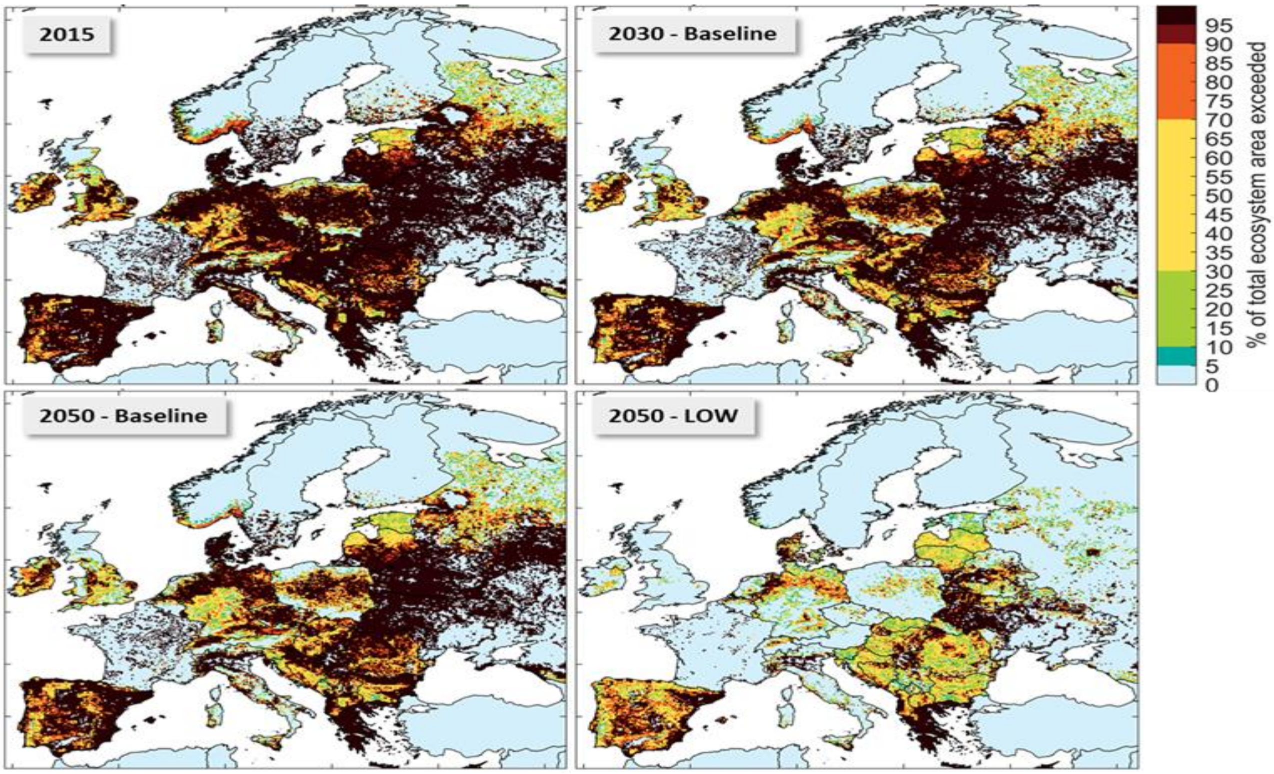


Figure 5
Acidification: exceedance of critical loads (total ecosystem area)



Source: GAINS model

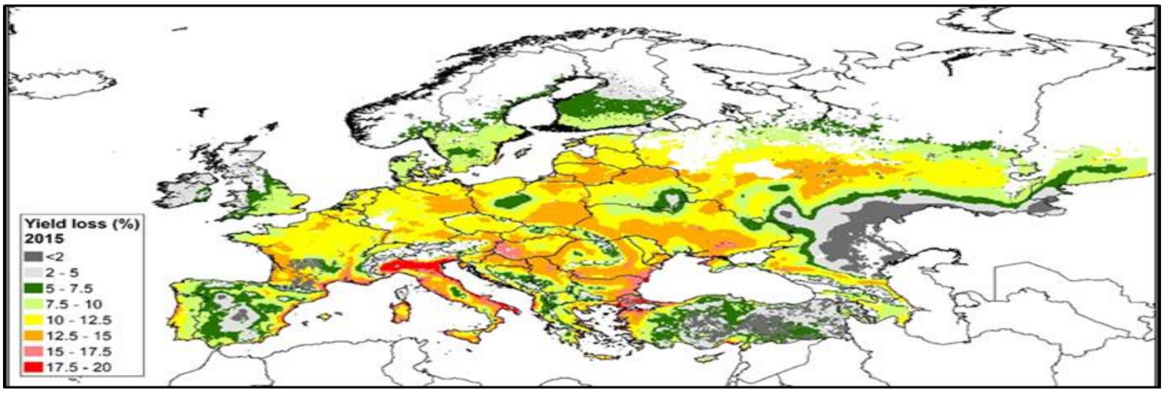
Figure 6
Eutrophication: exceedance of critical loads (total ecosystem area)



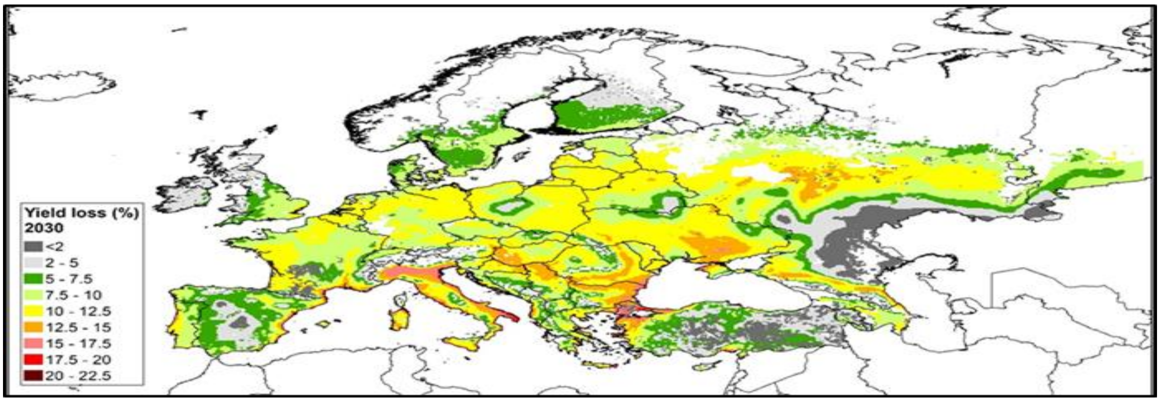
Source: GAINS model

Figure 7

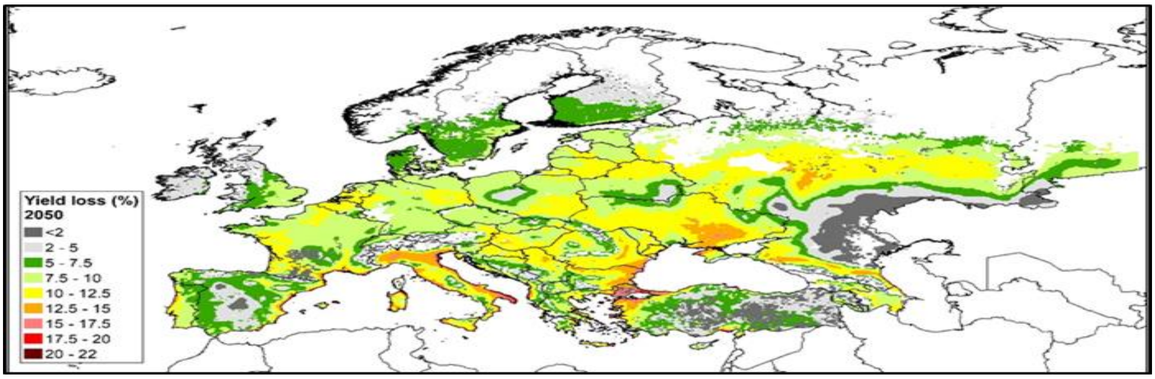
Wheat yield loss due to ozone (percentage loss based on the ozone flux metric POD$_3$IAM)



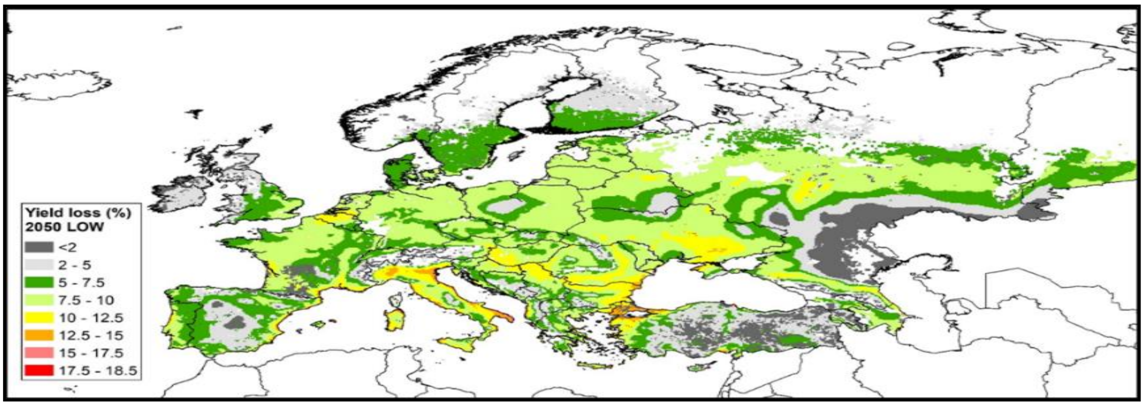
2015



Baseline 2030



Baseline 2050



LOW-scenario

Source: ICP Vegetation.

Abbreviations: EECCA, Eastern Europe, the Caucasus and Central Asia; EU, European Union; UK, United Kingdom.

III. Technological pathways towards ratification of the amended Gothenburg Protocol: case studies of four countries in Eastern and South-Eastern Europe, the Caucasus and Central Asia

33. The Task Force on Techno-economic Issues developed case studies to explore possible technological pathways towards ratification of the Gothenburg Protocol, as amended in 2012, in some countries of Eastern and South-Eastern Europe, the Caucasus and Central Asia in preparation for the thematic session on barriers towards ratification and implementation, planned as part of the forty-second session of the Executive Body. The full report will be made available as an informal document for the forty-second session of the Executive Body.[15] Below are presented conclusions for Georgia, Serbia, the Republic of Moldova and Kazakhstan.

Georgia

34. In Georgia, ambient air is monitored through eight stations and passive tube measurement campaigns. In 2019, the largest $PM_{2.5}$ concentrations were observed in the country's most industrialized cities. Average annual NO_2 concentrations were larger than the annual limit value in Tbilisi and some other cities.

35. As for current legislation, the European Union Ambient Air Quality Directive[16] and the European Union Air Quality Fourth Daughter Directive[17] are applied. Under a European Union-funded project, Georgia is improving its own permit and control systems for industrial sources and developing a legal framework for the European Union Industrial Emissions Directive.[18] A new law on industrial emissions, based on the European Union Industrial Emissions Directive, is expected to be adopted in September 2022, with full implementation possible by 2031. Draft by-laws on large combustion plans, including a BAT-based integrated permit, and on organic solvent uses, are being developed and implemented.

36. The main polluting sectors in Georgia for NO_x emissions are the transport sector (43 per cent of share in 2019) and the agriculture sector (32 per cent), while industrial processes (10 per cent), industrial combustion (6 per cent) and electricity production (2 per cent) are less significant. Although a significant decrease in emissions is observed in the past years, industrial activities (such as iron and steel production) remain the main source of SO_x emissions. The residential sector is responsible for 77 per cent of emissions of PM, whereas industrial combustion and processes had a share of 13 per cent in 2019.

37. The implementation of the Law on Industrial Emissions is expected to allow Georgia to be in compliance with annexes IV–VI and X to the Gothenburg Protocol as amended, including large combustion and industrial plants, presumably by 2031–2035. However, for annex VI to the Protocol, the implementation of VOC stage II emission limit values might require more time.

38. As an example, the following techniques are recommended for implementation:

(a) Regarding annex V to the Protocol: combustion optimization; combination of primary techniques, for example, air or fuel staging, flue-gas recirculation, low-NO_x burners; selective non-catalytic reduction; selective catalytic reduction;

(b) Annex X to the Protocol: fabric filters and electrostatic precipitators with proper sizing of the equipment. Optimized and new low emission appliances in the domestic heating. Application of the Code of good practice for wood-burning and small combustion installations (ECE/EB.AIR/2019/5).

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[15] See https://unece.org/info/Environmental-Policy/Air-Pollution/events/367824.

[16] Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008L0050&qid=1663770806171.

[17] Available at https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32004L0107.

[18] Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0075.

Serbia

39. In Serbia, there are three categories of air quality, with category III corresponding to the highest level of pollution. In 2019, 43 per cent of the population was living in category III areas.

40. Serbia began aligning national air quality policies and regulations with European Union legislation several years ago. It has advanced considerably in that regard, and the process is likely to be completed by 2025, in particular regarding the following:

(a) The Industrial Emissions Directive;

(b) The Stage I Petrol Vapour Recovery Directive and the Stage II Petrol Vapor Recovery Directive;[19]

(c) The Fuel Quality Directive;[20]

(d) The Sulfur Directive.[21]

41. The major sources of pollution in Serbia are electricity and heat generation for SO_2, NO_x and PM, and biomass burning in residential heating and industrial processes for $PM_{2,5}$ and VOC.

42. The implementation of the above-mentioned directives would allow Serbia to be in compliance with annexes IV–VI and X to the Protocol tentatively in 2030–2035. The implementation of the following techniques is recommended:

(a) Annex IV - boiler sorbent injection, dry sorbent injection, spray dry absorber, circulating fluidized bed dry scrubber, wet flue-gas desulfurization, possibly associated with the use of low sulfur (solid or liquid) fuels;

(b) Annex V - combustion optimization; combination of primary techniques, for example, air or fuel staging, flue-gas recirculation, low-NO_x burners; selective non-catalytic reduction; selective catalytic reduction.

Republic of Moldova

43. In the Republic of Moldova, air quality is currently monitored using a network of 17 old stationary stations. They are not recognized at the international level and their results are not shared with the European data system.

44. For over ten years, the Republic of Moldova has been aligning its national policies and regulations with European Union directives by transposition. The following directives have been transposed to date:

(a) The Ambient Air Quality Directive;

(b) The Air Quality Fourth Daughter Directive;

(c) The Paints Directive;[22]

(d) The Stage I Vapour Recovery Directive;

(e) The Sulfur Directive.

45. The Industrial Emissions Directive and the National Emissions reduction Commitments Directive[23] are currently being transposed.

46. Residential heating with the use of solid and liquid fuels is the major source of SO_2, $PM_{2.5}$ and VOC emissions, with 73 per cent, 89 per cent and 24 per cent of share respectively.

[19] Available at, respectively, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31994L0063 and https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0126.

[20] Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32009L0030.

[21] Available at https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX:32016L0802.

[22] Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0042.

[23] Available at 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.

Road transport is the main source of NO_x emissions, with a 51 per cent share. Emissions from industrial sources are less significant due to the small number of existing installations and the wide use of natural gas. The few existing large combustion plants burn natural gas.

47. The implementation of the above-mentioned directives would allow the Republic of Moldova to be in compliance with almost all of the requirements of annexes IV–VI and X to the Protocol tentatively in 2030–2035. The use of the following techniques is recommended, with a focus on PM emissions control:

(a) Annex X: fabric filters and electrostatic precipitators in industrial processes, with the proper sizing of the equipment. In domestic heating, optimized and new low emission appliances. Application of the "Code of good practice for wood-burning and small combustion installations;"

(b) Annex V: combustion optimization; combination of primary techniques, for example, air or fuel staging, flue-gas recirculation, low-NO_x burners; selective non-catalytic reduction; selective catalytic reduction.

Kazakhstan

48. In Kazakhstan, about 6,000–9,360 premature deaths are caused by air pollution every year. The network of monitoring stations is quite extended. The emission limit values result is regularly exceeded.

49. Kazakhstan has developed a road map and the National Action Plan for the ratification of the Convention's three most recent Protocols, although these are not yet approved by the competent authority. Kazakhstan began partially aligning national policies with the European Union Industrial Emissions Directive via the new 2021 Environmental Code, which introduces integrated environmental permits based on BAT starting from 2025, with country-specific BAT reference documents being elaborated.

50. Electricity and heat generation are major sources of SO_2 and NO_x emissions, with a 32 per cent and 29 per cent share, respectively, followed by petroleum refining and iron and steel plants. Residential heating is responsible for 33 per cent of $PM_{2.5}$ and for 20 per cent of NMVOC emissions, while iron and steel production contribute to 25 per cent of $PM_{2.5}$ emissions. Coal-fired large combustion plants are the largest sources of SO_2, NO_x and PM.

51. The implementation of the new Environmental Code and the definition of BAT would allow Kazakhstan to be in compliance with some of the requirements contained in annexes IV–V and X to the Protocol, as amended, covering industrial sources. However, such compliance is only possible if the implemented achievable emission level associated with application of the BATs is the same as in the Protocol's annexes. Compliance can be achieved in 2032–2035. Use of the following techniques is recommended:

(a) Annex IV: boiler sorbent injection, dry sorbent injection, spray dry absorber, circulating fluidized bed dry scrubber; wet flue-gas desulfurization, associated with the use of low sulfur (solid or liquid) fuels;

(b) Annex V: combustion optimization; combination of primary techniques, for example, air or fuel staging, flue-gas recirculation, low-NO_x burners; selective non-catalytic reduction; selective catalytic reduction.

IV. Barriers to implementation

52. As welcomed by the Working Group on Strategies and Review at its sixtieth session (Geneva, 11–14 April 2022), the Gothenburg Protocol review group, following its proposal, has prepared an informal document on barriers to ratification and implementation of the amended Gothenburg Protocol, including possible solutions to overcome them.[24] This informal document for the forty-second session of the Executive Body provides a categorization of the barriers identified so far (political, financial, institutional, regulatory, capacity and technical) together with possible solutions to overcome each type of barrier. It

[24] ECE/EB.AIR/WG.5/128, para. 20.

also provides information on the risks, benefits and drawbacks of proposed solutions involved, as well as some initial key findings and conclusions. It is intended to serve as a basis for non-Parties to identify and communicate their specific Protocol-related barriers and their specific suggestions for solutions. The initial key findings of the analysis in the informal document are summarized below.

53. The countries of Eastern Europe, the Caucasus and Central Asia and the Western Balkans have made real progress towards ratification and implementation of the latest amended Protocol in recent years, not least thanks to the broad and continued support of many Parties, technical bodies and the secretariat of the Convention in the form of outreach, capacity-building, training activities and other support. Many initiatives have been launched and efforts are ongoing to further assist these countries in moving forward. However, it is clear that more needs to be done. The countries of Eastern Europe, the Caucasus and Central Asia and the Western Balkans differ in: the speed at which they are moving; their needs; and their level of understanding of the complexity and implementation issues with regard to the amended Protocol.

54. Further assistance, tailored to their specific needs, would improve the possibility for the countries of Eastern Europe, the Caucasus and Central Asia and other non-Parties to take the necessary additional steps. As the needs of the different non-Parties with respect to ratification and implementation vary, it is difficult to find one-size-fits-all solutions. A tailor-made approach may be useful, but this inevitably involves risks.

55. It is difficult to identify common key barriers to ratification, as these vary among the current non-Parties, whereas the lack of financial resources, in combination with the technical complexity and demanding nature of the amended Gothenburg Protocol, stands out for most non-Parties. In this context, countries of Eastern Europe, the Caucasus and Central Asia have already expressed concern that a possible revision of the amended Gothenburg Protocol would further increase its ambition and complexity, further jeopardizing ratifications.

56. The introduction of new flexibilities or a transition to new approaches or other instruments to potentially help non-Parties on their way to ratification and implementation may entail certain risks (lowering the level of ambition, resulting in diverging commitments or needs for additional resources, etc.). As regards solutions to overcome the Protocol-related barriers of the amended Gothenburg Protocol, which could possibly be pursued in a next step following the completion of the review of the amended Gothenburg Protocol, the following tracks can be considered (without expressing a preference for any of them at this stage):

(a) Pursue solutions without revising or modifying the amended Gothenburg Protocol: make operational improvements to the current flexibility provisions and focus on capacity-building and non-related Protocol barriers;

(b) Pursue solutions within the framework of the amended Gothenburg Protocol: make use of the expedited amendment procedure pursuant to article 13 bis (6)–(7) of the Protocol to adopt amendments to technical annexes IV–XI, notwithstanding the fact that three Parties have declared that they are not bound by this procedure. New amendments to these technical annexes can include targeted solutions, changes to the timescales, new flexibilities or the introduction of specific provisions for countries of Eastern Europe, the Caucasus and Central Asia and other non-Parties in these technical annexes;

(c) Pursue solutions within an overall revision of the amended Gothenburg Protocol, requiring the classic ratification route by the Parties to enter into force;

(d) Pursue solutions within a new approach (a new mandatory or voluntary instrument, other type of action, etc.);

(e) Pursue a combination of approaches to meet the varying needs of the Parties to the Convention.

V. Adequacy of key articles of the Gothenburg Protocol

57. As stated in paragraph 88 of the main review report, in the present document, an assessment of the adequacy of the emission reduction obligations in the amended Gothenburg

Protocol is provided. The assessment of other key articles of the Protocol (e.g., on definitions, exchange of information and reporting) should include consideration of and be guided by the strategic priorities of the long-term strategy for the Convention for 2020–2030 and beyond (decision 2018/5, annex), as well as the findings and conclusions of the review of the Gothenburg Protocol. The question arises as to whether these articles are sufficiently helpful to include, for example, integrated nitrogen management, CH_4 or international cooperation in future work. Although a number of articles remain relevant, some could be reconsidered. All articles would benefit from an overall assessment of whether or not they continue to contribute effectively to the objectives of the Protocol and/or to better decision-making within the framework of the Convention, with due consideration of ratification barriers. An overall assessment of the internal consistency of the articles and coherence with other policy areas would also be useful.

58. The strategic priorities in the long-term strategy include the need for further strategies to reduce NH_3 and black carbon emissions, and the need to further address precursor pollutants of tropospheric ozone, including CH_4.[25] Opportunities for integrated approaches and synergies with other policy areas, such as air and climate, could be considered in other articles, as well as the global and regional nitrogen cycles, the influence of long-range air pollution on local air pollution to emphasize increased cooperation between different levels of government, and reference to marine ecosystems and/or marine shipping, as appropriate. Other actions linked to the correct implementation of certain articles (obligations) of the amended Gothenburg Protocol should also be taken into consideration. This includes revisions of outdated Executive Body implementing decisions and verification that all references in the Protocol to guidance to be adopted by the Executive Body have been effectively implemented through decisions.

VI. Options to address nitrogen

59. A wide range of measures is available to Parties to achieve national emissions reduction commitments for NH_3. These include: measures on animal housing, storage of manure, spreading of solid and liquid manures and of urea and other inorganic fertilizers on land, together with measures to promote recovery and reuse of nitrogen and other resources, with an emphasis on reducing pollution and developing the circular economy with innovation opportunities. Confidence in measures to control NH_3 emissions has increased greatly since these were first discussed by the Convention in the 1990s. Early uncertainty has been largely replaced with wide recognition that NH_3 abatement measures are available, cost effective and reliable.

60. NH_3 is also of concern to Canada and the United States of America, and additional assessments are needed to quantify the impacts. Canada hosted an NH_3 workshop (Ottawa, 10 October 2018) with participants from Canada, the United States of America and Europe; the event concluded with key messages regarding health and environmental impacts of NH_3, as well as tools and approaches available for mitigation.

61. Control of NH_3 emissions is now seen as part of a wider strategy to reduce the huge amount of valuable reactive nitrogen resource that is wasted. 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,[26] saving $100 billion per year globally,[27] as embraced as part of national action plans under the Colombo Declaration on Sustainable Nitrogen Management.

[25] Decision 2018/5, annex, paras. 28 and 50.

[26] Total nitrogen wasted has been defined as the sum of all forms of reactive nitrogen (N_r) lost as pollution plus denitrification to N_2, which is equally a waste of N_r resources (see Mark A. Sutton and others, “The nitrogen decade: mobilizing global action on nitrogen to 2030 and beyond”, *One Earth*, vol. 4, No. 1 (January 2021), pp. 10–14, in which a baseline of 2020 was used as a reference for halving wasted nitrogen globally).

[27] Mark A. Sutton, Nandula Raghuram and Tapan Kumar Adhya, “The Nitrogen Fix: From nitrogen cycle pollution to nitrogen circular economy”, in *Frontiers 2018/19: Emerging Issues of*

62. Annex IX is extremely short and contains little that is mandatory. There are many opportunities to revise annex IX, as already considered during the Gothenburg Protocol review/revision of 2008–2012.[28] Since the adoption of annex IX, new knowledge on the wider N-cycle has shown the importance of win-win opportunities for NH_3 emissions reduction by addressing them in an integrated manner with NO_x.[29] NO_x emissions from soils are currently excluded from the Gothenburg Protocol as amended (annex II to the Protocol, table 3), with ongoing reductions in NO_x emissions from combustion, soil NO_x may account for up to 25 per cent of total emissions for some parties by 2030. There is currently no annex to the Gothenburg Protocol describing measures and requirements for the control of emissions of NO_x from soils. Such emissions result from both agricultural soils and anthropogenic change to natural soils (for example, from increased atmospheric nitrogen deposition). Controlling emissions of NOx from soils offers an opportunity to go further in reducing total NOx emissions, and should be seen as part of strategies to reduce total amounts of wasted nitrogen resources, with co-benefits for climate, stratospheric ozone and water quality.[30] This highlights the need for coordinated reduction of NH_3 and NO_x emissions from agricultural soils, especially since this could facilitate simultaneous reduction of nitrous oxide (N_2O) emissions, di-nitrogen (N_2) emissions, and nitrate (NO_3^-) and other reactive nitrogen leaching within the context of more efficient nitrogen cycle management.

63. Several Parties to the Convention have made further progress in commitments to reduce NH_3 emissions, including in the revised European Union National Emissions reduction Commitments Directive. That directive describes both emission reduction commitments for the period 2020–2030 and after 2030, relative to 2005, and a set of specific measures for NH_3 emission reduction.[31]

64. While the main sources of NH_3 emissions in Europe are linked to livestock and crop activities, there is a very wide range of additional NH_3 sources arising from human activities, including from internal combustion engines, biomass burning, anaerobic digestion and wastewater, offering further opportunities for emission reduction.

65. The top priority areas for NH_3 emission abatement in annex IX identified by the Task Force on Reactive Nitrogen in 2011 (considering availability across the ECE region, cost, contribution to emission reduction and capacity building) need to be reconsidered. In 2011, priority measures were: (a) low-emission application of manures and fertilizers to land; (b) animal feeding strategies to reduce nitrogen excretion; (c) low-emission techniques for all new stores for cattle and pig slurries and poultry manure; (d) strategies to improve nitrogen

Environmental Concern, Bartlomiej Kolodziejczyk and Natalie Kofler (Nairobi, United Nations Environment Programme, 2019).

[28] Information related to revision of annex IX is contained in the following documents:
ECE/EB.AIR/WG.5/2008/10, paras. 31–32; ECE/EB.AIR/WG.5/2009/12, annex;
ECE/EB.AIR/WG.5/2010/4, paras. 5–74, and annex I;
ECE/EB.AIR/WG.5/2010/5;
ECE/EB.AIR/WG.5/2010/13, paras. 9–16 and 33, and annex;
ECE/EB.AIR/WG.5/2010/14;
Working Group on Strategies and Review forty-seventh session, informal document 2. Available at https://unece.org/environmental-policy/events/working-group-strategies-and-review-forty-seventh-session.
ECE/EB.AIR/WG.5/2011/3, paras. 23–32;
ECE/EB.AIR/WG.5/106, paras. 35–38;
ECE/EB.AIR/2012/11 (Draft revised annex IX, proposed text not supported by Task Force on Reactive Nitrogen); and
ECE/EB.AIR/WG.5/2012/3, para. 9.

[29] Mark A. Sutton and others, "The European Nitrogen Assessment 6 years after: What was the outcome and what are the future research challenges?", in *Innovative Solutions for Sustainable Management of Nitrogen: Conference proceedings*, Tommy Dalgaard and others, eds. (Tjele, Denmark, Aarhus University/dNmark Research Alliance, 2017).

[30] ECE/EB.AIR/2020/6–ECE/EB.AIR/WG.5/2020/5; and Sutton, "The European Nitrogen Assessment".

[31] Such a technical annex on NH_3, to some extent mirroring annex IX to the Gothenburg Protocol, was not included in the original National Emissions Ceilings Directive of 2001.

use efficiencies and reduce nitrogen surpluses and (e) low-emission techniques in new and largely rebuilt pig and poultry housing.[32] Since this list is now 10 years old, these priorities should be reviewed based on evolution of costs, innovation and policy experience. However, these measures remain essential in any NH_3 reduction plan.

66. Many Parties appear not to have fully implemented the requirements of annex IX on NH_3 measures.[33] It is not technically demanding. This appears to suggest that lack of full implementation of annex IX is linked to social/political barriers, where Parties have not prioritized measures on NH_3. Nevertheless, annex IX needs to be updated and extended, as it is no longer state-of-the-art being over 20 years old (prior to 1999). Feeding of livestock, housing of cattle and storage of cattle manure, processing and recovery of organic nutrient resources, grazing of livestock and other aspects of cropping are currently not covered. Measures for housing of pigs, poultry and other livestock and their associated manure storage, spreading to land of solid and liquid manure and spreading of urea, ammonium nitrate and other nitrogen containing fertilizers, need to be updated. The current annex IX misses opportunities from sustainable nitrogen management including reducing overall amounts of wasted nitrogen resources to air as NH_3, NO_x, nitrous oxide, di-nitrogen and to water as nitrate and other nitrogen forms, with a goal of progressing to more circular systems with higher system-wide nitrogen use efficiency. "Nature-based solutions", related to landscape and land use structure, so far as these reduce wasted nitrogen resources, are also missing.

67. The following guidance documents related to NH_3 and the wider nitrogen cycle require an update:

(a) The Guidance document on preventing and abating ammonia emissions from agricultural sources (ECE/EB.AIR.120), last revised in 2012, should be updated by 2024;

(b) The United Nations Economic Commission for Europe Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions (ECE/EB.AIR/129), last revised in 2015, should be updated by 2026;

(c) The Guidance document on national nitrogen budgets (ECE/EB.AIR/119), adopted by the Executive Body in 2012, should be revised by 2024.

68. The Guidance document on integrated sustainable nitrogen management (ECE/EB.AIR/149), having been adopted in 2020, is not currently a priority for revision.

69. Wider agricultural and integrated nutrient management policies offer great potential to reduce NH_3 and wider nitrogen pollution; for example, reform of agricultural funding (e.g., the Common Agricultural Policy) may influence NH_3 and other nitrogen emissions by driving changes in livestock numbers and in setting requirements for the use of low-emission technologies, including financing schemes. Several Parties, including the European Union, embrace the goal to "halve nitrogen waste by 2030" as formulated in the Colombo Declaration. Nature policies can also have a major influence on nitrogen pollution, as illustrated by the "nitrogen crisis" of the Netherlands, which has been driven by requirements of the European Union Habitats Directive[34] to avoid adverse effects of nitrogen negotiations

[32] ECE/EB.AIR/WG.5/2011/16, para. 16.

[33] Concerning establishment of national advisory codes of good agricultural practice to control ammonia emissions (see 1999 Gothenburg Protocol, annex IX, para. 3), although the original Protocol entered into force in 2005, analysis by the Task Force on Reactive Nitrogen in 2010 (ECE/EB.AIR/WG.5/2010/13, para. 33) found that very few Parties had established clearly identified national advisory codes. Subsequent review has seen the number slowly increasing, but overall, many Parties appear to have largely neglected this requirement of the Protocol. With notable exceptions, there has been only limited uptake of the national nitrogen budgets introduced as an optional element of the revised Gothenburg Protocol (see art. 7 (3) (a)–(d)). The main barriers appear to be the lack of any mandatory requirement, resources to provide demonstration national budgets, and resources for awareness-raising on the benefits of such an approach. There are plans for the International Nitrogen Management System, supported by the United Nations Environment Programme (UNEP)/Global Environment Facility to provide a future repository for national nitrogen budgets, including in the ECE region.

[34] Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043.

under the United Nations Framework Convention on Climate Change (UNFCCC) offers the opportunity to mobilize co-benefits for climate, air pollution, water, biodiversity and economy, as illustrated by the #Nitrogen4NetZero initiative.[35]

70. For agriculture, a behavioural change to reduce milk and meat consumption could provide an effective way to reduce NH_3 and CH_4 emissions. A structural shift towards less intensive farming could also contribute to these emission reductions (see also the 2017 report from the International Institute for Applied Systems Analysis on measures to address air pollution from agricultural sources).[36] Dietary change has huge potential to influence nitrogen losses to the environment, including NH_3, nitrous oxide, NO_x, nitrate and di-nitration. In Europe, meat and dairy consumption in excess of dietary needs contributes substantially to pollution and waste of nitrogen resources. The "Nitrogen on the Table" report showed that halving meat and dairy intake (demitarian scenario) would reduce NH_3 emissions by 40 per cent.[37] The scenarios also showed a doubling of food-chain nitrogen use efficiency from around 20 per cent to 40 per cent, while providing a major land opportunity for greening activities or increasing food crop export (since less agricultural land was needed to feed livestock). Feed imports and CH_4 emissions were also reduced.

71. Work conducted by the Expert Panel on Nitrogen and Food of the Task Force on Reactive Nitrogen shows a rich interlinkage between nitrogen and food, including the potential for dietary change and the health co-benefits. The results show that dietary change not only has a significant potential to reduce emissions of reactive nitrogen, but indeed it will be difficult, if not impossible, to reach ambitious climate, air and sustainability targets without a contribution from dietary change. An advance summary is provided as an annex to the Task Force's report to the Working Group on Strategies and Review (ECE/EB.AIR/WG.5/2021/2). The Expert Panel will continue to finalize the European Nitrogen Assessment Special Report in 2022.[38] The work of the Expert Panel has so far depended fully on in-kind contribution of the experts.

72. Many policies to shift food demand exist (i.e., food-based dietary guidelines, public procurement, food labelling, school and other education programmes, marketing policies, food standards, value added tax differentiation, etc.), which, however, need to be scaled up to be more effective, and integrated into comprehensive (food system) policy packages.[39]

VII. Options to address methane

73. With full implementation of the Protocol, background levels of ozone in the ECE region are expected to continue to increase due to CH_4, NOx and VOC emissions outside the ECE region. Further reductions of ozone precursor emissions within the ECE region are technically feasible and can decrease ozone concentrations and impacts within the region. The main anthropogenic sources of CH_4 emissions are agriculture (with cattle dominating in the ECE region), fossil fuel production and waste management. Cost-effective technical solutions are available to reduce CH_4 emissions from waste management and oil and gas production.[40] Fewer technological options are available for reducing CH_4 emissions from

[35] See www.inms.international/nitrogen4netzero.

[36] Markus Amman and others, "Measures to Address Air Pollution from Agricultural Sources" (n.p., International Institute for Applied Systems Analysis, 2017).

[37] H. Westhoek and others, *Nitrogen on the Table: The influence of food choices on nitrogen emissions and the European environment – Special Report of the European Nitrogen Assessment* (Edinburgh, Centre for Ecology and Hydrology, 2015).

[38] See www.clrtap-tfrn.org/content/epnf#Publications.

[39] See also ECE/EB.AIR/2021/7 and agenda item 4 (b), informal document No. 1, forty-first session of the Executive Body (Geneva (hybrid), 6–8 December 2021), available at https://unece.org/environmental-policy/events/executive-body-forty-first-session.

[40] See Lena Höglund-Isaksson and others, "Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 time frame – results from the GAINS model", *Environmental Research Communications*, vol. 2, No. 2 (February 2020) ; United States Environmental Protection Agency, "Non-CO_2 Greenhouse Gas Emissions Projections and Mitigation", available at

cattle. These measures are mostly related to dietary change of ruminants and comprise the following mitigating principles with a farm-specific approach: (a) improve feed quality and intake (organic matter digestibility, feeding value); (b) less fibrous feeds of low digestibility; (c) grass at early growth stage with high feeding value; (d) feed crops/low-N feed to control N excretion/emissions; (e) CH_4-lowering supplements (starch, fat); (f) implementation of biodiverse sward; and (g) supplementation of feed with additives, such as specific fatty acids/fat or methanogen inhibitors. Some of these measures could lead to additional NH_3 emissions.[41] Behavioural change leading to less (over)consumption of meat and dairy could offer synergetic benefits on health, climate, ozone formation and nitrogen pollution.[42]

74. Several options are available for addressing CH_4 as an ozone precursor under the Convention. They range in ambition level and legal status. The list of options presented in the informal document entitled "Options for addressing methane as an ozone precursor under the Air Convention"[43] is not exhaustive.. Depending on the decision taken regarding which (if any) policy mechanism is to be used to take action on CH_4, the options listed would require further assessment. It should be noted that the technical bodies of the Convention already address CH_4 as an ozone precursor. Reducing transboundary ozone in the ECE region is an objective of the Protocol (art. 2 (1)). It is important to note that CH_4 is addressed to some extent under the UNFCCC. However, since the UNFCCC is focused on limiting global warming, CH_4 is generally treated as interchangeable with other greenhouse gases, via conversion to carbon dioxide equivalent. Thus, the UNFCCC was not designed to take into account the health benefits of CH_4 mitigation, nor does it have quantitative commitments to focus particularly on CH_4 as an ozone precursor.

75. The role of CH_4 in ozone formation and its impact on health and environment is established in the scientific evidence from *Towards Cleaner Air: Scientific Assessment Report 2016*,[44] its policy response (ECE/EB.AIR/WG.5/2017/3 and Corr.1), and the information presented thus far within the review, including results of the Global Methane Assessment.[45] Results of the Global Methane Assessment indicate that available targeted CH_4 measures, together with additional measures contributing to priority development goals, can simultaneously reduce human-caused CH_4 emissions by as much as 45 per cent, or 180

www.epa.gov/global-mitigation-non-co2-greenhouse-gases; and UNEP/Climate and Clean Air Coalition, *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions* (Nairobi, 2021).
Measures for European Union countries are included in the note on the European Union strategy on methane, which focuses on reducing methane emissions in the energy, agriculture and waste sectors See https://energy.ec.europa.eu/topics/oil-gas-and-coal/methane-emissions_en#:~:text=The%20EU%20methane%20strategy%20COM,the%20fight%20against%20climate%20change and its road map and related documents https://ec.europa.eu/info/events/workshop-strategic-plan-reduce-methane-emissions-energy-sector-2020-mar-20_en and
Mathijs Harmsen and others, "The role of methane in future climate strategies: mitigation potentials and climate impacts", *Climatic Change*, vol. 163 (2020), pp. 1409–1425.

41 A. Bannink and others, "Applying a mechanistic fermentation and digestion model for dairy cows with emission and nutrient cycling inventory and accounting methodology", *Animal*, vol. 14, Supplement 2, pp. s406–s416 ; and Task Force on Reactive Nitrogen, "Methane and Ammonia Air Pollution", available at www.clrtap-tfrn.org/content/methane-and-ammonia-air-pollution.

42 Regarding rice cultivation,, changing water management has been identified as the most effective approach to consistently reducing CH_4 emissions from paddy fields. Mid-season drainage and intermittent irrigation have proven to significantly reduce CH_4 emissions. The alternate wetting and drying water management technique has also been identified as one of the most promising options for mitigating CH_4 emissions from rice cultivation, but can reduce nitrogen use efficiency and increase nitrogen losses. See R. Wassmann and others, "Chapter 2 Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies", *Advances in Agronomy*, vol. 101 (2009), pp. 59–122; and Nicholas Cowan and others, "Experimental comparison of continuous and intermittent flooding of rice in relation to methane, nitrous oxide and ammonia emissions and the implications for nitrogen use efficiency and yield", *Agriculture, Ecosystems and Environment*, vol. 319 (October 2021).

43 Available at https://unece.org/info/Environmental-Policy/Air-Pollution/events/367824.

44 ECE (Gylling, Denmark, Narayana Press, 2016).

45 A.R. Ravishankara and others, *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions* (Nairobi, United Nations Environment Programme, 2021).

million tonnes per year by 2030. The Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C[46] indicates that, in order to meet the minimum global effort required to limit global warming to 1.5°C over the long term, without overshooting, emissions of CH_4 (and black carbon) need to be reduced by 35 per cent or more by 2050, compared to 2010 levels. Therefore, it is becoming increasingly relevant to address CH_4, both as a climate forcer and as an ozone precursor. It is estimated that the ECE region contributes 20 per cent of global CH_4 emissions. The options should include those that address ECE emissions as well as those outside the region.

76. A number of international forums are undertaking work to address CH_4 emissions, for example, voluntary commitments under the Global Methane Pledge, information-sharing and capacity-building under the Global Methane Initiative, the Climate and Clean Air Coalition and emissions reporting under the UNFCCC. Action on CH_4 under the Air Convention should take into account two key considerations – the timing of political will and the level of ambition and geographic scale.

77. Options range in ambition and are split amongst four themes: status quo, new measures/commitments, information-based and voluntary-based. The options include:

(a) Maintaining current activities and taking no additional action (status quo);

(b) Supporting the Global Methane Pledge;

(c) Adopting national emission reduction targets or optimized national/regional CH_4 reduction commitments;

(d) CH_4-specific emission limit values for certain activities;

(e) Compiling, reviewing and improving CH_4 emissions information;

(f) Setting minimum requirements for monitoring and reporting of data;

(g) Developing guidance documents and/or a report on recommendations for CH_4 emission reduction measures or best practices.

78. The CH_4 contribution to transboundary ozone is significant enough to consider potential policy action under the Air Convention. The current work underway on CH_4 as an ozone precursor by a number of scientific and technical bodies of the Convention should continue. The Executive Body might wish to include continued discussions on the appropriate policy mechanism by which to achieve CH_4 reductions in the 2022–2023 workplan of the Working Group on Strategies and Review. Further information can be found in the informal document "Options for addressing methane as an ozone precursor under the Air Convention".

VIII. International cooperation on air pollution

79. In view of the hemispheric character of air pollution, especially ozone formation, cooperation with other countries, organizations, and forums outside of ECE is needed to enable and motivate emissions reductions beyond the ECE region. Options should be explored on how this cooperation could be realized, including through the work of the Task Force on International Cooperation on Air Pollution, as appropriate within its mandate (decision 2021/5) .

80. The Executive Body at its forty-first session (Geneva (hybrid), 6–8 December 2021) adopted the mandate of the Task Force on International Cooperation on Air Pollution, welcoming the offer of Sweden and the United Kingdom of Great Britain and Northern Ireland to lead it. The Task Force will promote international collaboration towards preventing and reducing air pollution in order to improve global air quality. It is intended to be a

[46] Valérie Masson-Delmotte and others, eds., *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (Cambridge and New York, Cambridge University Press, 2018).

repository for technical information and a convener of countries and organizations, with the goal of increasing international cooperation on addressing air pollution.

81. The principal functions of the Task Force are to:

(a) Act as an international platform to facilitate mutual learning and collaboration on air pollution;

(b) Foster emissions reductions of air pollutants through exchange of information on best practices and policy approaches;

(c) Facilitate the sharing of information on funding opportunities and technical capacity-building;

(d) Promote an evidence-based approach to air quality management;

(e) Work towards raising global public awareness of the health and environmental impacts of air pollution.[47]

82. The work identified above will be conducted through coordination, cooperation, and collaboration with subsidiary bodies under the Convention, as well as related international organizations, multilateral bodies, and international scientific efforts. The events organized by the Task Force will foster information-sharing and stimulate the engagement of non-Parties to the Convention to help all countries and regions tackle air pollution.

[47] Decision 2021/5, para. 4, and annex, paras. 1 and 3.