# *Annex II Technical information for the review of the Gothenburg Protocol*

*Summary*

The present document provides additional policy-relevant information to supplement the conclusions in the Gothenburg Protocol review report. The Executive Body is invited to consider the present document, unofficially referred to as "Annex II", at its forty-second session (Geneva, 12–16 December 2022).

## I. Introduction

1. The present document was compiled by the Gothenburg Protocol Review Group based on the technical information provided by the Task Forces of 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 2019/4.3 The present document provides additional policy-relevant technical information to supplement the information and conclusions in the Gothenburg Protocol review report.
2. This report describes policy scenarios up to 2050, case studies on the technological pathways chosen in selected EECCA-and SEE- countries, barriers to implementation, adequacy of key articles of the Gothenburg Protocol, options to address nitrogen, options to address methane and international cooperation on air pollution.

## II. Policy scenarios

3. The scenarios have been 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's 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 ammonia ($NH_3$) compared to the projected emission reductions of $SO_2$, $NO_x$ and primary PM. The regional deposition rates of S and N 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 expected to still be exceeded in some areas (North Italy, areas in Western Balkan and EECCA).

In the longer term, some processes may lead to increasing PM levels again, for example, higher temperatures may increase biogenic VOC emissions (and hence formation of secondary organic aerosols) and increasing NOx and $NH_3$ emissions from soils might also increase secondary PM formation. GAINS 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-methane volatile organic compounds (NMVOC) emissions from residential solid fuel burning and agricultural waste burning, and methane ($CH_4$) emissions from municipal waste treatment, the fossil fuel sector and agriculture are also possible. Beyond these technical abatement options emission reductions can result from structural changes in the energy, transport and food systems.

6. In countries of Eastern Europe, the Caucasus and Central Asia, South-Eastern Europe, 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 (IMO) agreements on emission control areas or initiatives by port authorities to encourage clean ships and to provide shore-to-ship electricity access.

*GAINS model improvements by CIAM*

7. The GAINS modelling domain is extended and includes all EECCA countries, i.e., covers EECCA, including Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan, Tajikistan. Soil NOx emissions are included and are consistent with the EMEP/EEA Guidebook and national reporting. NMVOC emissions from livestock manures, crops and grasslands are implemented in GAINS applying EMEP/EEA Guidebook methodology. Slurry acidification is added as $NH_3$ mitigation option. The waste management sector model has been revised and includes consistently multipollutant impacts of control options (including methane emissions). The critical load 2021 database is implemented in GAINS jointly with the CCE. Health impacts assessment methods are discussed with TFH. 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.[1] Emission scenarios are summarized in figure 1.

*GAINS scenarios*

8. The **baseline** includes air pollutants ($SO_2$, $NO_X$, $PM_{2.5}$, BC, $NH_3$, VOC) and methane 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 CEIP. 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 EU, energy and agriculture policies follow the 55% 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 VI-A of the main review report). For West Balkan, Rep of Moldova, Georgia, and Ukraine new energy and agricultural scenarios were developed. For EFTA, Türkiye, and remaining EECCA-countries activity projections were derived from the IEA World Energy Outlook and FAO. Recent shock events have not been considered; scenarios were developed before the Ukraine war.

9. The baseline scenario shows strong reductions of air pollutants ($SO_2$: -80% between 2005 and 2030, $NO_x$: -50-80%, $PM_{2.5}$: -25-70%) in the EU, North America, and also in West Balkan countries, owing to the Energy Community agreements that include commitments to strong reduction of emissions from stationary sources in the coming decades. EECCA countries 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, with about 40% and 20% respectively between 2005 and 2030.

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

10. Methane declines in the baseline only in the EU (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 US-EPA.

11. The **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 (BAT) 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), 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 manures 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, one can see that the mitigation potential increases towards 2050.

12. For $SO_2$ (apart from EECCA) 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. Note that 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. For $NH_3$ current abatement policies are very modest. 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 EU+EFTA, a large abatement potential exists, especially in industry and residential heating in EECCA and West Balkan countries. Residential heating is dominating in many EECCA cities, 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 the human diet. This brings significant additional reductions of ammonia and methane. Compared to the MTFR an additional 20-40% reduction is estimated. The LOW scenario assumes for all regions climate policies with strong reduction of fossil fuel use and a simultaneous increase in biofuels and renewable energy (wind, solar, etc. The trajectories for fossil fuels use, as well as the structure of energy use in general differs across the regions. For the EU, the baseline already includes a strong reduction of fossil fuel use and therefore this energy projection for the EU is also used in the LOW scenario.

16. For $SO_2$ and $NO_x$ most regions have significant reductions in the baseline (although less in EECCA countries) and therefore the further mitigation potential is limited. However, one needs to note that in relative terms emissions in the LOW scenario can be 50% lower than in the MTFR scenario. For $NH_3$ the picture is different, the baseline shows no significant reduction, but for all regions the structural and behavioral changes in the LOW scenario provide a significant additional abatement potential and will also bring CH4 co-benefits).

***Results*** [2]

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 UNECE domain excl. 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 EU limit value (25 µg/m$^3$) will be met in 2030 in the EU. Still elevated concentrations persist in Balkan and EECCA countries (see figure 2). Overall levels in large parts of the EMEP domain remain above the WHO guideline in 2030. The MTFR scenario for 2030 does not bring a lot of 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 only for 1/3 of the population the WHO guideline level would be attained. MTFR brings large scale improvements, also across the Balkan, as there is enough time to introduce further technical measures. Finally, the LOW scenario gives even lower concentrations. More than 60% of the population in the EMEP domain would be exposed to $PM_{2.5}$ levels below the 2021 WHO guideline by 2050 (over 80% in the EU+EFTA+UK, but only 30% in EECCA + Türkiye, where nearly 30% is also exposed to more than 10 µg/m$^3$). See figure 3.

*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 EU27 in 2020. This is lower than the EEA estimate of 307.000 cases, that also includes impacts of exposure below the WHO-guideline value (https://www.eea.europa.eu/publications/air-quality-in-europe-2021/health-impacts-of-air-pollution). Exposure to $NO_2$ caused about 21.200 cases. The EEA estimates that the number of cases due to ozone-exposure above 70 micrograms (SOMO 35 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. Note that $PM_{2.5}$and $NO_2$ numbers cannot be added because of double counting.

20. GAINS-estimates for the EU27 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%.[3] Premature mortality due to (excess) $NO_2$-exposure is expected to decrease by more than 80%. The MTFR scenario for 2030 would lead to premature mortality reductions of 80% for $PM_{2.5}$ and 85% for $NO_2$. In 2050 MTFR would give 90% less cases of premature mortality due to $PM_{2.5}$ compared to 2020 and 97% 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 on air pollutant concentration in the cities. Existing measurement data, albeit sparse outside the EU, confirm the results of the GAINS model that many of the cities in the region face PM2.5 concentrations well above the national and current EU standards. Analysis done so far for West Balkan and EECCA shows that the local contribution of residential combustion is important or dominating in many cities (in West Balkan local residential heating sources might cause 50% or more of the concentrations) with the power sector being an important regional source. It is important to highlight

[2] A supplement will be made available with tables on emissions, share of the population per country above WHO-AQG, 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.

[3] Second Clean Air Outlook report: Full implementation of clean air measures could reduce premature deaths due to air pollution by 55% in 2030 (europa.eu)

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 Europe and EECCA countries 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 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% of the $PM_{2.5}$ emissions consists of elemental carbon and about 40-50% is attributed to the sum of elemental (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, I.e., 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 obtain climate co-benefits. Additionally, volatile organic compounds that are also emitted from incomplete combustion condensate to particles when the flue gas cools down. This so called 'condensable' fraction of PM increases significantly total $PM_{2.5}$ emissions, especially for low efficient wood burning residential installations, and has not been consistently considered in the 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, e.g., Austria and Germany, this may contribute to increase of total $PM_{2.5}$ emissions of up to around 40%, 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%.

*Ecosystem protection*

23. For the EU, the exceedance of the critical loads for acidification will be reduced in the baseline scenario from about 9% of all ecosystems in 2015 to 3% in 2030 and 2% in 2050. In the LOW scenario, the exceedance in the EU could drop to below 1% of the ecosystems by 2050. For non-EU countries in the EMEP domain, the exceedance will decline from about 4% of the ecosystems in 2015 to 2% in the 2050 baseline and less than 0.5% in the LOW scenario. See figures 4 and 5.

24. The exceedance of the critical loads for eutrophication in the EU will be reduced in the baseline scenario from 80% of all ecosystems in 2015 to 70% in 2030 and 65% in 2050. In the LOW scenario 35% of the ecosystems in the EU will remain with an exceedance, even in 2050. For non-EU countries in the EMEP domain, the exceedance will decline from 50% of the ecosystems in 2015 to around 43% in the 2050 baseline and 15% in the LOW scenario. See figure 6.

*Lakes*

25. Based on MSC-W calculations deposition of sulphur and nitrogen at all ICP Waters sites will decline, but at a slower pace than in the period 2000-2020. ICP waters estimates that sulphate 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 continue to be lower than pre-acidification levels. Climate change as well as annual variability in climate are having a greater effect on ANC as acid deposition is declining, and this tendency will likely 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 HELCOM 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. The CCE calculated the average accumulated exceedance (AAE) of the critical atmospheric input of the Baltic sub-basins using deposition projections from MSC-West. 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 2030 Baseline scenario, will reduce the AAE in the sub-basins with the highest exceedances by 60%. In the MTFR scenario the reduction in these basins will become 80% 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 coast lines.

*Ozone*

27. The GAINS-baseline (and MTFR) scenario assumes a further increase in global methane emissions between 2005 and 2050. Only in the EU (+EFTA+UK) methane emissions are expected to decrease (by more than 40%) due to measures in the energy and waste sector. Methane emissions in EECCA region and West-Balkan are expected to remain constant. Methane emissions in US and Canada are expected to increase. They are associated with the unconventional gas exploration, Note, that there are documented differences in emission factors used in the GAINS model and by the US-EPA (GAINS assumes higher losses). The increase in global methane emissions is expected to offset the decreases in surface ozone due to $NO_x$ and NMVOC controls within Europe and North America (see GPG document on Synergies and interactions with other policy areas).

28. The LOW-scenario achieves reductions of methane emissions in North America, EECCA and West-Balkan consistent with the 30% reduction target in 2030 of for countries that joined the Global Methane Pledge. 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 with up to [5 ppb] in Europe in 2030 and give benefits for health, crop production and ecosystem protection. This will also reduce temperature increase. Continuing decline of methane emissions beyond 2030 (in the LOW-scenario), will result in even lower ozone concentrations in 2050.[4]

29. The ICP Vegetation expects that the average wheat yield loss in Europe due to ozone (using the POD3IAM metric) will decrease from 9.3% in 2015 to 7.8% 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% in 2050. For deciduous forests, the average % biomass loss in the 25 European countries with the greatest deciduous forest cover is expected to decrease from 18.6% in 2015 to 16.5% in 2050 in the baseline scenario and to 14.7% in the LOW-scenario. See figure 7.

30. In 2015, estimated total wheat production losses for Europe due to ozone were 23.8M ton, greater than the annual production for Ukraine (21.8 M tons). By 2050, total losses for Europe are predicted to have reduced by 7M ton for the LOW-scenario, equivalent to the current wheat production for 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 16.8M ton 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% of the 23 investigated sites. The largest contribution to soiling is from particulate matter. Even if the modelled data shows that most of the targets are reached it is also 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 the confidence that the protection targets will be reached.

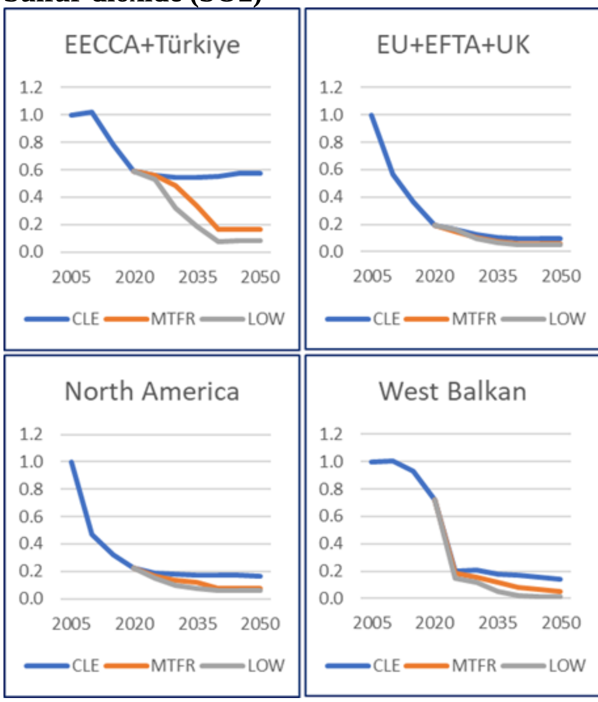
[4] MSC-W results will become available in autumn.

***Conclusion***

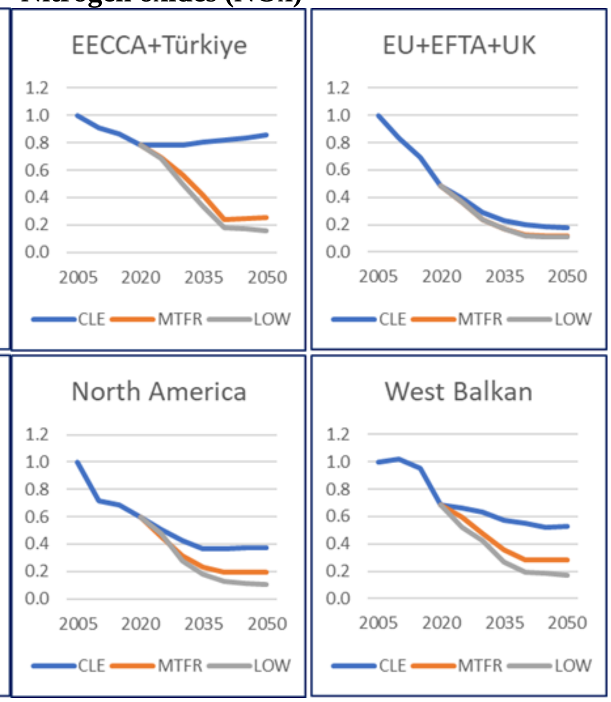
32. Current reduction plans will in the coming decades improve air quality and lead to less acidification and eutrophication than with the current emission reduction obligations for 2020 (and beyond) in the Gothenburg Protocol.  At the same time the scenario analysis shows that there are technical and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

*Figure 1: Emission trends in baseline, MTFR and LOW scenario*

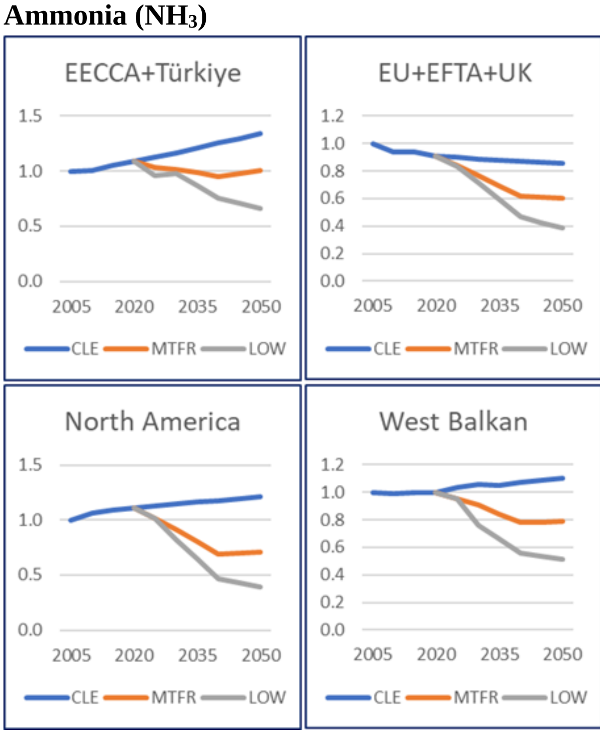
**Sulfur dioxide (SO2)**




**Nitrogen oxides (NOx)**




**Ammonia ($NH_3$)**




**Particulate matter ($PM_{2.5}$)**

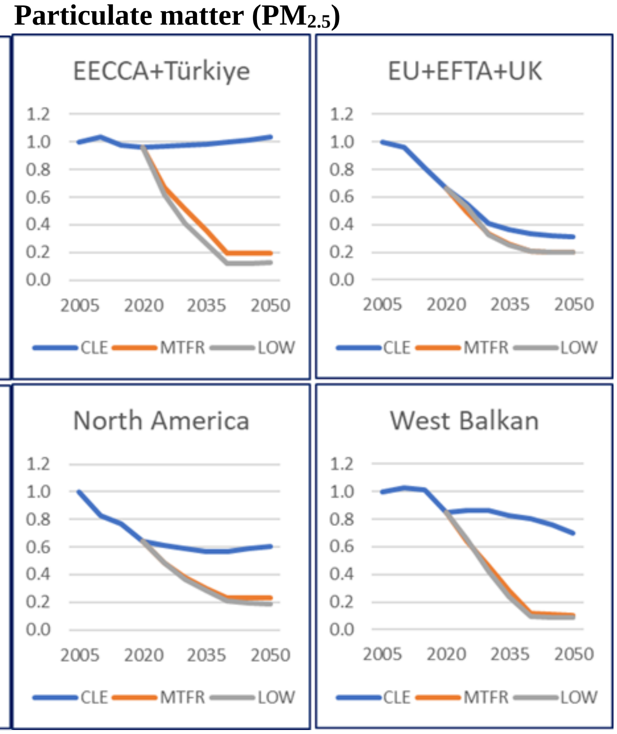


***Figure 2: PM2.5 concentrations in 2015, 2030-2050 baseline and 2050 LOW-scenario***

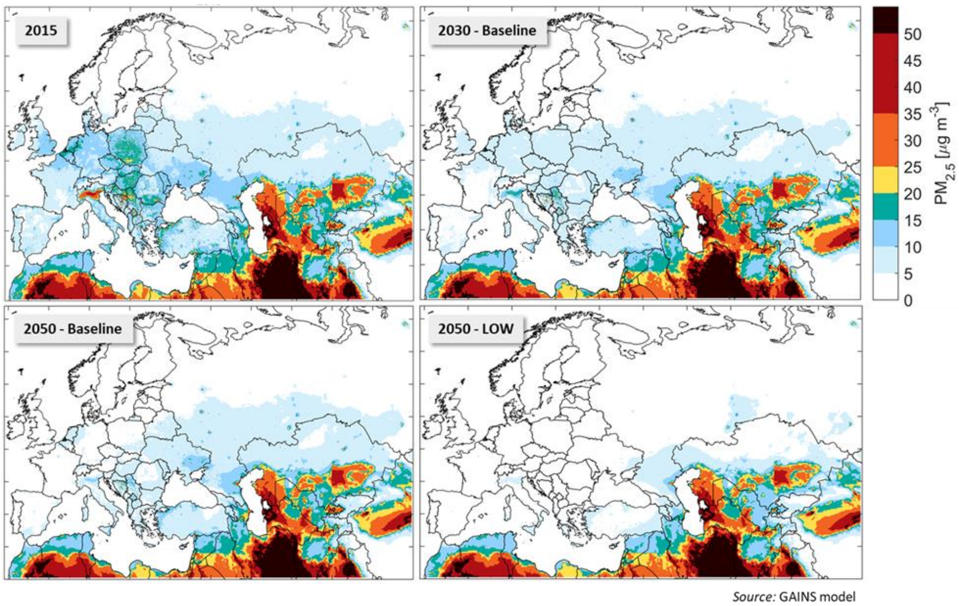



***Figure 3: Population exposure in the UNECE domain, excluding North America***

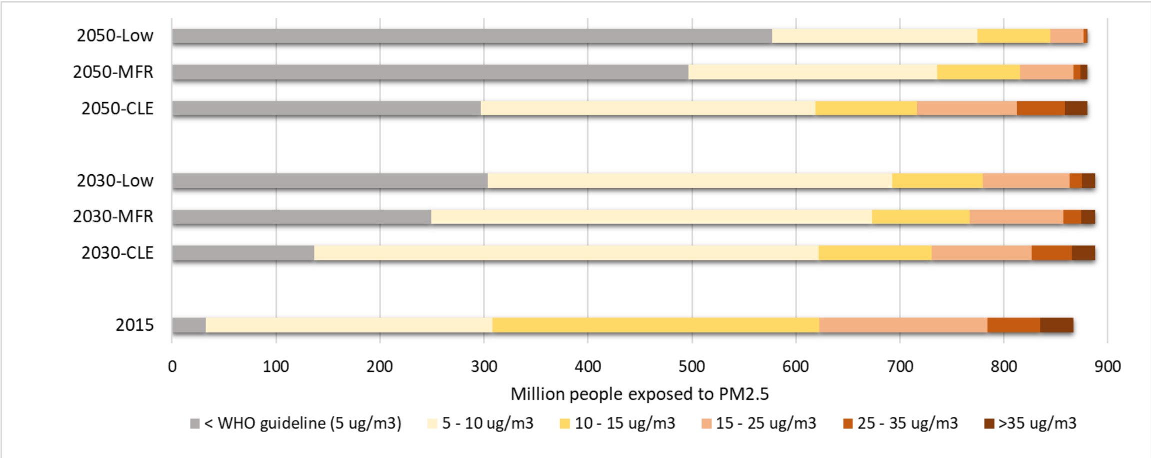


*Figure 4: Exceedance of critical loads for acidification and eutrophication in Europe*

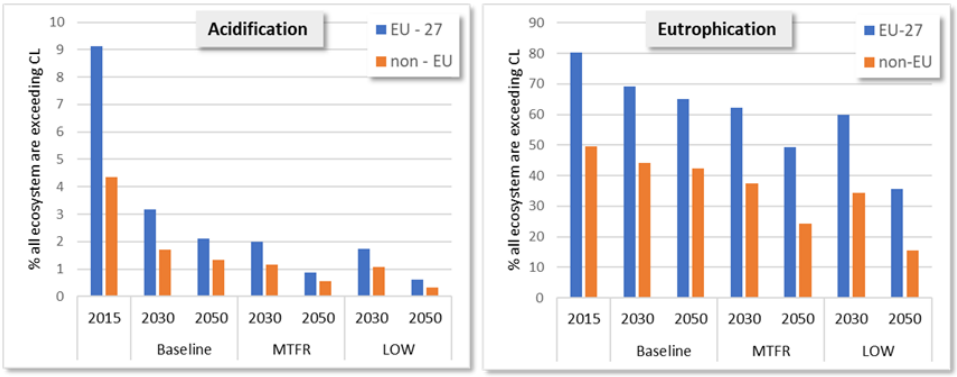
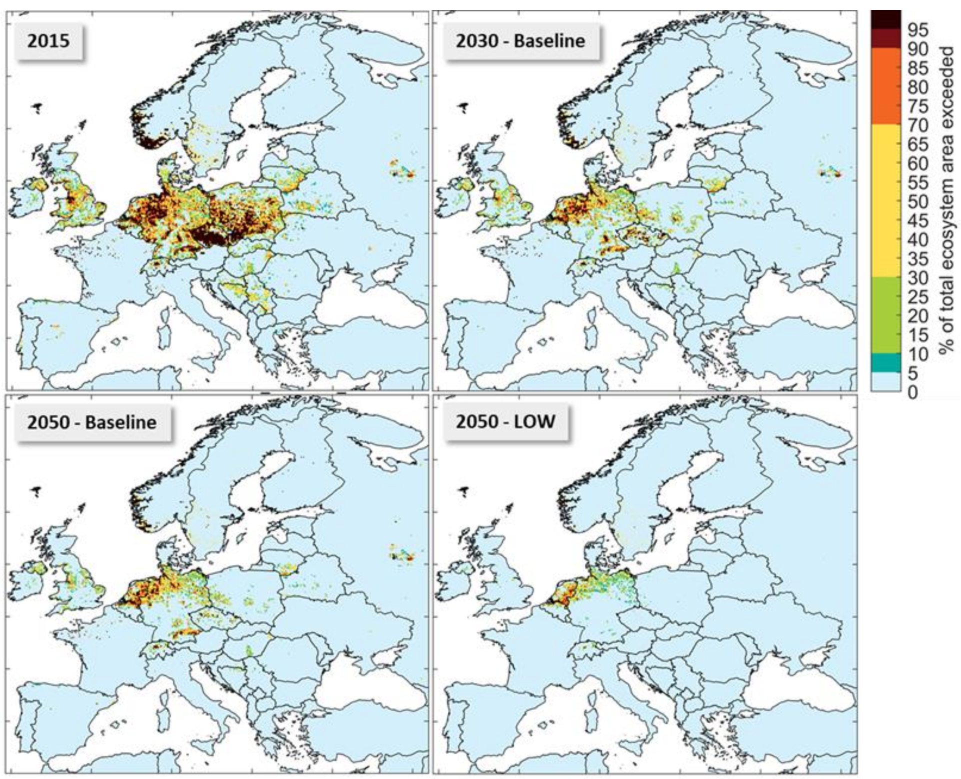
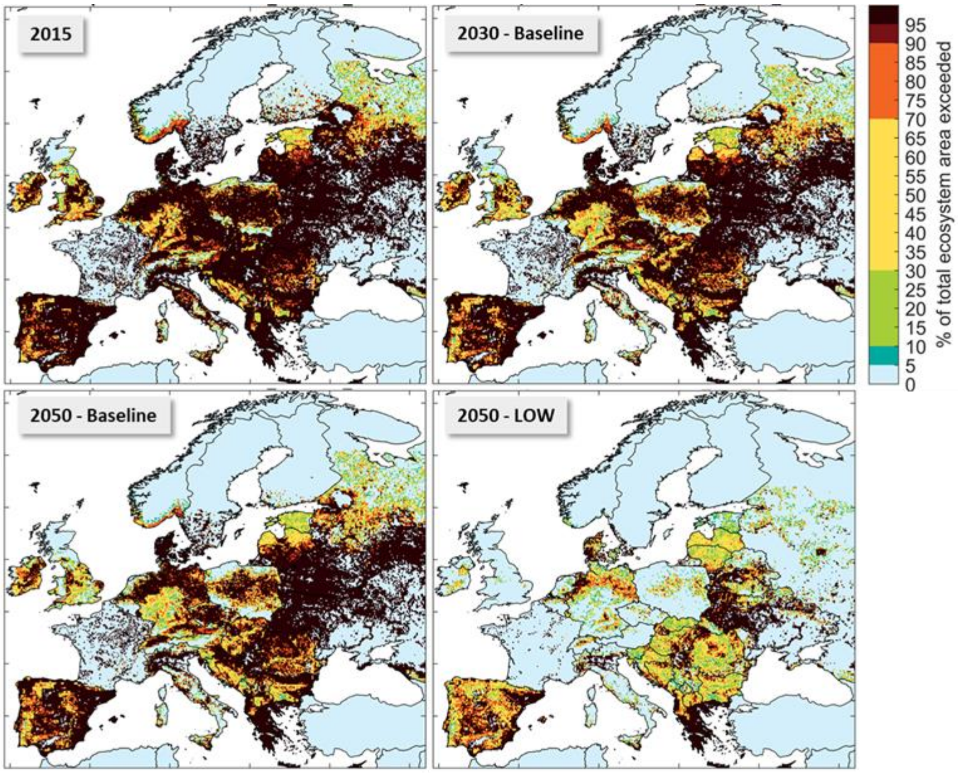



*Figure 5: Acidification: exceedance of critical loads (total ecosystem area)*



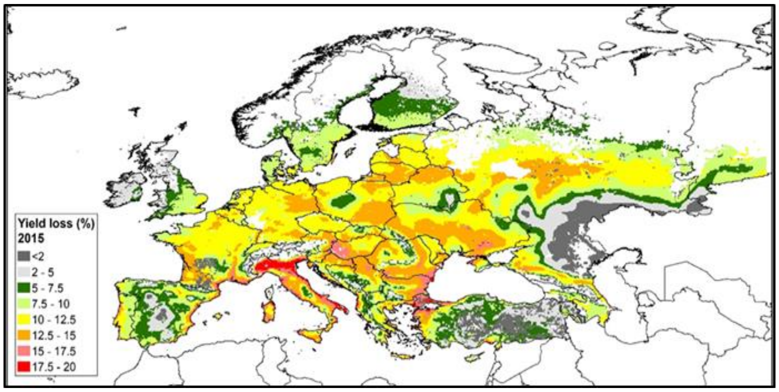

*Source:* GAINS model

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

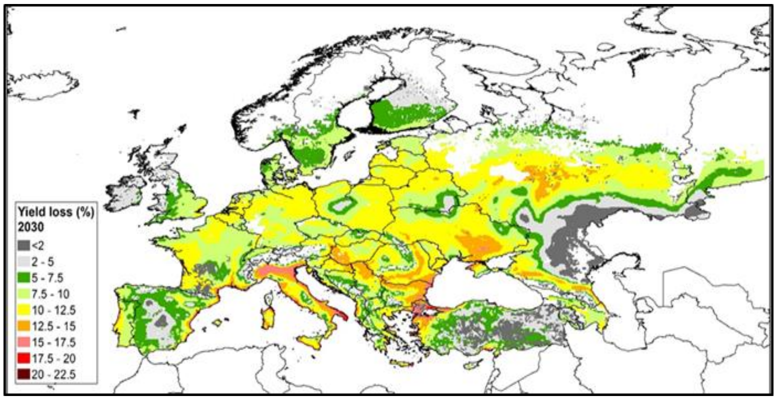



*Source:* GAINS model

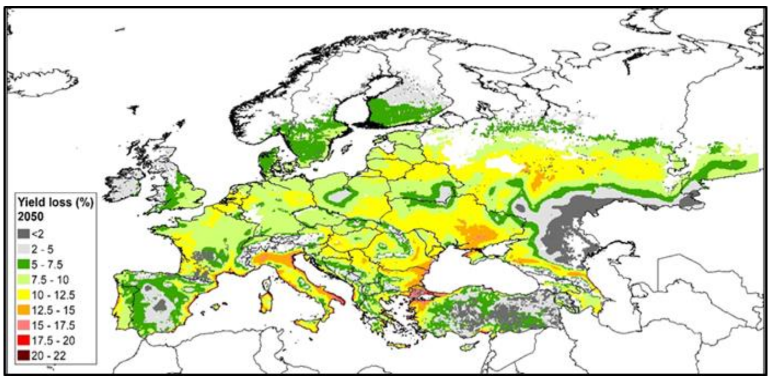
*Figure 7: Wheat yield loss due to ozone (% loss based on the ozone flux metric $POD_3IAM$)*



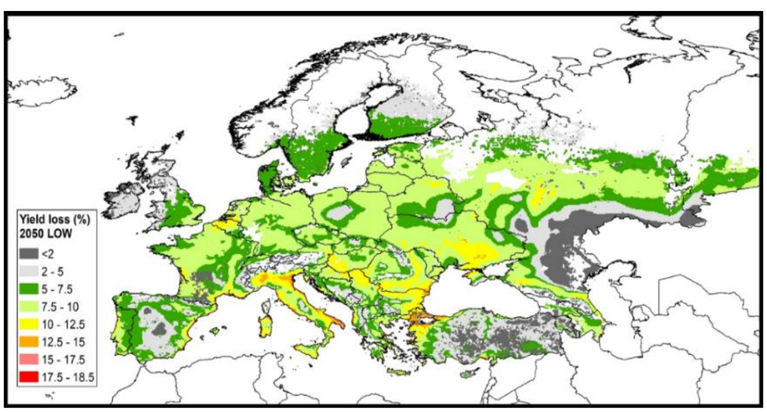

2015




Baseline 2030




Baseline 2050




LOW-scenario

# III. Technological Pathways toward ratification of the Amended Gothenburg Protocol – Case studies for four EECCA and SEE countries

33. TFTEI developed case studies to explore the possible Technological Pathways toward the Ratification of the AGP, in some EECCA countries (and SEE), as preparatory phase for the Thematic Session on Barriers, planned at the beginning of the forty-second session of the Executive Body, in December 2022. The full report will be made available as an informal document for the forty-second session of the Executive Body. Here, the summary conclusions for Georgia, Serbia, Moldova and Kazakhstan are reported.

**Georgia**

Introduction

34. In Georgia, ambient air is monitored through 8 stations and passive tube measurement campaigns. In 2019, the largest $PM_{2.5}$ concentrations were observed in the most industrialized cities of Georgia. Average annual $NO_2$ concentrations resulted larger than the annual limit value, in Tbilisi and some other cities.

Current Legislation

35. The EU Directives, 2008/50 on Ambient Air Quality and Cleaner Air for Europe and 2004/107/EC on Arsenic, Cadmium, Mercury, Nickel and PAH in Ambient Air, are applied. In the scope of an EU funded project, Georgia is improving its own permit and control systems of industrial sources and developing the legal framework for the EU IED. A new law on Industrial Emissions, similar to the EU IED is expected to be adopted in September 2022. Draft by-laws on LCPs, including BAT based integrated permit, and on organic solvent uses, are being developed and implemented. The full implementation of IED Law will likely be possible by 2031.

Critical Sectors

36. NOx - the transport sector, resulted the largest source in 2019, with 43% of share. The agriculture sector is the second major source (32%) while electricity production (2%), industrial combustion (6%) and industrial processes (10%) are less significant.

SO2 – Although a significant decrease in emissions is observed in the past years, the Industrial activities are the main source of $SO_x$ emissions, e.g., iron and steel production.

PM - the residential sector resulted predominantly, with 77% of the share. Industrial combustion and processes had a share of 13%, in 2019.

Technological Pathway

37. The implementation of the Law on Industrial Emissions is expected to allow Georgia to be in compliance with the four AGP Technical Annexes IV, V, VI and X, including LCPs and large industrial plants, presumably by 2031-2035. However, for Annex VI, the implementation of VOC stage II ELVs might need more time.

38. The following techniques are recommended as examples:

NOx Annex V: combustion optimization; combination of primary techniques, e.g., air or fuel staging, flue-gas recirculation, low-NOx burners; selective non-catalytic reduction; selective catalytic reduction.

PM Annex X: 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 practices for solid fuel burning and small combustion installations.

**Serbia**

Introduction

39. In the Republic of Serbia, air quality is classified in three categories, where the category three corresponds to the highest level of pollution. In 2019, 43 % of the population was living in category III areas.

Current Legislation

40. For many years, Serbia started to align its own air quality policies and regulations with EU legislation, likely to be completed by 2025, in particular, in reference with the following EU Directives:

Industrial Emission Directive (IED);

Directive 1994/63/EC on Stage I Petrol vapor recovery and Directive 2009/126/EC on Stage II Petrol vapor recovery;

EU Fuel Quality Directive 2009/30/EC;

Directive 2016/802 on reduction in the sulphur content in fuels; and

Serbia is in a quite advanced situation in the legislation implementation.

Critical Sectors

41. Major sources are: electricity and heat generation for $SO_2$, NOx and PM, biomass burning in residential heating and industrial processes for $PM_{2,5}$, VOC.

Technological Pathway

42. The implementation of the above cited directives, would allow Serbia to be in compliance with the four AGP technical annexes IV, V, VI and X, tentatively around 2030-35. The implementation of the following techniques is recommended:

SOx Annex IV - boiler sorbent injection, dry sorbent injection, spray dry absorber, circulating fluidized bed dry scrubber, wet flue-gas desulphurization, possibly associated with the use of low sulphur (solid or liquid) fuels.

NOx Annex V - combustion optimization; combination of primary techniques, e.g., air or fuel staging, flue-gas recirculation, low-NOx burners; selective non-catalytic reduction; selective catalytic reduction.

**Moldova**

Introduction

43. In the Republic of Moldova, the 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.

Current Legislation

44. Moldova has transposed the Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe and the Directive 2004/107/EC on Arsenic, Cadmium, Mercury, Nickel and PAH in ambient air. For more than ten years, Moldova started to align its policies and regulations with EU Directives, by transposition. Until now, the following Directives were transposed:

Directive 2004/42/EC on the limitation of emissions of VOC due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products;

Directive 1994/63/EC, Stage I on the control of VOC emissions resulting from the storage of petrol, and its distribution, from terminals to the service stations;

Directive 2016/802 on reduction in the sulphur content in fuels; and

Directive 2010/75/EU on Industrial Emissions (IED) currently under transposition; and

Directive 2016/2284 on the reduction of national emissions of certain atmospheric pollutants currently under transposition.

Critical Sectors

45. Residential heating is the major source of $SO_2$, $PM_{2.5}$ and VOC emissions, with respectively 73%, 89% and 24% of share, driven by the use of solid and liquid fuels. Road transport is the main source of NOx emissions, with a 51% share. The emissions from industrial sources are much less significant due to the few existing installations and the wide use of natural gas. The few existing LCPs burn natural gas.

Technological Pathway
46. The implementation of the above cited directives would allow Moldova to be in compliance with almost all the requirements of the four AGP technical annexes IV, V, VI and X, tentatively around 2030-35. The following techniques are recommended, with priority on PM:
PM 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 practices for solid fuel burning and small combustion installations;” and
NOx Annex V: combustion optimization; combination of primary techniques, e.g., air or fuel staging, flue-gas recirculation, low-NOx burners; selective non-catalytic reduction; selective catalytic reduction.

**Kazakhstan**
Introduction
47. In the Republic of Kazakhstan, every year, about 6,000–9,360 premature deaths are recorded, due to the air pollution. The network of monitoring stations is quite extended. In Kazakhstan, the ELVs result regularly exceeded.

Current Legislation
48. Kazakhstan developed the road map and the National Action Plan for the ratification of three latest LRTAP Protocols, although not yet approved by the competent authority. Kazakhstan started the process to partially align, the national policies with EU IED, via the new 2021 Environmental Code. The Code introduces integrated environmental permits based on BAT, starting from 2025, with country specific BAT reference documents being elaborated.

Critical sectors
49. Electricity and heat generation are major sources of $SO_2$ and NOx emissions, with a 32% and 29% share, respectively, followed by petroleum refining and iron and steel plants. Residential heating is responsible for 33% of PM2.5 and for 20% of NMVOC emissions. while iron and steel production contribute for 25% of $PM_{2.5}$. Coal fired LCPs are the largest sources of $SO_2$, NOx, and PM.

Technological Pathway
50. The implementation of the new Environmental Code and the definition of BAT, would allow Kazakhstan to be in compliance with some of the requirements of AGP Technical Annexes IV, V and X, for the industrial sources covered, however, only if the BAT AELs implemented will be the same as in the AGP Technical Annexes. Compliance could be achieved around 2032-2035. The following techniques are recommended:
SOx Annex IV: boiler sorbent injection, dry sorbent injection, spray dry absorber, circulating fluidised bed dry scrubber; wet flue-gas desulphurization, associated with the use of low sulphur (solid or liquid) fuels; and
NOx Annex V: combustion optimization; combination of primary techniques, e.g., air or fuel staging, flue-gas recirculation, low-NOx burners; selective non-catalytic reduction; selective catalytic reduction.

# IV. Barriers to implementation

51. As welcomed by the Working Group on Strategies and review at its sixtieth session, the Gothenburg Protocol Review Group has prepared an informal document on barriers to ratification and implementation of the amended Gothenburg Protocol, including possible solutions to overcome them. This informal document, to be shared at the forty-second session of the Executive Body, provides a categorisation of the barriers identified so far (political, financial, institutional, regulatory, capacity and technical barriers), together with possible solutions to overcome each type of barrier. It 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 summarised in next paragraphs.

52. The EECCA and Western Balkan countries have made real progress towards ratification and implementation of the latest amended Protocols 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 still more needs to be done. The EECCA and Western Balkan countries are moving at different speeds and have different needs. They remain at different levels of understanding of the complexity and implementation issues with regard to the amended Protocols.

53. Further assistance, tailored to their specific needs, would improve the possibility for the EECCA countries and other non-Parties to take the necessary additional steps. As the needs of the different non-parties to ratification and implementation vary, it is difficult to find solutions that work for everyone. A tailor-made approach may be useful, but inevitably involves risks.

54. It is difficult to identify the common key barriers to ratification as these vary among the current non-Parties, but a 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, EECCA countries have already expressed concern that a possible revision of the amended Gothenburg Protocol would further increase its ambition and complexity, further jeopardizing ratifications.

55. 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 paragraphs 6 and 7 of article 13bis to adopt amendments to technical annexes IV to XI, notwithstanding the fact that three Parties have declared not to be 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 EECCA countries 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

56.As stated in paragraph 86 of the main review report, Section I of this Annex assessed the adequacy of the emission reduction obligations in the Amended Gothenburg Protocol. The assessment of other key articles of the Protocol (such as 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, as well as the findings and conclusions of the review of the Gothenburg Protocol. Are these articles sufficiently helpful to include e.g., integrated nitrogen management, methane or international cooperation in future work? Although a number of articles remain relevant as they are, 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 Air Convention with due consideration to ratification barriers. An overall assessment of internal consistency of the articles and coherence with other policy areas would also be useful.

57. The strategic priorities on the Long-term strategy include the need for further strategies to reduce ammonia and black carbon emissions; as well as the need to further address precursor pollutants of tropospheric ozone including methane. Opportunities for integrated approaches and synergies with other policy areas like air and climate policies could be considered in the 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 the Executive Body implementing decisions that are no longer up to date and a 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

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

59. Ammonia is also of concern to Canada and the United States of America and additional assessments are needed to quantify the impacts. Canada hosted an ammonia workshop in Ottawa, 10 October 2018 with participants from Canada, the United States of America and Europe, concluded with a number of key messages regarding the health and environmental impacts of ammonia, as well as tools and approaches available for mitigation.

60. Control of ammonia 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 (INMS) have drawn attention to a global loss of reactive nitrogen worth US$200 billion per year, pointing to the opportunity to "halve nitrogen waste" by 2030[5], saving US$100 billion per year globally[6], as embraced as part of national action plans under the Colombo Declaration.[7]

61. 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.[8] Since the adoption of Annex IX, new knowledge on the wider N-cycle has shown the importance of win-win opportunities for ammonia emissions reduction by addressing in an integrated manner with nitrogen oxides.[9] $NO_x$ emissions from soils are currently excluded from the Gothenburg Protocol as amended (Annex II, Table 3), with ongoing reductions in $NO_x$ emissions from combustion, soil $NO_x$ may account for up to 25% 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 nitrogen oxides from soils. Such emissions result from both agricultural soils and anthropogenic change to natural soils (e.g., 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[10] This highlights the

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[5] 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 "The Nitrogen Decade: mobilizing global action on nitrogen to 2030 and beyond", *One Earth* 4, 10-14. https://doi.org/10.1016/j.oneear.2020.12.016, where a baseline of 2020 has been used as a reference for halving wasted nitrogen globally)

[6] UNEP Frontiers Report: The Nitrogen Fix: https://apo.org.au/sites/default/files/resource-files/2019-03/apo-nid224376.pdf

[7] Colombo Declaration on Sustainable Nitrogen Management: https://papersmart.unon.org/resolution/sustainable-nitrogen-management

[8] The Working Group may wish to note the following documents related to revision of Annex IX:

- **ECE/EB.AIR/WG.5/2008/10** (Paragraphs 31-32).
- **ECE/EB.AIR/WG.5/2009/12** (Annex: Report on work in progress on Annex IX).
- **ECE/EB.AIR/WG.5/2010/4** (Paragraphs 5-74, including High (A), Middle (B) and Low (C) ambition options, plus Annex I: Information on possible farm-size thresholds in relation to mandatory measures for land application of manures.
- **ECE/EB.AIR/WG.5/2010/5** Options for revising the Gothenburg Protocol. Draft Revised Technical Annex IX (bracketed options for revision of the protocol) (Note prepared by TFRN co-chairs).
- **ECE/EB.AIR/WG.5/2010/13** (Paragraphs 9-16, 33 and Annex: Explanation of amendments to the options for revision of the Gothenburg Protocol, Annex IX).
- **ECE/EB.AIR/WG.5/2010/14** Draft revised Annex IX.
- WGSR-47th Session, Informal Document 2. Draft revised technical Annex IX – with annotation and explanation.
- **ECE/EB.AIR/WG.5/2011/3:** Draft revised Annex IX – updated annotated draft and clean copy including revised options A, B, C. **ECE/EB.AIR/WG.5/2011/13:** (Paragraphs 23-32 on explanation of draft Annex IX).
- **ECE/EB.AIR/WG.5/106:** Report of WGSR-49 (Paragraphs 35-38).
- ECE/EB.AIR/2012/11: Draft revised Annex IX. The proposed text was not supported by TFRN.
- ECE/EB.AIR/WG.5/2012/3: (Paragraph 9).

[9] Sutton M.A. et al. (2017) 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.* (Eds.: Dalgaard T. et al.). pp 40-49. Aarhus University and the dNmark Research Alliance

[10] Guidance Document on Integrated Sustainable Nitrogen Management ECE/EB.AIR/2020/6-ECE/EB.AIR/WG.5/2020/5.
See also: 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, Aarhus, Denmark (25-28 June 2017), pp 40-49. Aarhus. https://static1.squarespace.com/static/58cff61c414fb598d9e947ca/t/5abb898faa4a99a0ab4e71d9/1522239888660/The+European+Nitrogen+Assessment+-+Prof+Mark+Sutton+%28003%29.pdf

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 management of the nitrogen cycle.

62. Several Parties of the Convention have made further progress in commitments to reduce ammonia emissions, including in the revised National Emissions Reduction Commitments Directive of the European Union (Directive (EU) 2016/2284)[11]. That directive describes both emission reduction commitments for years between 2020-2030 and after 2030, relative to 2005 and a set of specific measures for ammonia emission reduction.[12]

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

64. The "Top Five" priority areas for ammonia emission abatement in Annex IX that were identified by TFRN in 2011 (ECE/EB.AIR/WG.5/2011/16; considering availability across UNECE region, cost, contribution to emission reduction and capacity building), need to be reconsidered. In 2011, priority measures were: 1. low-emission application of manures and fertilizers to land, 2. animal feeding strategies to reduce nitrogen excretion, 3. low emission techniques for new stores for cattle and pig slurries and poultry manure, 4. strategies to improve nitrogen use efficiencies and reduce nitrogen surpluses, and 5. low emission techniques in new and largely rebuilt pig and poultry housing. Since this list is now 10 years old, these priorities should be reviewed based on evolution of costs, innovation and policy experience. However, it is clear that these top 5 measures remain essential in any ammonia reduction plan.

65. Many parties appear not to have fully implemented the requirements of Annex IX on ammonia measures.[13] 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 ammonia. 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 ammonia, nitrogen oxides, nitrous oxide, di-nitrogen and to water

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG

[12] Such a technical annex on ammonia to some extent mirroring Annex IX of the Gothenburg Protocol was not included in the original National Emissions Ceilings Directive of 2001

[13] Concerning establishment of 'National Ammonia Codes' (NACs), as required by Annex IX, paragraph 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, paragraph 33) found that very few parties had established clearly identified National Ammonia 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 National Nitrogen Budgets, which was introduced as an optional element of the revised Gothenburg Protocol. 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. It is currently planned that the International Nitrogen Management System supported by UNEP/GEF will provide a future repository for national nitrogen budgets, including in the UNECE region.

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.

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

- The Ammonia Guidance Document (ECE/EB.AIR.120), last revised in 2012, [should be updated by 2024]
- Framework (advisory) code of good agricultural practice for reducing ammonia emissions (EB.AIR_WG.5_2001_7), last revised in 2015 [should be updated by 2026]
- The Guidance Document on National Nitrogen Budgets (ECE/EB.AIR/119), adopted by the Executive Body in 2012 [should be revised by 2024].

The Guidance Document on Integrated Sustainable Nitrogen Management (ECE/EB.AIR/2020/6-ECE/EB.AIR/WG.5/2020/5), having been adopted in 2020 is not currently a priority for revision.

67. Wider agricultural and integrated nutrient management policies offer great potential to reduce ammonia and wider nitrogen pollution. For example: reform of agricultural funding (such as CAP) may influence ammonia and other nitrogen emissions by driving changes in the numbers of livestock and in setting requirements for the use of low-emission technologies, including financing schemes. Several parties including the European Union, embrace the goal to "reduce nutrient pollution by 50% 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 EU Habitats Directive to avoid adverse effects of nitrogen on the Natura 2000 network. Sustainable Nitrogen Management as part of climate negotiations under the UN Framework Convention on Climate Change offers the opportunity to mobilize co-benefits for climate, air pollution, water, biodiversity and economy, as illustrated by the #Nitrogen4NetZero initiative[14].

68. For agriculture a behavioral change to reduce milk and meat consumption could form a powerful way to reduce emissions of ammonia and methane. A structural shift towards less intensive farming could also contribute to these emission reductions. See also the 2017 report from IIASA on measures to address air pollution from agricultural sources. Dietary change has huge potential to influence nitrogen losses to the environment, including ammonia, nitrous oxide, nitrogen oxides, nitrate and di-nitration. In Europe, meat and dairy consumption in excess of dietary needs is contributing 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 ammonia emissions by 40%.[15``] The scenarios also showed a doubling of food-chain nitrogen use efficiency from around 20% to 40%, while providing a major land opportunity for greening activities or increasing food crop export (since not so much agricultural land was needed to feed livestock). Feed imports and methane emissions were also reduced.

69. Work conducted as part of the TFRN Expert Panel on Nitrogen and Food (EPNF), 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 reducing 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 TFRN report to the 59th Session of WGSR (May 2021). The EPNF will continue finalizing the ENA Special Report in 2022 (http://www.clrtap-

[14] https://www.inms.international/nitrogen4netzero

[15] Nitrogen on the Table**:** The influence of food choices on nitrogen emissions and the European environment. (European Nitrogen Assessment Special Report on Nitrogen and Food.) (Westhoek et al., 2015, CEH) http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNF%20Documents/Nitrogen_on_the_Table_Report_WEB.pdf

tfrn.org/content/epnf#Publications). The EPNF work so far depended fully on in-kind contribution of the experts.

70. A large number of policies to shift food demand exist (i.e., Food Based Dietary Guidelines; public procurement; food labelling; school and other education programs; marketing policies; food standards etc.; VAT differentiation; etc), which, however, need to scale up to be more effective, and be integrated into comprehensive (food system) policy packages. Also see the Ammonia Assessment report: ECE_EB.AIR_WG.5_2021_7-2102624E.pdf (unece.org)

# VII. Options to address methane

71. With full implementation of the Protocol, background levels of ozone in the ECE region are expected to continue to increase due to methane, 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 methane emissions are agriculture (with cattle dominating in the ECE region), fossil fuel production and waste management. Cost-effective technical solutions are available to reduce methane emissions from waste management and oil and gas production.[16] In order to reduce methane emissions from cattle, fewer technological options are available. These measures mostly are related to dietary change of ruminants and comprise the following mitigating principles with a farm-specific approach: i) Improve feed quality and intake (Organic Matter digestibility, feeding value). ii) Less fibrous feeds of low digestibility. iii) Grass at early growth stage with high feeding value. iv) Feed crops/low-N feed to control N excretion/emissions. v) $CH_4$-lowering supplements (starch, fat), vi) Implementation of biodiverse swards, and vii) supplementation of feed with additives, such as specific fatty acids/fat or methanogen inhibitors. Some of these measures could lead to additional ammonia emissions.[17] Behavioral change leading to less (over-) consumption of meat and dairy could offer synergetic benefits on health, climate, ozone formation, as well as nitrogen pollution.[18]

72. A number of options are available for addressing methane as an ozone precursor under the *UNECE's Air Convention*. They range in ambition level and legal status. The options presented in

[16] Höglund-Isaksson et al. (2020). Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the GAINS model. Environ. Res. Commun. 2 (2020) 025004 https://doi.org/10.1088/2515-7620/ab7457
https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases.
https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report
Measures for EU countries are included in the note on the EU strategy on methane, which focuses on reducing methane emissions in the energy, agriculture and waste sectors (see https://ec.europa.eu/energy/topics/oil-gas-and-coal/methane-gas-emissions-en its roadmap and related documents (https://ec.europa.eu/info/events/workshop-strategic-plan-reduce-methane-emissions-energy-sector-2020-mar-20_en )
The role of methane in future climate strategies: mitigation potentials and climate impacts | SpringerLink

[17] See: Bannink et al. 2020. Applying a mechanistic fermentation and digestion model for dairy cows with emission and nutrient cycling inventory and accounting methodology. *Animal*. Vol. 14, Supplement 2, Pages 406-416
And: http://www.clrtap-tfrn.org/content/methane-and-ammonia-air-pollution

[18] Regarding rice cultivation, an extremely important crop in the world, changing water management has been identified as the most effective approach to consistently reducing $CH_4$ emissions from paddy rice fields. Midseason drainage and intermittent irrigation have proven to significantly reduce methane 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: Wassmann et al., 2009. Chapter 2 Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. *Advances in Agronomy*, Vol. 101, Pages 59-122 and:
Cowan N., Bhatia A., Drewer J., SuttonM. et al. (under review)

the informal paper on potential options for addressing methane are not exhaustive, and additional options may also exist. Depending on the decision taken regarding what (if any) policy mechanism is to be used to take action on methane, the options listed would require further assessment. Note that the technical bodies of the Convention already address methane as an ozone precursor. Reducing transboundary ozone in the UNECE region is an objective of the Protocol per Article 2.1. It is important to note that methane is addressed to some extent under the UNFCCC. However, since the UNFCCC is focussed on limiting global warming, methane 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 methane mitigation, nor does it have quantitative commitments to focus particularly on methane as an ozone precursor.

73. The role of methane in ozone formation and its impact on health and environment is established in the scientific evidence from the 2016 Scientific Assessment Report[19], its Policy Response (ECE/EB.AIR/WG.5/2017/3and Corr.1), as well as the information presented thus far in the Review, including results of the Global Methane Assessment.[20] Results of the Global Methane Assessment indicate that available targeted methane measures, together with additional measures that contribute to priority development goals, can simultaneously reduce human-caused methane emissions by as much as 45%, or 180 million tonnes a year (Mt/yr) by 2030. The IPCC's Report on Global Warming of 1.5°C 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 methane (and black carbon) need to be reduced by 35% or more by 2050, compared to 2010 levels. Therefore, it is becoming increasingly relevant to address methane, both as a climate forcer and as an ozone precursor. It is estimated that the UNECE region contributes 20% of global methane emissions. The options should include those that address UNECE emissions as well as those outside the region.

74. A number of international fora are undertaking work to address methane emissions. They range from voluntary commitments under the Global Methane Pledge to information sharing and capacity building under the Global Methane Initiative, CCAC, emissions reporting under the UNFCCC amongst others. Taking action on methane under the Convention should take into account two key considerations – the timing of political will and the level of ambition and geographic scale.

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

- Maintaining current activities and taking no additional action (status quo)
- Supporting the Global Methane Pledge
- Adopting national emission reduction targets or optimized national/regional methane reduction commitments
- Methane specific emission limit values for certain activities
- Compiling, reviewing and improving methane emissions information
- Setting minimum requirements for monitoring and reporting of data
- Developing guidance documents and/or a report on recommendations for methane emission reduction measures or best practices

76. The methane contribution to transboundary ozone is significant enough to consider potential policy action under the Air Convention. The current work underway on methane as on ozone precursor by a number of scientific and technical bodies of the Air Convention should continue. The Working Group on Strategies and Review should add to their 2022-2023 workplan to undertake continued discussions on the appropriate policy mechanism by which to achieve methane reductions. See also the informal document "Options for addressing methane as an ozone precursor under the Air Convention" for the forty-second session of the Executive Body.

[19] Towards Cleaner Air Scientific Assessment Report 2016 | UNECE

[20] Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions (2021), United Nations Environment Programme and Climate and Clean Air Coalition, https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report

# VIII. International cooperation on air pollution

77. In view of the hemispheric character of air pollution, especially ozone formation, cooperation with other countries, organizations, and fora outside of the 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 (TFICAP or The Forum), as appropriate within its mandate.

78. The forty-first session of the Executive Body (December 2021) gave the United Kingdom and Sweden a mandate to set up a new Task Force under the WGSR (TFICAP). TFICAP will promote international collaboration towards preventing and reducing air pollution to improve global air quality. It is intended to be a repository for technical information and a convener of countries and organizations, with the goal of increasing international cooperation on addressing air pollution.

79. 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.

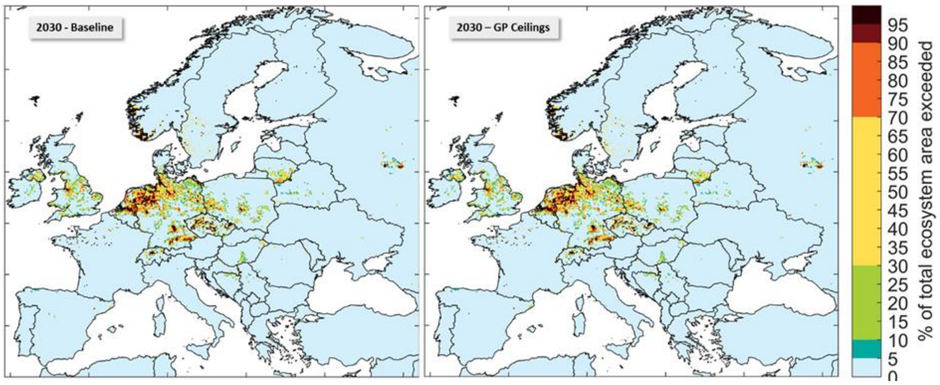
80. The work identified above will be conducted through coordination, cooperation, and collaboration with subsidiary bodies under the Convention, as well as related international organizations, multilateral bodies, and international scientific efforts. International Forum events will foster information-sharing and stimulate the engagement of non-Parties to the Convention on Long-range Transboundary Air Pollution to help all countries and regions tackle air pollution.

## Supplementary Information from CIAM

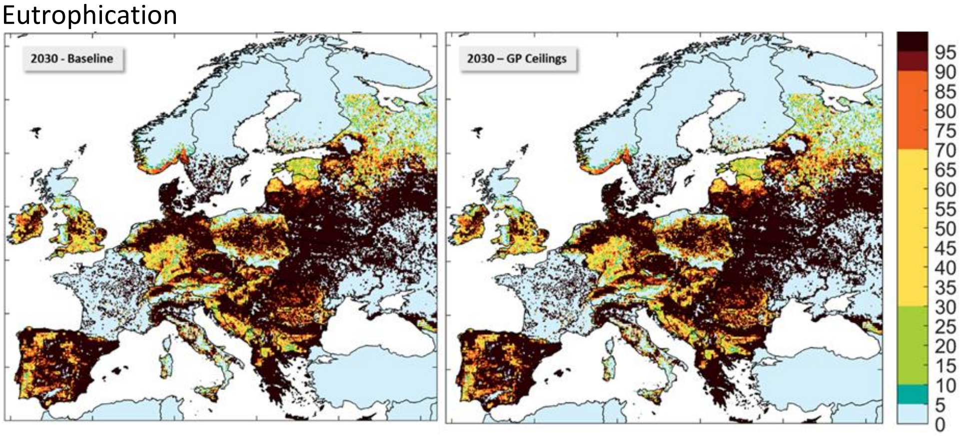
## Comparison between the baseline scenario (2030 CLE) and the impact of full implementation of the Gothenburg Protocol Ceilings in 2030

The figures below show little changes between the baseline scenario and full compliance to the emission reduction commitments in the Gothenburg Protocol, e.g., for the PM exposure, although the tables below show more significant differences for single countries.

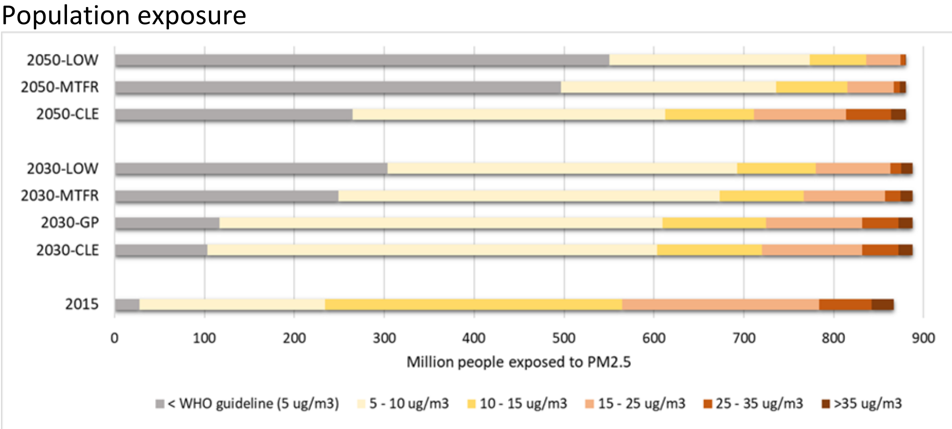
Acidification




Eutrophication




Population exposure



## Country tables

**Table 1: Emissions in GAINS-LRTAP scenarios**

| SO2 - kt SO2 | | Baseline | | MTFR | | LOW | |
|---|---|---|---|---|---|---|---|
| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| EU-27 | 6798 | 794 | 578 | 621 | 322 | 621 | 322 |
| EFTA+UK | 818 | 169 | 131 | 149 | 112 | 104 | 72 |
| West Balkan | 886 | 181 | 123 | 141 | 44 | 107 | 15 |
| EECCA+Turkiye | 6530 | 3629 | 3938 | 2714 | 887 | 1980 | 545 |
| North America | 15765 | 2865 | 2640 | 2159 | 1177 | 1550 | 959 |
| **Total** | **30796** | **7639** | **7411** | **5783** | **2542** | **4362** | **1914** |

**NOx - kt NO2 (soil NOx is excluded)**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 9694 | 2463 | 1331 | 2161 | 882 | 2161 | 882 |
| EFTA+UK | 1960 | 545 | 325 | 484 | 238 | 484 | 205 |
| West Balkan | 269 | 162 | 130 | 128 | 73 | 114 | 44 |
| EECCA+Turkiye | 6277 | 4736 | 5290 | 3510 | 1498 | 3122 | 950 |
| North America | 19025 | 7637 | 6589 | 5853 | 3455 | 5180 | 1843 |
| **Total** | **37225** | **15543** | **13666** | **12137** | **6146** | **11062** | **3923** |

**NOx - kt NO2 (soil NOx included)**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 10470 | 3236 | 2061 | 2680 | 1372 | 2631 | 1196 |
| EFTA+UK | 2072 | 646 | 426 | 554 | 308 | 556 | 254 |
| West Balkan | 291 | 186 | 157 | 145 | 92 | 128 | 56 |
| EECCA+Turkiye | 6720 | 5295 | 5906 | 3902 | 1928 | 3459 | 1201 |
| North America | 19627 | 8342 | 7313 | 6161 | 3768 | 5463 | 2049 |
| **Total** | **39180** | **17705** | **15864** | **13441** | **7467** | **12237** | **4756** |
| Increase due soil | 105% | 114% | 116% | 111% | 122% | 111% | 121% |

**NH3 - kt NH3**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 3813 | 3403 | 3267 | 2939 | 2327 | 2756 | 1460 |
| EFTA+UK | 391 | 352 | 358 | 309 | 267 | 289 | 177 |
| West Balkan | 106 | 112 | 117 | 96 | 83 | 81 | 54 |
| EECCA+Turkiye | 1926 | 2250 | 2577 | 1959 | 1937 | 1885 | 1278 |
| North America | 4274 | 4915 | 5190 | 3906 | 3037 | 3492 | 1667 |
| **Total** | **10510** | **11031** | **11508** | **9209** | **7651** | **8503** | **4635** |

**NMVOC - kt NMVOC (agricultural VOC are excluded)**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 7451 | 3832 | 3192 | 3333 | 2236 | 3333 | 2236 |
| EFTA+UK | 1411 | 843 | 775 | 718 | 525 | 720 | 534 |
| West Balkan | 329 | 326 | 258 | 187 | 64 | 178 | 82 |
| EECCA+Turkiye | 5390 | 4755 | 5073 | 3466 | 1934 | 3245 | 1829 |
| North America | 12764 | 10171 | 9705 | 9746 | 5295 | 9554 | 3772 |
| **Total** | **27345** | **19928** | **19003** | **17450** | **10054** | **17030** | **8453** |

**PM2.5 - kt PM2.5**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 1781 | 751 | 544 | 586 | 332 | 546 | 321 |
| EFTA+UK | 167 | 81 | 63 | 73 | 48 | 68 | 44 |
| West Balkan | 186 | 163 | 136 | 89 | 21 | 79 | 17 |
| EECCA+Turkiye | 1900 | 1811 | 1922 | 942 | 324 | 779 | 233 |
| North America | 1925 | 1132 | 1162 | 727 | 448 | 701 | 356 |
| **Total** | **5959** | **3938** | **3826** | **2418** | **1173** | **2173** | **972** |

**Black Carbon - kt BC**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 337 | 75 | 38 | 54 | 21 | 63 | 25 |
| EFTA+UK | 37 | 10 | 6 | 7 | 4 | 8 | 4 |
| West Balkan | 18 | 18 | 14 | 9 | 1 | 9 | 2 |
| EECCA+Turkiye | 226 | 176 | 166 | 88 | 28 | 70 | 12 |
| North America | 326 | 171 | 170 | 160 | 59 | 160 | 39 |
| **Total** | **945** | **450** | **394** | **319** | **114** | **311** | **82** |

**CH4 - kt CH4**

| Region | 2005 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|
| EU-27 | 20063 | 13093 | 10859 | 9486 | 6734 | 8781 | 3950 |
| EFTA+UK | 4253 | 2111 | 1776 | 1373 | 1117 | 1358 | 695 |
| West Balkan | 670 | 655 | 711 | 556 | 371 | 462 | 189 |
| EECCA+Turkiye | 29060 | 28655 | 30844 | 12011 | 9750 | 11781 | 6213 |
| North America | 29841 | 40984 | 42727 | 27938 | 23094 | 27289 | 15268 |
| **Total** | **83886** | **85498** | **86918** | **51363** | **41066** | **49671** | **26315** |

### Table 2: Population exposed to PM2.5 levels above 5 μg/m$^3$ (million)

| | | Baseline | | MTFR | | LOW | | GP compliant | |
|---|---|---|---|---|---|---|---|---|---|
| Country | 2015 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Austria | 8,3 | 7,0 | 4,0 | 3,4 | 0,5 | 3,3 | 0,3 | 6,2 | |
| Belgium | 11,3 | 11,9 | 10,4 | 10,9 | 3,7 | 10,5 | 1,1 | 11,8 | |
| Bulgaria | 7,2 | 6,1 | 4,9 | 4,9 | 0,1 | 4,0 | 0,3 | 6,1 | |
| Croatia | 4,2 | 3,7 | 2,8 | 3,5 | 0,3 | 3,2 | 0,0 | 3,7 | |
| Cyprus | 1,2 | 1,3 | 1,4 | 1,3 | 1,4 | 1,3 | 1,4 | 1,3 | |
| Czech Rep. | 10,6 | 10,2 | 4,1 | 3,5 | - | 2,8 | - | 9,9 | |
| Denmark | 5,7 | 4,9 | 0,0 | 4,5 | - | 1,7 | - | 4,6 | |
| Estonia | 0,7 | 0,0 | 0,0 | - | - | - | - | - | |
| Finland | 2,4 | 1,1 | 0,8 | 0,6 | - | 0,6 | 0,6 | 0,9 | |
| France | 63,3 | 45,5 | 25,5 | 31,2 | 16,4 | 25,1 | 12,4 | 40,4 | |
| Germany | 81,7 | 78,3 | 35,6 | 36,9 | 3,6 | 33,2 | 2,8 | 74,3 | |
| Greece | 11,2 | 10,7 | 9,6 | 10,4 | 8,4 | 9,9 | 7,1 | 10,7 | |
| Hungary | 9,8 | 9,2 | 7,5 | 8,7 | - | 8,2 | 0,9 | 9,2 | |
| Ireland | 4,0 | - | - | - | - | - | - | - | |
| Italy | 59,2 | 56,3 | 50,4 | 55,6 | 47,7 | 54,7 | 31,7 | 55,9 | |
| Latvia | 1,9 | 0,7 | 0,2 | 0,2 | - | 0,2 | - | 0,5 | |
| Lithuania | 2,9 | 1,4 | 0,2 | 0,0 | - | 0,0 | - | 1,3 | |
| Luxembourg | 0,6 | 0,7 | 0,1 | - | - | - | - | 0,7 | |
| Malta | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 | |
| Netherlands | 16,9 | 17,6 | 17,5 | 17,6 | 9,7 | 17,6 | 0,8 | 17,6 | |
| Poland | 38,3 | 35,6 | 13,0 | 10,9 | 0,0 | 10,0 | - | 35,4 | |
| Portugal | 10,0 | 7,0 | 5,0 | 5,5 | 4,3 | 3,5 | 1,1 | 6,9 | |
| Romania | 19,9 | 17,0 | 13,1 | 11,5 | 1,8 | 10,0 | 2,0 | 16,7 | |
| Slovakia | 5,4 | 5,0 | 2,1 | 2,0 | - | 1,7 | - | 4,9 | |
| Slovenia | 2,1 | 2,0 | 1,3 | 1,7 | 0,1 | 1,6 | 0,2 | 2,0 | |
| Spain | 43,1 | 34,5 | 28,7 | 32,3 | 26,4 | 29,9 | 15,4 | 33,8 | |
| Sweden | 5,1 | 2,7 | 1,6 | 1,8 | 0,4 | 0,8 | 0,9 | 2,4 | |
| **EU-27** | **427,3** | **370,6** | **240,4** | **259,3** | **125,4** | **234,2** | **79,2** | **357,5** | |
| | | | | | | | | | |
| Albania | 2,9 | 2,9 | 2,6 | 2,9 | 2,3 | 2,9 | 1,7 | 2,9 | |
| Armenia | 2,9 | 2,9 | 2,7 | 2,9 | 2,7 | 2,9 | 2,7 | 2,9 | |
| Azerbaijan | 9,5 | 10,6 | 11,0 | 10,5 | 10,9 | 10,5 | 11,0 | 10,6 | |
| Belarus | 9,5 | 8,9 | 7,8 | 5,1 | - | 4,6 | 0,6 | 8,8 | |
| Bosnia-H | 3,5 | 3,4 | 2,9 | 3,3 | 1,2 | 3,1 | 0,8 | 3,4 | |
| Georgia | 3,7 | 3,5 | 3,2 | 3,4 | 2,3 | 3,4 | 2,3 | 3,5 | |
| Iceland | 0,1 | 0,1 | 0,1 | 0,1 | 0,1 | - | - | 0,1 | |
| Kazakhstan | 17,5 | 19,6 | 22,6 | 19,5 | 21,4 | 18,8 | 19,6 | 19,6 | |
| Kosovo | 1,8 | 1,6 | 1,2 | 1,0 | 0,1 | 0,9 | 0,2 | 1,6 | |
| Kyrgyzstan | 5,5 | 6,6 | 7,9 | 6,8 | 7,7 | 6,7 | 7,0 | 6,6 | |
| North Macedonia | 2,1 | 2,0 | 1,8 | 1,9 | 0,7 | 1,7 | 0,6 | 2,0 | |
| R Moldova | 4,1 | 3,8 | 3,3 | 3,8 | - | 2,3 | - | 3,8 | |
| Montenegro | 0,6 | 0,5 | 0,4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,5 | |
| Norway | 1,3 | 0,3 | 0,3 | 0,3 | - | - | 0,7 | 0,5 | |
| Russia | 97,7 | 92,7 | 84,1 | 77,6 | 38,7 | 69,5 | 36,4 | 92,7 | |
| Serbia | 8,9 | 8,4 | 7,2 | 6,0 | 0,0 | 5,5 | 0,8 | 8,4 | |
| Switzerland | 7,9 | 7,7 | 7,9 | 6,0 | 1,4 | 6,2 | 3,9 | 7,6 | |
| Tajikistan | - | - | - | - | - | - | - | - | |
| Türkiye | 78,1 | 87,7 | 94,8 | 86,4 | 84,8 | 85,0 | 79,8 | 87,7 | |
| Turkmenistan | - | - | - | - | - | - | - | - | |
| Ukraine | 44,7 | 40,7 | 35,9 | 35,4 | 11,3 | 32,7 | 13,1 | 40,7 | |
| United Kingdom | 64,3 | 55,5 | 14,1 | 51,4 | 9,2 | 38,7 | 6,0 | 55,0 | |
| Uzbekistan | | | | | | | | | |
| **Non-EU** | **366,6** | **359,5** | **311,9** | **324,6** | **194,8** | **295,4** | **187,3** | **358,9** | |
| | | | | | | | | | |
| **Total** | **793,9** | **730,1** | **552,3** | **583,9** | **320,2** | **529,6** | **266,5** | **716,4** | |

**Table 3: Years of life lost (million)**

| | | Baseline | | MTFR | | LOW | | GP compliant | |
|---|---|---|---|---|---|---|---|---|---|
| Country | 2015 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Austria | 6,1 | 3,116 | 2,275 | 2,644 | 1,722 | | 1,575 | 2,737 | |
| Belgium | 10,0 | 5,046 | 3,664 | 4,311 | 2,698 | | 2,339 | 4,916 | |
| Bulgaria | 7,9 | 4,301 | 3,181 | 3,179 | 1,734 | | 1,567 | 4,18 | |
| Croatia | 5,5 | 2,453 | 1,691 | 1,766 | 0,989 | | 0,886 | 2,377 | |
| Cyprus | 0,6 | 0,468 | 0,452 | 0,386 | 0,298 | | 0,284 | 0,46 | |
| Czech Rep. | 10,6 | 4,756 | 3,325 | 3,984 | 2,306 | | 2,064 | 4,388 | |
| Denmark | 3,0 | 1,676 | 1,242 | 1,416 | 0,877 | | 0,774 | 1,66 | |
| Estonia | 0,6 | 0,367 | 0,297 | 0,298 | 0,195 | | 0,171 | 0,315 | |
| Finland | 1,8 | 1,181 | 1,055 | 1,07 | 0,864 | | 0,825 | 1,148 | |
| France | 41,0 | 22,266 | 17,668 | 19,518 | 13,726 | | 12,675 | 21,059 | |
| Germany | 56,6 | 30,446 | 23,209 | 26,131 | 17,233 | | 15,383 | 28,705 | |
| Greece | 11,4 | 5,753 | 5,113 | 4,757 | 3,708 | | 3,551 | 5,686 | |
| Hungary | 13,6 | 7,104 | 4,253 | 5,317 | 2,695 | | 2,399 | 6,933 | |
| Ireland | 1,4 | 0,71 | 0,582 | 0,617 | 0,447 | | 0,399 | 0,699 | |
| Italy | 63,0 | 31,188 | 22,830 | 28,482 | 17,362 | | 16,024 | 29,602 | |
| Latvia | 1,8 | 0,949 | 0,635 | 0,729 | 0,397 | | 0,366 | 0,903 | |
| Lithuania | 2,4 | 1,384 | 0,982 | 1,033 | 0,583 | | 0,522 | 1,324 | |
| Luxembourg | 0,3 | 0,164 | 0,119 | 0,143 | 0,089 | | 0,081 | 0,159 | |
| Malta | 0,2 | 0,191 | 0,199 | 0,162 | 0,141 | | 0,137 | 0,189 | |
| Netherlands | 14,2 | 7,771 | 5,723 | 6,721 | 4,304 | | 3,736 | 7,529 | |
| Poland | 50,2 | 19,233 | 13,217 | 15,877 | 8,51 | | 7,957 | 19,147 | |
| Portugal | 5,0 | 3,006 | 2,707 | 2,495 | 1,873 | | 1,859 | 2,979 | |
| Romania | 25,7 | 12,42 | 9,290 | 9,494 | 5,348 | | 4,793 | 11,674 | |
| Slovakia | 5,9 | 2,65 | 1,836 | 2,09 | 1,163 | | 1,036 | 2,571 | |
| Slovenia | 2,2 | 1,232 | 0,678 | 0,903 | 0,431 | | 0,408 | 1,225 | |
| Spain | 26,6 | 14,696 | 12,535 | 14,296 | 8,839 | | 8,59 | 14,288 | |
| Sweden | 3,0 | 2,012 | 1,726 | 1,818 | 1,432 | | 1,359 | 1,972 | |
| **EU-27** | **371** | **187** | **140** | **160** | **100** | **0** | **92** | **179** | |
| | | | | | | | | | |
| Albania | **5** | 3,493 | 3,735 | 2,249 | 1,118 | | 0,998 | 3,448 | |
| Armenia | 3 | 2,396 | 2,406 | 1,864 | 1,122 | | 1,116 | 2,394 | |
| Azerbaijan | 6 | 5,826 | 6,641 | 5,183 | 3,315 | | 2,79 | 5,823 | |
| Belarus | 9 | 7,519 | 7,066 | 5,474 | 2,668 | | 2,292 | 7,300 | |
| Bosnia-H | 10 | 6,538 | 5,724 | 4,165 | 1,497 | | 1,17 | 6,427 | |
| Georgia | 3 | 3,207 | 3,434 | 2,572 | 1,328 | | 1,196 | 3,203 | |
| Iceland | | | | | | | | | |
| Kazakhstan | | | | | | | | | |
| Kosovo | 4 | 3,266 | 2,930 | 2,077 | 0,744 | | 0,551 | 3,206 | |
| Kyrgyzstan | | | | | | | | | |
| North Macedonia | 3 | 2,232 | 2,065 | 1,473 | 0,697 | | 0,558 | 2,198 | |
| R Moldova | 4 | 3,018 | 2,845 | 2,128 | 1,148 | | 0,876 | 2,878 | |
| Montenegro | 1 | 0,792 | 0,686 | 0,514 | 0,195 | | 0,155 | 0,778 | |
| Norway | 1 | 0,786 | 0,691 | 0,724 | 0,576 | | 0,686 | 0,807 | |
| Russia | 90 | 91,9 | 89,376 | 64,848 | 35,76 | | 30,04 | 91,664 | |
| Serbia | 15 | 13,893 | 9,672 | 9,011 | 3,186 | | 2,509 | 13,682 | |
| Switzerland | 5 | 3,111 | 2,620 | 2,78 | 2,028 | | 1,892 | 2,896 | |
| Tajikistan | | | | | | | | | |
| Türkiye | 107 | 80,857 | 63,154 | 62,187 | 32,429 | | 28,423 | 80,346 | |
| Turkmenistan | | | | | | | | | |
| Ukraine | 43 | 35,293 | 37,629 | 24,838 | 14,043 | | 11,562 | 35,025 | |
| United Kingdom | 40 | 20,374 | 14,758 | 17,546 | 11,18 | | 10,044 | 19,915 | |
| Uzbekistan | | | | | | | | | |
| **Non-EU** | **350** | **285** | **255** | **210** | **113** | **0** | **97** | **282** | **0** |
| | | | | | | | | | |
| **Total** | **721** | **471** | **396** | **369** | **213** | **0** | **189** | **461** | **0** |

**Table 4: Premature deaths from ozone (cases/yr)**

| | | Baseline | | MTFR | | LOW | | GP compliant | |
|---|---|---|---|---|---|---|---|---|---|
| Country | 2015 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Austria | 475 | 319 | 336 | 284 | 275 | 279 | 254 | 316 | |
| Belgium | 362 | 272 | 299 | 252 | 261 | 248 | 246 | 271 | |
| Bulgaria | 596 | 431 | 344 | 373 | 268 | 360 | 244 | 430 | |
| Croatia | 312 | 197 | 166 | 172 | 130 | 169 | 120 | 196 | |
| Cyprus | 54 | 60 | 86 | 55 | 74 | 55 | 71 | 60 | |
| Czech Rep. | 537 | 384 | 342 | 338 | 274 | 332 | 254 | 382 | |
| Denmark | 131 | 110 | 110 | 100 | 93 | 99 | 88 | 109 | |
| Estonia | 23 | 17 | 15 | 15 | 12 | 15 | 11 | 17 | |
| Finland | 70 | 62 | 65 | 57 | 54 | 56 | 51 | 62 | |
| France | 2206 | 1787 | 2004 | 1635 | 1752 | 1614 | 1654 | 1779 | |
| Germany | 3752 | 2786 | 2675 | 2532 | 2273 | 2496 | 2126 | 2769 | |
| Greece | 669 | 579 | 633 | 525 | 531 | 515 | 502 | 578 | |
| Hungary | 678 | 474 | 392 | 410 | 306 | 399 | 279 | 472 | |
| Ireland | 60 | 65 | 89 | 63 | 84 | 63 | 83 | 65 | |
| Italy | 4695 | 3522 | 3630 | 3251 | 3106 | 3239 | 3001 | 3506 | |
| Latvia | 53 | 36 | 28 | 31 | 21 | 31 | 19 | 36 | |
| Lithuania | 92 | 66 | 55 | 57 | 41 | 56 | 37 | 66 | |
| Luxembourg | 18 | 13 | 16 | 12 | 13 | 12 | 13 | 13 | |
| Malta | 22 | 23 | 27 | 21 | 25 | 21 | 24 | 23 | |
| Netherlands | 382 | 334 | 381 | 307 | 329 | 303 | 308 | 332 | |
| Poland | 1463 | 1075 | 1008 | 933 | 775 | 916 | 715 | 1071 | |
| Portugal | 435 | 378 | 421 | 358 | 388 | 357 | 382 | 376 | |
| Romania | 1247 | 945 | 834 | 812 | 630 | 786 | 575 | 943 | |
| Slovakia | 274 | 204 | 196 | 177 | 151 | 173 | 139 | 204 | |
| Slovenia | 112 | 79 | 80 | 70 | 64 | 69 | 60 | 79 | |
| Spain | 2113 | 1893 | 2273 | 1772 | 2061 | 1761 | 2012 | 1890 | |
| Sweden | 168 | 132 | 137 | 120 | 116 | 119 | 109 | 132 | |
| **EU-27** | **21001** | **16244** | **16644** | **14734** | **14106** | **14542** | **13375** | **16176** | |
| | | | | | | | | | |
| Albania | 126 | 129 | 155 | 112 | 120 | 110 | 112 | 128 | |
| Armenia | 203 | 206 | 246 | 193 | 199 | 191 | 190 | 206 | |
| Azerbaijan | 245 | 327 | 513 | 295 | 359 | 287 | 336 | 327 | |
| Belarus | 271 | 202 | 184 | 173 | 135 | 169 | 124 | 201 | |
| Bosnia-H | 217 | 160 | 152 | 139 | 116 | 134 | 107 | 160 | |
| Georgia | 206 | 169 | 176 | 157 | 123 | 154 | 115 | 169 | |
| Iceland | 4 | 5 | 7 | 5 | 7 | 5 | 7 | 5 | |
| Kazakhstan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Kosovo | 51 | 39 | 34 | 34 | 27 | 33 | 24 | 39 | |
| Kyrgyzstan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| North Macedonia | 140 | 117 | 123 | 104 | 100 | 101 | 91 | 117 | |
| R Moldova | 208 | 177 | 188 | 153 | 137 | 147 | 125 | 177 | |
| Montenegro | 37 | 30 | 31 | 27 | 25 | 25 | 23 | 30 | |
| Norway | 81 | 74 | 93 | 70 | 85 | 70 | 83 | 74 | |
| Russia | 3099 | 2875 | 2867 | 2588 | 2249 | 2528 | 2133 | 2872 | |
| Serbia | 559 | 406 | 341 | 347 | 258 | 332 | 229 | 405 | |
| Switzerland | 387 | 315 | 372 | 289 | 317 | 286 | 296 | 306 | |
| Tajikistan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Türkiye | 2444 | 2803 | 4049 | 2639 | 3611 | 2616 | 3521 | 2801 | |
| Turkmenistan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Ukraine | 2580 | 1986 | 1797 | 1745 | 1373 | 1693 | 1275 | 1983 | |
| United Kingdom | 1238 | 1168 | 1360 | 1102 | 1234 | 1094 | 1192 | 1161 | |
| Uzbekistan | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| **Non-EU** | **12098** | **11188** | **12689** | **10172** | **10474** | **9975** | **9983** | **11160** | |
| | | | | | | | | | |
| **Total** | **33099** | **27432** | **29332** | **24905** | **24581** | **24517** | **23358** | **27336** | |

## Table 5: Acidification (% of ecosystem area exceeding critical loads)

| | | | Baseline | | MTFR | | LOW | | GP compliant | |
|---|---|---|---|---|---|---|---|---|---|---|
| Country | Ecosystem area [km2 | 2015 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Austria | 38.901 | 0,6 | 0,0 | 0,0 | | | | | 0,0 | |
| Belgium | 15.482 | 42,1 | 32,4 | 28,9 | 30,1 | 22,9 | 27,8 | 15,4 | 32,4 | |
| Bulgaria | 54.242 | 0,0 | | | | | | | | |
| Croatia | 36.341 | 3,3 | 0,5 | 0,3 | 0,1 | | 0,1 | | 0,5 | |
| Cyprus | 1.692 | | | | | | | | | |
| Czech Rep. | 23.831 | 77,8 | 19,4 | 5,4 | 5,7 | 0,2 | 5,4 | 0,0 | 16,1 | |
| Denmark | 6.657 | 13,5 | 1,6 | 0,6 | 0,6 | | 0,3 | | 1,2 | |
| Estonia | 30.583 | | | | | | | | | |
| Finland | 281 | 0,4 | 0,3 | 0,3 | 0,3 | 0,1 | 0,3 | 0,0 | 0,3 | |
| France | 176.852 | 5,5 | 2,1 | 1,2 | 0,8 | 0,0 | 0,2 | | 2,1 | |
| Germany | 103.401 | 48,3 | 21,9 | 16,4 | 16,0 | 6,4 | 14,2 | 3,5 | 21,0 | |
| Greece | 77.626 | 0,6 | 0,1 | 0,1 | 0,1 | | 0,1 | | 0,1 | |
| Hungary | 29.969 | 5,8 | 2,6 | 1,8 | 1,5 | 0,0 | 0,3 | | 2,4 | |
| Ireland | 16.195 | 1,1 | 0,6 | 0,4 | 0,3 | 0,1 | 0,2 | | 0,4 | |
| Italy | 100.954 | 0,5 | 0,1 | 0,1 | 0,1 | 0,0 | 0,1 | 0,0 | 0,1 | |
| Latvia | 44.142 | 2,2 | 0,1 | | 0,1 | | | | 0,1 | |
| Lithuania | 26.331 | 24,0 | 14,3 | 8,6 | 4,8 | 0,4 | 3,2 | | 11,9 | |
| Luxembourg | 1.376 | 13,6 | 1,3 | 0,7 | 0,4 | | 0,4 | | 1,1 | |
| Malta | 35 | | | | | | | | | |
| Netherlands | 2.755 | 72,4 | 71,2 | 70,5 | 70,8 | 68,9 | 70,4 | 56,9 | 71,2 | |
| Poland | 95.931 | 42,0 | 5,9 | 2,1 | 2,3 | 0,1 | 2,1 | 0,1 | 5,3 | |
| Portugal | 41.903 | 1,6 | 0,3 | 0,3 | 0,2 | 0,0 | 0,3 | 0,0 | 0,3 | |
| Romania | 109.259 | 0,8 | 0,2 | 0,0 | 0,0 | 0,0 | 0,0 | | 0,1 | |
| Slovakia | 26.757 | 5,3 | 0,7 | 0,2 | 0,2 | | 0,2 | | 0,5 | |
| Slovenia | 14.052 | 0,0 | 0,0 | 0,0 | | | | | 0,0 | |
| Spain | 251.625 | 0,6 | 0,1 | 0,1 | 0,1 | 0,0 | 0,0 | | 0,1 | |
| Sweden | 391.665 | 3,3 | 1,2 | 1,0 | 1,0 | 0,7 | 1,0 | 0,7 | 1,2 | |
| **EU-27** | **1.718.839** | **9,1** | **3,2** | **2,1** | **2,0** | **0,9** | **1,7** | **0,6** | **3,0** | |
| | | | | | | | | | | |
| Albania | 19.947 | | | | | | | | | |
| Armenia | | | | | | | | | | |
| Azerbaijan | | | | | | | | | | |
| Belarus | 66.499 | 5,6 | 1,0 | 0,8 | 0,3 | 0,0 | 0,2 | | 0,8 | |
| Bosnia-H | 36.959 | 11,1 | 1,1 | 0,6 | 0,1 | | | | 1,1 | |
| Georgia | | | | | | | | | | |
| Iceland | | | | | | | | | | |
| Kazakhstan | | | | | | | | | | |
| Kosovo | 4.693 | 7,0 | | | | | | | | |
| Kyrgyzstan | | | | | | | | | | |
| North Macedonia | 16.846 | 1,0 | | | | | | | | |
| R Moldova | 3.773 | | | | | | | | | |
| Montenegro | 9.041 | | | | | | | | | |
| Norway | 320.380 | 9,4 | 4,9 | 3,6 | 3,8 | 1,9 | 3,6 | 1,3 | 4,6 | |
| Russia | 643.092 | 0,5 | 0,3 | 0,4 | 0,1 | 0,0 | 0,1 | 0,0 | 0,3 | |
| Serbia | 33.005 | 17,2 | 0,4 | 0,3 | 0,2 | 0,0 | 0,0 | | 0,4 | |
| Switzerland | 9.733 | 16,4 | 11,4 | 10,6 | 10,5 | 7,7 | 9,3 | 3,1 | 11,0 | |
| Tajikistan | | | | | | | | | | |
| Türkiye | | | | | | | | | | |
| Turkmenistan | | | | | | | | | | |
| Ukraine | 97.758 | 1,2 | 0,0 | 0,0 | 0,0 | | 0,0 | | 0,0 | |
| United Kingdom | 75.806 | 10,6 | 3,7 | 2,4 | 2,2 | 0,8 | 1,8 | 0,1 | 3,4 | |
| Uzbekistan | | | | | | | | | | |
| **Non-EU** | **1.337.532** | **4,4** | **1,7** | **1,3** | **1,2** | **0,6** | **1,1** | **0,3** | **1,6** | |
| | | | | | | | | | | |
| **Total** | **3.056.371** | **7,0** | **2,5** | **1,8** | **1,6** | **0,7** | **1,4** | **0,5** | **2,4** | |

**Table 6: Eutrophication (% of ecosystem area exceeding critical loads)**

| | | | Baseline | | MTFR | | LOW | | GP compliant | |
|---|---|---|---|---|---|---|---|---|---|---|
| Country | Ecosystem area [km2] | 2015 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Austria | 50.489 | 65,1 | 42,6 | 35,4 | 28,4 | 12,5 | 24,9 | 1,3 | 37,4 | |
| Belgium | 15.552 | 65,7 | 53,0 | 45,4 | 50,1 | 41,1 | 45,0 | 29,6 | 52,0 | |
| Bulgaria | 54.322 | 85,6 | 72,3 | 67,1 | 57,3 | 39,5 | 51,6 | 33,6 | 71,2 | |
| Croatia | 36.411 | 90,5 | 79,5 | 77,1 | 73,7 | 61,5 | 73,5 | 46,4 | 78,7 | |
| Cyprus | 1.691 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | |
| Czech Rep. | 23.831 | 96,8 | 81,5 | 71,0 | 69,7 | 35,7 | 68,6 | 5,1 | 80,1 | |
| Denmark | 6.665 | 100,0 | 99,7 | 99,2 | 99,5 | 96,7 | 99,2 | 63,1 | 99,6 | |
| Estonia | 30.592 | 46,4 | 33,4 | 30,1 | 29,5 | 17,7 | 28,7 | 10,7 | 31,3 | |
| Finland | 41.047 | 10,6 | 2,5 | 0,9 | 1,4 | 0,0 | 1,2 | | 2,2 | |
| France | 176.937 | 83,5 | 66,4 | 61,2 | 57,3 | 41,8 | 51,3 | 11,2 | 65,9 | |
| Germany | 103.988 | 79,8 | 68,0 | 62,3 | 61,9 | 46,3 | 59,0 | 27,1 | 67,2 | |
| Greece | 77.844 | 100,0 | 99,9 | 99,9 | 99,9 | 99,7 | 99,9 | 98,8 | 99,9 | |
| Hungary | 30.007 | 91,2 | 73,8 | 70,1 | 68,8 | 64,0 | 67,9 | 48,6 | 71,5 | |
| Ireland | 16.776 | 48,2 | 44,8 | 42,8 | 40,4 | 32,8 | 33,6 | 4,3 | 42,3 | |
| Italy | 105.815 | 71,5 | 50,0 | 45,6 | 42,5 | 30,0 | 41,9 | 17,8 | 48,8 | |
| Latvia | 44.159 | 91,4 | 72,6 | 60,3 | 58,8 | 42,4 | 53,8 | 38,2 | 70,2 | |
| Lithuania | 26.352 | 99,0 | 97,3 | 94,2 | 93,1 | 68,9 | 89,9 | 38,4 | 97,0 | |
| Luxembourg | 1.377 | 100,0 | 100,0 | 98,8 | 97,2 | 90,1 | 96,4 | 54,4 | 100,0 | |
| Malta | 35 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 | |
| Netherlands | 2.976 | 87,8 | 77,5 | 72,2 | 75,5 | 57,7 | 66,2 | 20,7 | 77,5 | |
| Poland | 95.929 | 75,8 | 59,6 | 50,2 | 46,8 | 20,4 | 47,0 | 6,8 | 57,7 | |
| Portugal | 42.008 | 84,2 | 70,5 | 69,2 | 64,3 | 58,8 | 64,7 | 56,7 | 70,1 | |
| Romania | 109.333 | 93,9 | 90,4 | 86,4 | 83,2 | 67,6 | 79,3 | 43,6 | 90,1 | |
| Slovakia | 26.799 | 96,2 | 86,9 | 84,0 | 82,7 | 59,5 | 79,9 | 32,2 | 86,4 | |
| Slovenia | 14.066 | 86,1 | 62,1 | 57,0 | 54,9 | 38,2 | 52,4 | 25,2 | 60,5 | |
| Spain | 251.922 | 95,2 | 90,4 | 89,1 | 85,4 | 78,3 | 84,7 | 72,9 | 90,0 | |
| Sweden | 58.643 | 14,3 | 12,5 | 11,3 | 11,5 | 4,8 | 11,2 | 2,4 | 12,5 | |
| **EU-27** | **1.445.569** | **80,2** | **69,2** | **65,0** | **62,2** | **49,4** | **60,0** | **35,5** | **68,2** | |
| | | | | | | | | | | |
| Albania | 19.971 | 92,9 | 89,5 | 89,5 | 85,1 | 77,7 | 85,7 | 74,9 | 89,4 | |
| Armenia | | | | | | | | | | |
| Azerbaijan | | | | | | | | | | |
| Belarus | 66.500 | 100,0 | 99,8 | 99,8 | 98,4 | 89,1 | 96,6 | 46,0 | 99,8 | |
| Bosnia-H | 37.044 | 74,5 | 70,5 | 69,3 | 66,6 | 57,6 | 65,6 | 50,4 | 70,2 | |
| Georgia | | | | | | | | | | |
| Iceland | | | | | | | | | | |
| Kazakhstan | | | | | | | | | | |
| Kosovo | 4.703 | 83,9 | 69,0 | 66,5 | 51,7 | 38,5 | 39,5 | 18,5 | 67,8 | |
| Kyrgyzstan | | | | | | | | | | |
| North Macedonia | 16.892 | 83,0 | 71,2 | 69,1 | 63,0 | 55,1 | 58,2 | 51,2 | 71,1 | |
| R Moldova | 3.774 | 99,8 | 98,4 | 98,4 | 80,6 | 65,0 | 76,8 | 52,5 | 98,4 | |
| Montenegro | 9.059 | 60,6 | 52,9 | 48,8 | 43,5 | 36,1 | 36,7 | 32,1 | 52,5 | |
| Norway | 303.446 | 11,9 | 7,2 | 5,4 | 5,4 | 2,0 | 4,9 | 0,4 | 6,9 | |
| Russia | 643.119 | 50,4 | 44,1 | 42,2 | 33,0 | 12,1 | 28,7 | 5,6 | 43,9 | |
| Serbia | 33.064 | 91,4 | 86,1 | 84,0 | 78,3 | 64,1 | 67,2 | 42,1 | 85,8 | |
| Switzerland | 24.248 | 57,6 | 48,4 | 45,0 | 44,4 | 35,1 | 40,3 | 13,0 | 46,2 | |
| Tajikistan | | | | | | | | | | |
| Türkiye | | | | | | | | | | |
| Turkmenistan | | | | | | | | | | |
| Ukraine | 97.773 | 100,0 | 100,0 | 99,9 | 99,4 | 96,0 | 98,8 | 73,1 | 99,9 | |
| United Kingdom | 71.070 | 25,6 | 15,4 | 11,4 | 11,1 | 3,9 | 9,0 | 0,4 | 14,7 | |
| Uzbekistan | | | | | | | | | | |
| **Non-EU** | **1.330.663** | **49,6** | **44,2** | **42,5** | **37,4** | **24,3** | **34,4** | **15,4** | **44,0** | |
| | | | | | | | | | | |
| **Total** | **2.776.232** | **65,6** | **57,2** | **54,2** | **50,3** | **37,4** | **47,7** | **25,9** | **56,6** | |