Executive Body

Forty-first session
Geneva, 6–8 December 2021
Item 5 of the provisional agenda
Review of sufficiency and effectiveness of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone

Supplementary information for the review of the Gothenburg Protocol

I. Introduction

1. Summary of the Review process

II. Report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone

A. Introduction

1. A short history and background to the review with references to some of the key milestones (the scientific assessment of the Convention[1], the long-term strategy for the Convention for 2020–2030 and beyond, the entry into force of the Gothenburg Protocol as amended, article 10 provisions and Executive Body decision 2019/4). A description of the purpose and scope of the review report, applied methodologies for the analysis and general approach for the review will also be included here.

B. Legal requirements for the review

2. Article 10 of the Gothenburg Protocol requires that Parties keep under review the obligations of the Protocol and broadly specifies the modalities of such reviews. Paragraphs 2 (a) and (b) of article 10 are important in determining some of the content and structure of the review report, while paragraph 2 (c) deals with procedural matters for the review. Although paragraphs 2 (a) and 2 (b) include information on a broader review of the Gothenburg Protocol, paragraphs 3 and 4 refer to specific elements that shall be included in the review, i.e., measures to address black carbon and ammonia, respectively.

3. Include explanation of the broader elements that legally need to be addressed under the review, including their content and related issues (the adequacy of the obligations, assessment of emission reduction commitments). Description of the specific elements to be addressed under the review (evaluation of ammonia and black carbon measures).

C. Emissions

Emissions trends will be elaborated and updated with data from the 2021 submission, which is still under process. Graphs and figures will be delivered by September.

4. Although the situation significantly improved over the past years there is still space for further improvement regarding quality of the emission reporting processes. In 2020, 48 Parties submitted emissions inventories under the Convention. The coverage of reporting Parties increased over the last years to 94%. However, for 17 Parties the completeness was not satisfactory in the submission 2020, either because they did not submit any data or they did not provide data for all priority pollutants or they did not provide a full time series or they did not provide activity data (Technical Report CEIP 4/2020). It should be noted that for countries in the ‘EMEP East’ domain, the reporting situation has considerably improved over the years, although a decline is observed between 2019 and 2020 submission round: for the year 2018 (reported in 2020), the share of ‘no submissions’ amounted to 40 % in this region, while it was only 20% of countries included in ‘EMEP East’ region in 2017 (reported in 2019). According to the emission reporting procedure, the key element to ensure good transparency of the inventories is a good Informative Inventory Report. Eleven Parties did not provide an Informative Inventory Report (IIR) in the year 2020 and three Parties provided an (IIR) but did not follow the recommended structure. For these Parties the transparency was not given.

---

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

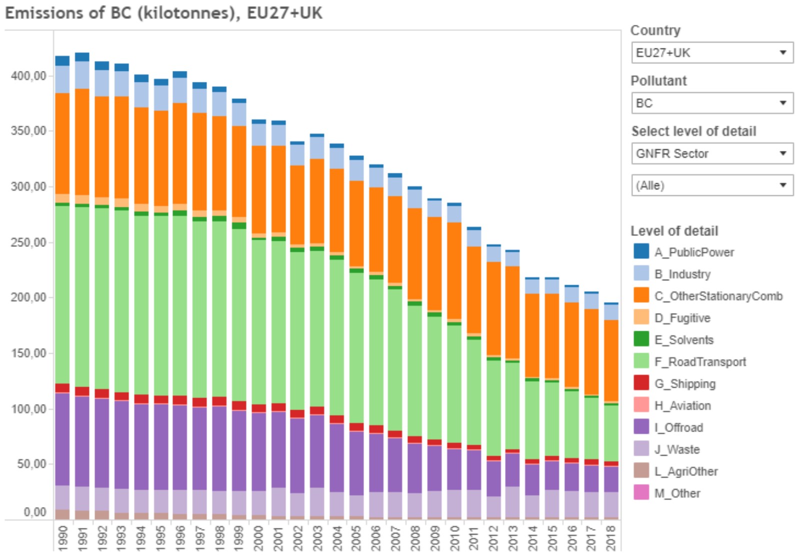
5. All emissions inventories bear uncertainties. Uncertainty information should be part of every emission inventory as stated in the Guidelines for Reporting Emissions and Projections Data under the Convention (ECE/EB.AIR/125). However, less than half of the Parties reported uncertainty estimates in their inventory submission in 2021. Usually Parties report the uncertainty for total emissions and emission trends. The availability of uncertainty estimates has increased in recent years although progress has been rather slow. It can be concluded that uncertainty estimation is still a topic that receives too little attention in the Informative Inventory Reports of many Parties and that it is currently not possible to estimate the uncertainty of pollutant emissions in the whole EMEP area with the information provided by Parties.

Pollutant	Uncertainty range reported by Parties for National Total (%)	Number of Parties providing an uncertainty estimate for National Total	Uncertainty range reported by Parties for the emission trend (%)	Number of Parties providing an uncertainty estimate for the emission trend
NO_x	8.5 to 59	19	1 to 31	19
NMVOC	15 to 112	19	1.8 to 32.2	19
SO_x	5 to 47	19	0.2 to 103	19
NH_3	9.5 to 143	19	3.1 to 364.8	19
$PM_{2.5}$	9.96 to 96.6	17	3 to 140	18
BC	27.1 to 302	7	3.1 to 67	7

Note: The values in this table are from the 2021 submission and will be updated with resubmissions later in the year

6. The specific question of black carbon and inclusion of condensable in PM will be developed in the future versions of the document once the latest reports will be analysed. What can be said today about BC:

7. Black carbon emissions are reported on a voluntary basis. The number of countries which provide emission estimates for black carbon increased over the past year. In 2021, 40 countries reported BC emissions. Quality of the data reported still needs to be improved, since inconsistency between country and sector sharing are noted.



Country: EU27+UK
Pollutant: BC
Select level of detail: GNFR Sector
(Alle)

1.2(a), 1.2(b), 1.2(c), 1.2(d), 1.2(e) (CEIP[2], TFEIP[3])

- ➔ see above and in the joint CEIP's note. This section will be elaborated and updated with data from the 2021 submission. Used sources of information are the Inventory Review 2020: Review of emission data reported under the LRTAP Convention Stage 1 and 2 review Status of gridded and LPS data (https://www.ceip.at/status-

---

[2] The Centre on Emission Inventories and Projections.

[3] The Task Force on Emission Inventories and Projections.

of-reporting-and-review-results/2021-submission and https://www.ceip.at/review-of-emission-inventories/technical-review-reports and https://www.ceip.at/ceip-reports/inventory-review-2020-dataviewer) and the stage 3 review reports (https://www.ceip.at/review-of-emission-inventories/in-depth-review-of-ae-inventories)

➔ Regarding uncertainties, a report is in preparation: “Uncertainties and recalculations of emission inventories submitted under CLRTAP”, CEIP Technical Report XX/20201. Further inputs available in *the Informative Inventory Reports (https://www.ceip.at/status-of-reporting-and-review-results/2021-submission)*

1.3 (CEIP, TFEIP)

➔ Answers will be provided in Spring 2022

1.4(a), 1.4(b), 1.4(c), 1.4(d) (TFEIP, TFIAM[4])

➔ Answers will be provided in September 2021 (trends) and on projections in Spring 2022[5]

4.1 (CEIP, TFEIP)

➔ See above for BC. Answer will be updated in September 2021 once 2021 reports have been reviewed and analysed

4.4 (CEIP, TFEIP, TFIAM)

➔ Answers elaborated for spring 2022 accounting for the work of the ad hoc expert group on condensables

Fall 2021 – spring 2022, CEIP, CIAM/TFIAM:

1. Main causes of emission reductions and relative contributions to these reductions of climate, energy, transport and agricultural policies and measures

8. CIAM will analyze emission trends delivered by CEIP to guarantee consistency with trends in energy use, agriculture and traffic. CIAM could explain the contribution of abatement policy and energy policy to emission reduction. Both seem to be equally important, see Scientific Assessment Report 2016, p 11 figure 17 (Rafaj et al 2014). Several national ex-post assessments of air quality policies, showed that internationally agreed environmental legislation has had a significant influence on the improvement of air quality in their country, showing the success and benefits of international co-operation (e.g. UK, NL – see TFIAM48-report, Task Force on Integrated Assessment Modelling - TFIAM - IIASA).

9. Also see the JRC analysis of the role of European standard setting to emission reductions around the globe (M Crippa et al. Forty years of improvements in European air quality, acp-16-3825-2016.pdf (copernicus.org). The Clean Air Outlook 1 and 2 for the EU provided an assessment of the trends in the emissions and impact of various legislation in recent years. Review of the EU Air policy - Environment - European Commission (europa.eu). Additionally, for primary PM and black carbon the analysis[6] provided analysis and estimate of drivers of emission changes in the period 1990-2010.

---

[4] The Task Force on Integrated Assessment Modelling.

[5] Report on air quality and GHG emissions in the Western Balkans https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/status-air-pollutants-and-greenhouse-gases-western-balkans

[6] Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., Borken-Kleefeld, J., and Schöpp, W.: Global anthropogenic emissions of particulate matter including black carbon, Atmos. Chem. Phys., 17, 8681–8723, https://doi.org/10.5194/acp-17-8681-2017 , 2017

2. Key sectors with large reduction potentials, specifically in Eastern, South-Eastern Europe and Turkey, the Caucasus and Central Asia

10. CIAM is currently updating (best available) emission projections for several EECCA- and west-Balkan countries. Large emission reductions seen possible in marine shipping[7] and within UNECE countries: ammonia from agriculture, PM2.5 emissions from residential solid fuel burning and agricultural waste burning and methane emissions from waste treatment. Additionally, in EECCA/SEE countries emission reductions are possible from coal burning, transport and waste treatment.

D. Measured and modelled atmospheric concentrations and deposition levels

11. Ozone is a secondary pollutant, and observed trends reflect meteorological variability to a much greater extent than trends in precursor compounds. Trends are also affected by titration effects, in which decreasing NOx emissions can increase ozone, especially in wintertime. Trends in summertime O3, and metrics of higher ozone (MDA8, SOMO35), are stronger and clearer than those in annual data, though site to site variability is large (Chang et al., 2017). Using stringent data-capture criteria, median trends in daily maximum ozone during June-August were -0.6 ppb/yr at EMEP sites (EMEP model -0.4 ppb/yr). Observed trends showed much more variability than modelled trends, and observed trends being more affected by the high ozone summers of 2003 and 2006 in some regions.

12. Annual average concentrations of sulphur dioxide and particulate sulphate, and wet deposition of oxidized sulphur, has been declining since the 1980s. At EMEP background sites, the changes from 2000-2018 is on average -4 %/y, -2.9 %/y and -3.3 %/y for sulphur dioxide, particulate sulphate and wet deposition of oxidized sulphur, respectively (EMEP model results: -5.3%/y, -4.0%, -4.5%/y.

13. From around 1990 onwards, the total emissions of NOx declined significantly in Europe, followed by declining nitrogen dioxide concentrations and total nitrate (nitric acid plus particulate nitrate) in air and reduced oxidized nitrogen deposition at EMEP background sites. From 2000-2018, the average reductions at long term EMEP background sites have been -1.5 %/y, -1.9 %/y and -1.7 %/y for nitrogen dioxide concentrations, particulate nitrate and wet deposition of oxidized nitrogen, respectively (EMEP model results: -2.3 %/y, -2.3 %, -2.4%/y).

14. Only modest reductions of ammonia emissions have been achieved since 2000 compared to other pollutants. As a result, ammonium in precipitation has declined marginally (median of -0.08 %/y from 2000-2018 at long term EMEP sites). However, the formation of particulate ammonium in air depends not only on the availability of ammonia, but also on the availability of nitric acid (formed from NOx) and sulphate (formed from SOx). With large reductions in SOx and NOx emissions during the last decades, ammonia is to a large extent in excess and the availability of nitric acid and sulphate limit the formation of ammonium, resulting in a decline of ammonium in air of on average -2.8 %/y at long term EMEP sites. Total reduced nitrogen in air (ammonia + particulate ammonium) is reduced less (-1 %/y from 2000-2018), as a larger fraction of total reduced nitrogen being ammonia (but with a shorter lifetime than ammonium aerosol). The majority of sites for ammonia in air show no significant trends.

15. Since 2000, there has been significant reductions in PM_{10} and $PM_{2.5}$ (on average -1.7 and -2.3 %/y at EMEP long term observational sites, and slightly more in EMEP model calculations (-2.0 and -2.6 %/y). SIA (particulate sulphate, nitrate and ammonium) has decreased significantly since 2000, with sulphate showing the largest decrease (SO4: -2.9 (-4.0) %/y, NO3:-1.9 (-2.3) %/y, NH4: -2.8 (-2.9) %/y, EMEP model in parenthesis). For the natural components (sea salt and dust), less long-term observational sites exist, and only few of them show significant trends. For carbonaceous aerosol there are very few sites with long term, consistent measurements. One study show a 4 %/yr decrease in elemental carbon since

---

[7] See background technical report on shipping developed by TFTEI https://unece.org/environmental-policy/events/working-group-strategies-and-review-fifty-eighth-session.

2001, indicating a reduction from anthropogenic sources, whereas trends in organic carbon is (more) influenced by natural sources, and thus more difficult to assess (**OM/EC: This will be further assessed and can be answered better during Fall 2021)**.

16. At EMEP regional sites, exceedances of the WHO air quality guidelines (AQG) for PM10 and PM2.5 are in the later years seen at around ⅓ and ½ of the observational sites respectively. EMEP MSC-W model simulations show a decrease in the area with (rural and urban background) daily PM_{10} and $PM_{2.5}$ exceedances of WHO AQG from 2000 to 2018.

17. Overall, the trends of sulphur and nitrogen compounds in air and precipitation follow the emission trends within Europe and the influence of transcontinental transport is negligible. For PM, wildfires and wind-blown dust originating outside Europe influence concentration levels substantially during episodes (typically a few times a year). **For ozone, see TFHTAP answer**.

18. **Regarding future trends,** emission projections in Europe indicate that future ammonia emission reductions will be relatively small compared to the emission reductions of sulphur dioxide, nitrogen oxides and primary particulate matter. The depositions of sulphur and nitrogen are projected to change similarly to emissions of SOx, NOx and NH3. Assuming that NEC 2030 will be met (-19%, -77%, -63% compared to 2005 for NH3, SOx and NOx emissions, respectively), deposition of oxidized nitrogen will decrease much more than deposition of reduced nitrogen - leading to an increased fraction of reduced versus total deposition of nitrogen, expected to reach more than 60% in large parts of Europe by 2030. For ammonium, the much larger reductions of SOx and NOx emissions compared to NH3 emissions are projected to lead to reductions in particulate ammonium of around the same magnitude as the SOx/NOx emission reductions. Reductions of primary PM emissions, together with precursors of the secondary inorganic aerosols are projected to lead to reduced PM2.5 and PM10 concentrations by 2030. (Jonson et al, in prep, EMEP Report I/2020). Even so, WHO limit values for $PM_{2.5}$ (yearly and daily) are expected to be exceeded in some areas also in 2030. In the longer term, some processes may promote higher PM levels again, e.g. higher temperature may increase biogenic VOC emissions (and hence SOA formation), or soil-NO and NH3 emissions

19. Comment about the monitoring network: the observational network is dominated by sites in EU+EEA and has hardly any coverage in the EECCA & western Balkan area, thus the trends reported here are not representative for these regions. Furthermore, the lack of (consistent and high quality) emission reporting for these areas, and especially long-term emission data sets, makes it very difficult to model trends in this area. The improved resolution in the EMEP model results (and in the emissions) has in general improved the comparison to observations, especially for the primary components. While model results in the old resolution (50kmx50km) were representative for the regional background, the model results in the new resolution can represent urban background scale as well.

20. Exceedances of critical loads are slightly higher in the high-resolution model results (0.1x0.1) than in the old 50x50km results for acidification (EMEP Status Report 1/2018, page 33). The high exceedance area in and around the Netherlands is slightly more extended with the 0.1×0.1 deposition, both for acidification and eutrophication. The overall pattern, however, is very similar. The overall exceedances of eutrophication CLs are slightly smaller under the 0.1×0.1◦ depositions. A reason for this could be that the high-resolution deposition resolves the population centres much better. These areas generally have higher depositions but less (semi-)natural ecosystems. This may be an additional argument for the use of high-resolution depositions for exceedance calculations. Overall, the changes are small, e.g. 5.28% vs 5.25% area exceeded for acidification and 62.5% vs 61.2% for eutrophication for Europe for 2015 (Based on EMEP Status Report 1/2017).

21. The overall differences in blame matrices due to different model resolutions for the country-to-itself contribution are small for depositions (a few percent), but somewhat larger for PM and ozone (up to 11%). For the individual transboundary contributions, differences can be larger, especially when the pollution is transported across mountain areas and/or is very small. Changes in the chemical atmosphere also influence the effectiveness of emission reductions for air quality improvement. The much larger decrease in SOx and NOx emissions than NH3 emissions during the last decades (and which is projected to continue) impact the

efficiency of reducing NH3 emissions to curb PM2.5 concentrations. EMEP MSC-W model calculations indicate that reductions in PM2.5 per gram of ammonia emissions mitigated in 2030 versus 2005 are significantly reduced (Jonson et al, in prep).

22. There are hardly any (long term) EMEP observations in the EECCA & western Balkan area. Combined with the lack of consistent, high quality (and long term) emissions for countries in the eastern part of the EMEP domain, it is very difficult to assess and project air pollution and its effects in these areas. Condensable organics have been highlighted as one such problem (Simpson et al., 2020), and so-called intermediate volatility organics may also emerge as an important issue. Further discussion is needed between the EMEP Task Forces, Parties, and in conjunction with the Emission Inventory Guidebook. There are also issues with the consistent inclusion or exclusion of some other emission components, e.g. emissions from agricultural soil-NO, waste-burning, or VOC emissions. Additional measurements of nitrogen deposition in sea areas (islands or on ships) would be beneficial for better monitoring of eutrophication trends in marine ecosystems and to evaluate/constrain models.

What is the annual change (or change every 5 years) in exceedance of critical loads for acidification and eutrophication between 1990 and 2018/2019 in terms of percentage ecosystems with exceedances and accumulated excess, based on current critical loads?

23. The exceedances of European Critical Loads (CLs) (figures 1-4) are computed for the total nitrogen (N) and sulphur (S) depositions in the years 2000, 2005, 2010, 2015 and 2019, modelled on the 0.1°x 0.1° longitude-latitude grid (approx. 11 x 5.5 km2 at 60°N) by MSC-West, and the most current European Critical Load database compiled by CCE in 2021,

24. The Critical Load database consists of two components. The first component is the aggregated data from national contributions. (see documentation on the CCE website[8]). The second component consists in data from the recently completed Critical Load background database of the Coordination Center for Effects (CCE) (Reinds et al., 2021[9]) for the areas for which no contributions were provided from the respective NFCs.

25. Both components have been merged and in this consolidated database Critical Loads are available for about 4.1 million ecosystems in Europe with an area of about 2.9 million km2 for acidification impacts and about 2.6 million km^2 for the effects of eutrophication[10]. The analysed ecosystems for the CL for acidification are mainly forests (54%) but also freshwater ecosystems (24%) and grasslands (16%). The CL dataset for eutrophication contains also mainly forests (65%) and different types of grasslands (20%).

26. The calculated exceedance in a grid cell shown in this section is displayed as a so-called "average cumulative exceedance" (AAE[11]), As indicated in the maps, Critical Loads of acidity are exceeded in a much smaller area (see Figure 1). Acidity exceedances occur on 14,0% (2000) and 4.4% (2019) of the ecosystem area and the European average AAE is about 124 eq ha^{-1} yr^{-1} (2000) and 23 eq ha^{-1} yr^{-1} (2019). Overall statistics for the share of Critical Load exceedance and European average of AAE are shown in Figure 3.

27. By contrast, the Critical Loads for eutrophication are exceeded in large parts of the model domain in all years. The share of ecosystems where the Critical Load for eutrophication is exceeded decreases relatively slowly, starting at 75 % in 2000 and going down to 64.3% in 2019 (See figure 2). European average AAE is about 438 eq ha^{-1} yr^{-1} (2000) and 264 eq ha^{-1} yr^{-1} (2019) (Figure 4).

---

[8] https://www.umweltbundesamt.de/en/call-for-data?parent=69334

[9] Reinds G.-J., Thomas D, Posch M, Slootweg J (2021) Critical loads for eutrophication and acidification for European terrestrial ecosystems. Final report. CCE, Dessau, Germany. Download: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-07-12_doku_03-2021-critical_load.pdf

[10] Note, that due to missing input data the previous background data (Hettelingh, J.-P. et al. 2017) was used for Cyprus and Malta. At the same time no national data for these countries is available

[11] AAE: area-weighted average of the exceedances of the Critical Loads of all ecosystems in the respective grid cell (eq ha^{-1}yr^{-1})

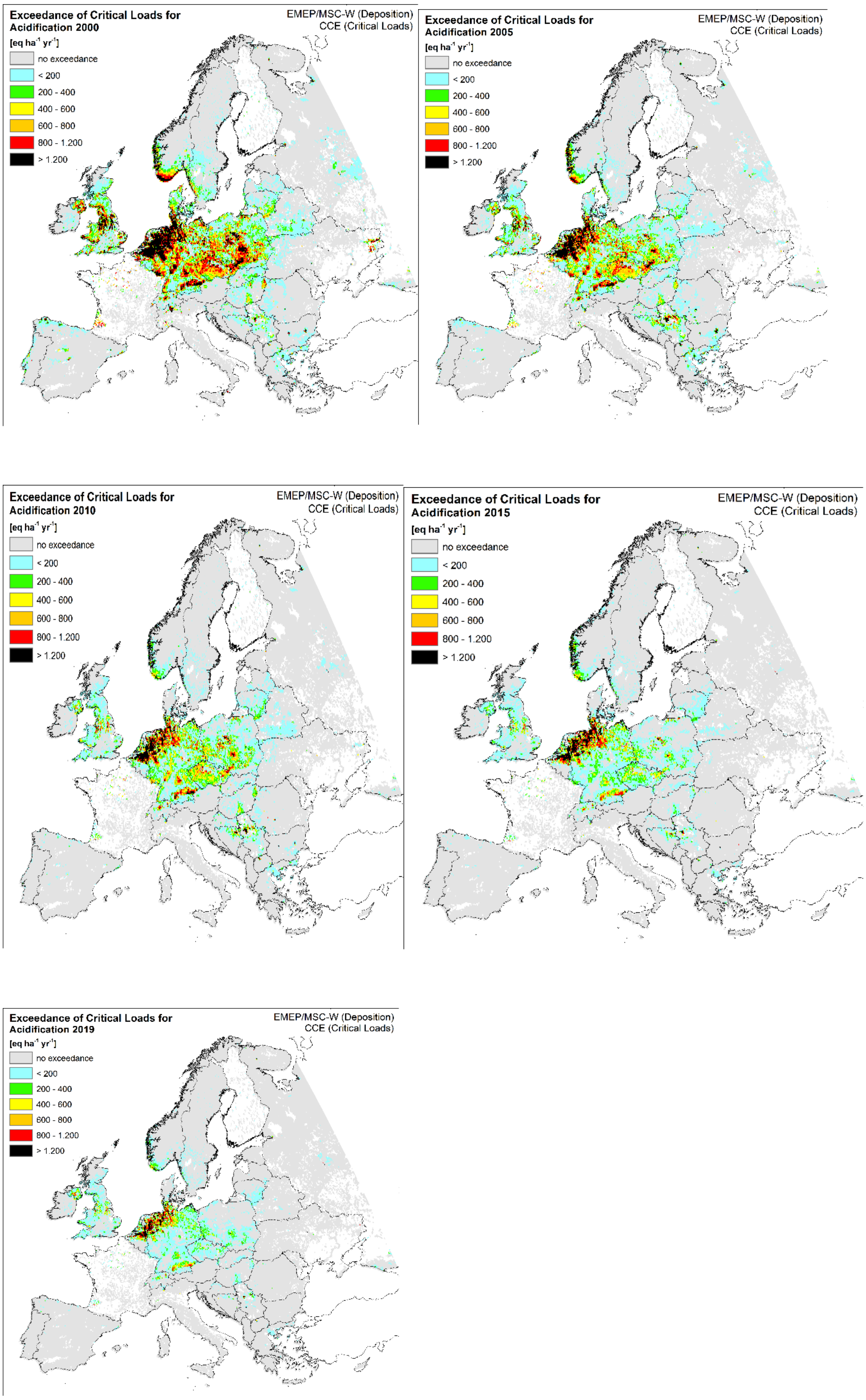


Figure 1: Critical Load Exceedance for Acidification for the years (2000, 2005, 2010, 2015 and 2019)

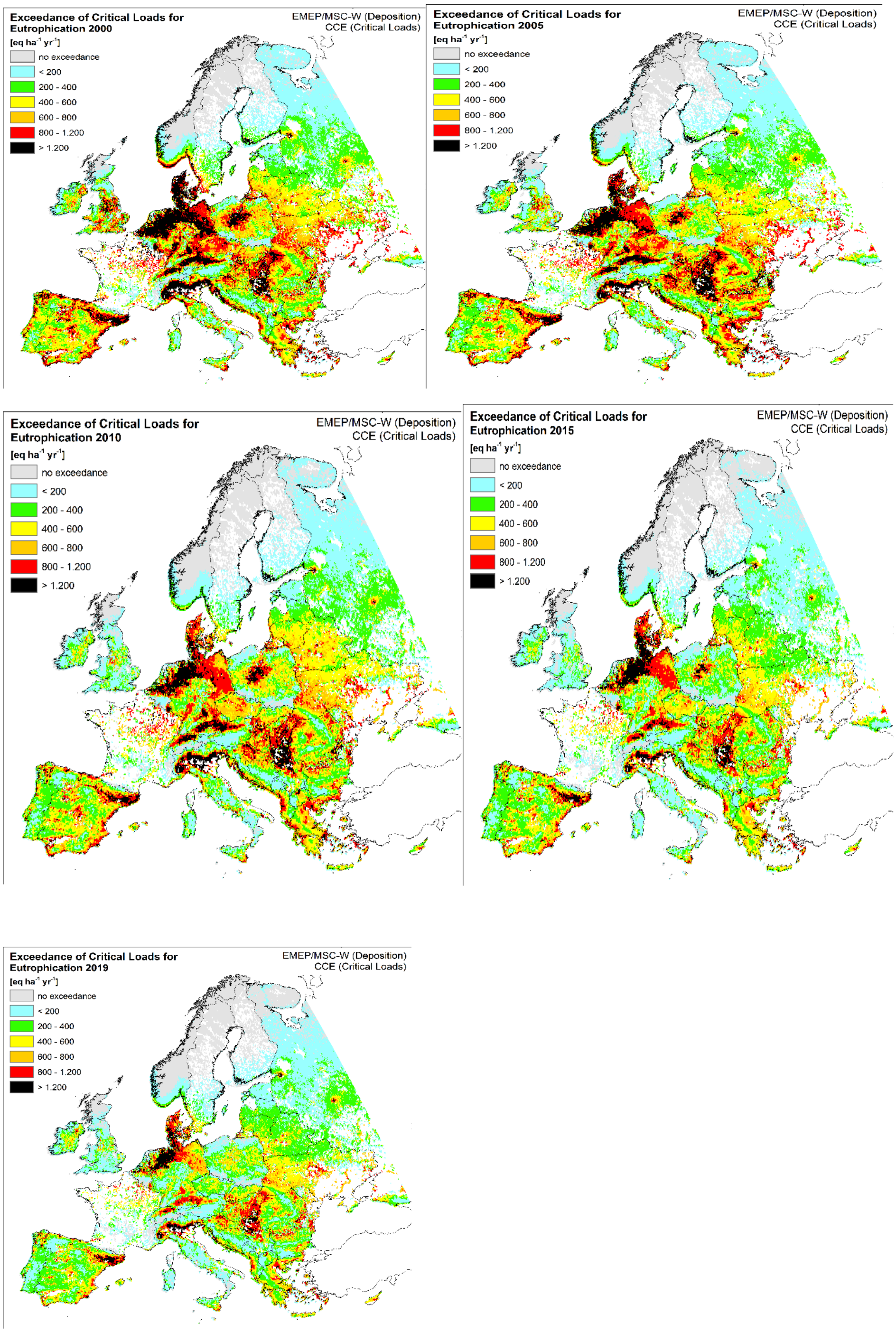


Figure 2: Critical Load Exceedance for Eutrophication for the years (2000, 2005, 2010, 2015 and 2019)

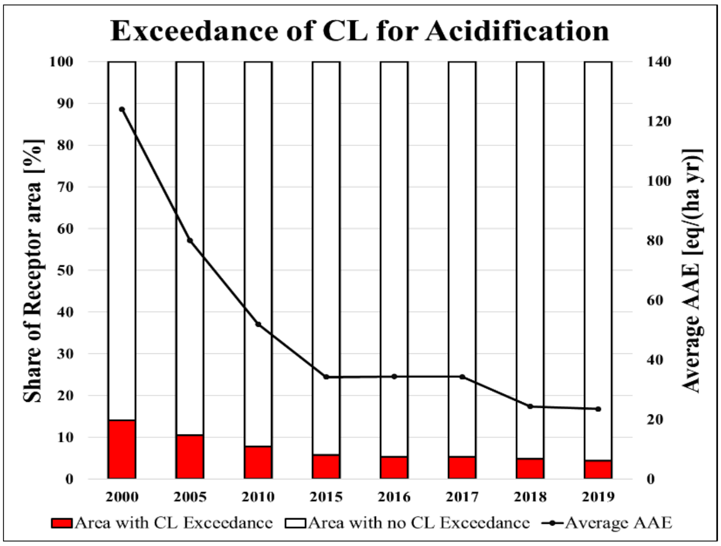


Figure 3: Overall statistics for exceedance of Critical Loads for acidification.

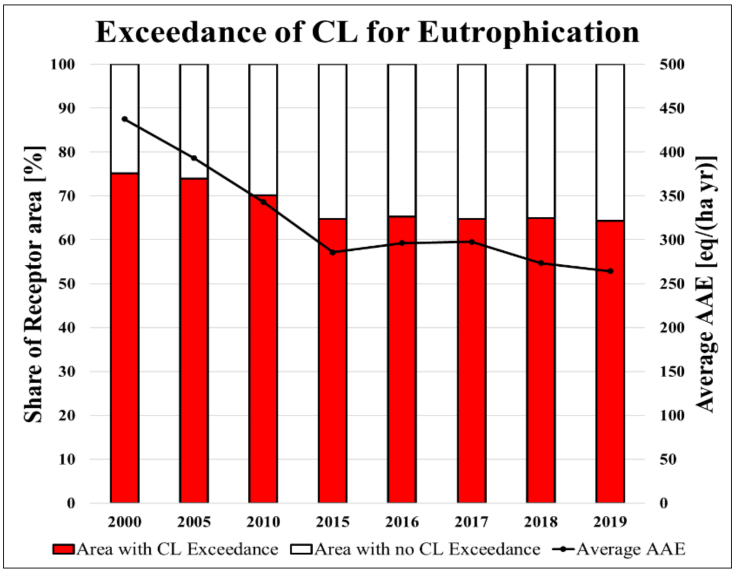


Figure 4: Overall statistics for exceedance of Critical Loads for eutrophication

28. For the analysis on how different Nitrogen species (oxidized and reduced) may affect the CL exceedance for eutrophication, and focused on year 2019, the areas with exceedance of these CL were evaluated in terms of the amount of total nitrogen deposition and the contribution of the different nitrogen species to the total deposition (Figure 5).

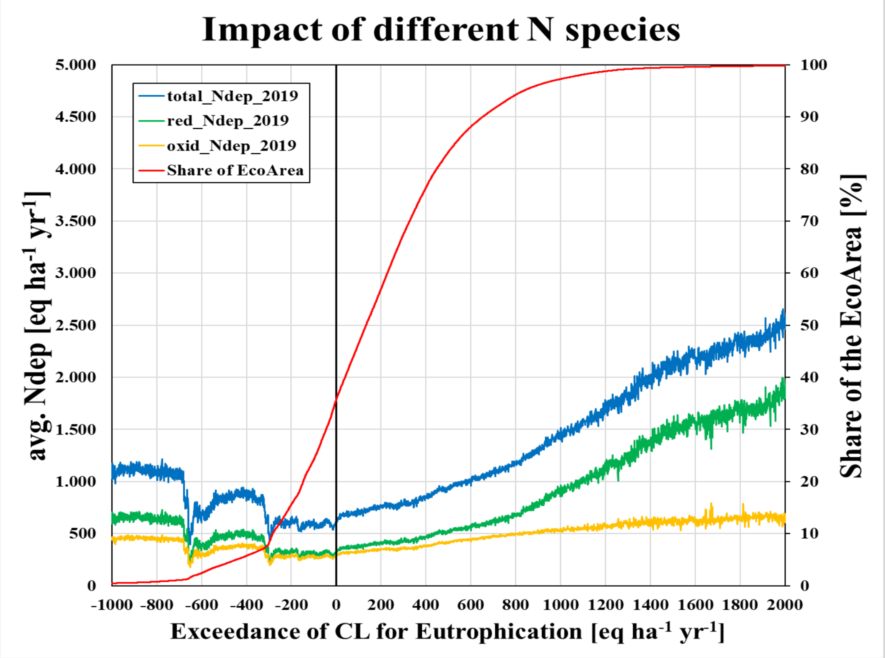


Figure 5: Exceedance of CL for Eutrophication (2019) and different species of Nitrogen deposition

29. The deposition of reduced nitrogen (green line) on CL relevant receptor areas is always higher than the deposition of oxidized nitrogen (yellow line). However also oxidized nitrogen at all areas at risk contributes to it in the order of 30 % to roughly 50 %. Therefore, in order to effectively reduce the sensitive areas affected by eutrophication, a combined reduction of oxidized and reduced nitrogen is required.

2.1, 2.2, 2.3(a), 2.6, 2.7 (EMEP-MSC-W[12], TFMM[13], WGE[14])

- ➔ See above for 2.1
- ➔ See attached file from the EMEP centers for 2.2 (marine ecosystems)
- ➔ 2.3 (ozone exposure) will be answered in fall 2021 with updated data based on work done for EMEP summer 2021 (updated EMEP emissions, updated model calculations, updated CLs, updated obs trends).
- ➔ See above for 2.6 and EMEP centers note
- ➔ See above for 2.7

6.3(c) (TFEIP, TFIAM)

- ➔ Trends in methane emission and their impact: will be documented in Spring 2022

---

[12] The Meteorological Synthesizing Centre-West.

[13] The Task Force on Measurements and Modelling.

[14] The Working Group on Effects.

1. The observed and projected trends in urban air quality. Contribution of long-range transport to air pollutant concentrations in cities. The distance to the WHO air quality guideline values

30. Observed trends in urban air quality (at traffic stations and urban background stations) can be derived from EMEP/CCC, TFMM, EEA, WMO and WHO (and US/CAN?) can probably be made available in spring 2021. Studies by CIAM and JRC indicate the main sources of urban air pollution. Declining trends in average exposure of the urban population are to a large part the result of national and European wide emission reductions. Concentrations at urban traffic sites decline due to the penetration of newer vehicles that apply stricter emission limit values. However due to traffic increase, high shares of old cars, other sources than transport and the contribution of non-urban sources in many cities current WHO air quality guideline values and even EU air quality limit values are not yet met. An indicative baseline projection could be made available by CIAM in *spring 2022* using the new source receptor matrix developed by MSC-W. The SHERPA PM2.5 atlas will be updated in autumn 2021. Studies for 12 pilot cities in Russia are under way under the Russian air quality programme with 12 pilot cities. See: https://rpn.gov.ru/activity/fresh-air/info/ in Russian

31. An important question is whether a local air quality approach could be a stimulating driver for additional air quality policy, both in countries that signed the protocol and countries that are not parties to the protocol. CIAM works jointly with MSC-W to extend the domain, update source-receptor relationships for all species and include PPM tracking (enabling fine scale 0.1-degree analysis) and updated downscaling by MSC-W (100-250m). *See also 4.3: formation of PM2.5 including condensables – MSC-W/CIAM spring 2022.* A Nordic Council of Ministers-project ends in Dec 2021 (TNO, NILU, SYKE, EMEP, IIASA) which delivers new emission factors, the impact of mitigation measures, and a review of spatial emission and concentration patterns. The updated analysis will include condensables.

2. The change in exceedance of critical loads between 1990 and 2018/2019 and projected changes up to 2030 and beyond

32. The Chemical Coordinating Centre (CCE) will perform exceedance calculation for critical loads for acidification and eutrophication in the perspective of the review process. Updated Critical Loads will be available by summer. Updates may comprise updated national submissions and critical loads calculated with the newly updated background database of CCE The calculation of exceedances will be based on deposition data provided by MSC-West, CEIP, MSC-West This work still needs to be coordinated for data timing specification and availability until September 2021. Its purpose is the comparison of exceedance calculation between years 2000 and 2019.

33. The temporal developments of the exceedance of the CLs at ICP IM sites indicated the more effective reductions of S deposition compared to N . The monitoring data confirm that emission abatement actions are having their intended effects on CL exceedances and ecosystem impacts. The results also provided evidence on the link between CL exceedances and empirical impacts, increasing confidence in the methodology used for the European-scale CL calculations.

3. The change in water, soil and ecosystem quality indicators between 1990 and 2018/2019 and projected changes up to 2030 and beyond

34. According to ICP monitoring data, Sulphate concentrations show more than 40% decline for the period 1990-2016. Changes were more prevalent in the 90s than after 2000, indicating smoother trends in recent years. The trajectories of sulphate, ANC and pH indicate that the recovery was slowing down in Europe and accelerating in North America since the early 2000s. (ICP Waters report 142/2020).

35. Monitoring data show that the pronounced increase in diversity at ICP-Waters sites with the most pronounced chemical recovery and the strong correlation between sulphate and/or ANC and diversity suggest that a reduction in acidifying components of the water has had a strong influence on species diversity of aquatic invertebrates. Year-to-year variation in temperature was negatively correlated with diversity, suggesting that temperature has a

secondary influence on diversity since the diversity is increasing, despite the negative correlation with temperature. Still, the effects from temperature suggest that these communities will be sensitive to long-term climate change. The strong correlation between acid components of the water and species diversity suggests that biodiversity will continue to increase when acid deposition decreases. The widespread response of aquatic diversity resulting from emission reductions of acidifying components to the atmosphere demonstrates the potential of international policy for achieving positive effects on the state of the environment.

36. Projected changes: Projections extended to 2030, require new projections for deposition from EMEP. this work could be done for chemical parameters by the summer, if the deposition data are available by then. No projections for biology

37. The ICP Forests long-term measurements show that there is a long-time lag between emission abatement and changes in soil solution acidity. Moreover, eutrophying or acidifying effects of inorganic N and S deposition led to imbalances in tree nutrition across Europe as briefly discussed in the following. In many parts of Europe positive tree growth were observed during the last decades. Among other things, the increased nitrogen deposition contributed to the observed tree growth stimulation. An increased tree growth will result in an increased nutrient demand and an excess of nitrogen due to air pollution may have an impact on the tree nutrient status. The analysis of foliar data collected at ICP Forests sites showed that due to the enhanced nitrogen deposition, there is a shift from nitrogen limitation to phosphorus limitation at many forests Europe. It is supposed that nutrient imbalances can affect the resilience of the European forests to a changing climate.

38. Results of the ICP IM monitoring network confirm the positive effects of the continuing emission reductions (Vuorenmaa et al. 2018; 2020, Forsius et al. 2020). ICP IM sites showed dominantly negative trend slopes of total inorganic nitrogen (TIN) in concentrations (95% of the sites; mean slope -1.08 μeq L−1 yr−1) and fluxes (91% of sites, mean slope -0.84 meq m−2 yr−1) of bulk/wet deposition between years 1990 and 2017, . Concentrations of TIN in runoff water for years 1990-2017 exhibited dominantly downward trend slopes (76% of sites, mean slope -0.48 μeq L−1 yr−1), and for fluxes 69% of the sites (mean slope -0.21 meq m−2 yr−1), respectively. Decrease of NO_3 and NH_4 in concentrations was significant at 59% (-0.36 μeq L−1 yr−1) and 36% (-0.05 μeq L−1 yr−1) of the sites, and but the decrease in fluxes was significant only at 25% (-0.18 meq m−2 yr−1) and 31% (-0.04 meq m−2 yr−1) of the sites, respectively. Decreasing trends for S and N emissions and deposition reduction responses in runoff water chemistry tended to be more gradual since the early 2000s.

39. Dynamic models are needed in order to assess the times scales of impacts and recovery from changes in air pollution emissions. Interaction with changes in climate variables is also of key importance. Decreases in N deposition under the CLE scenario will most likely be insufficient to allow recovery from eutrophication. Model predictions indicated that oligotrophic /favouring nutrient-poor conditions) forest understory plant species will further decrease. This result is partially due to confounding processes related to climate effects and to major decreases in S deposition and consequent recovery from soil acidification. Emissions reductions of oxidized and reduced N compounds need to be considerably greater to allow recovery from chronially high N deposition.

4. Observed and projected trend in ozone exposure of the population above critical levels

40. Information about the past and current population exposure to ozone is available from the European Environment Agency (summarised for example, in the Air quality in Europe - 2020 report). This information is available primarily for the EU-28, for population in areas exposed to ozone (O_3) concentrations in relation to the EU target value threshold and in reference to the WHO air quality guidelines (WHO AQGs). The estimates of the exposure of total European population (not only urban) in 2018 and changes over time are also available. To extract relevant information, interaction with the EEA will be needed. Recent analysis of ozone have shown that reductions in emissions have reduced the peak ozone concentrations but ozone concentrations have not really decreased in all the countries and rural areas show higher levels than urban areas. In mid-2021, new WHO AQGs are expected to be published,

including also new guideline values for ozone. Question will also be discussed within the TFH, including at the annual TFH meeting in early May 2021[15].

5. Monitoring and modelling system of the Convention

41. Ecosystem effects, which were the main reason for the establishment of the Convention, are to some extent reduced, but the acidification effects of historical emissions will remain for decades and the emissions of ammonia have so far only been reduced by 20–30% in Europe and even less in North America. Looking at health effects, it is difficult to talk about success, when hundreds of thousands of inhabitants on both continents are predicted to meet an earlier death due to air pollution. The research communities within air pollution and climate change need to work more closely together. Basic questions still need further investigations to develop the best policies. Such areas include: better understanding of health effects from air pollution, nitrogen effects to ecosystems, and air pollution interactions with climate through carbon storage in ecosystems and impacts on radiation balances.

42. A combination of long-term monitoring and research is needed to document and understand complex interactions of air pollutants, climate change and other disturbances. Disturbance interactions can have unpredictable and surprising consequences which are as yet insufficiently studied. There is a need to extend the current ecosystem monitoring system to include more sites representing other sensitive habitats such as heathlands, grasslands and wetlands. The “IM light” initiative of ICP IM is an important process in this respect.

43. Increased cooperation with developing research infrastructures under the EU, such as eLTER, ICOS and ACTRIS would provide possibilities to extend the site networks and increase scientific competence. Coordination with ecosystem monitoring efforts of the EU National Emission Ceilings Directive (NEC) would provide similar benefits.

44. Regarding health effects, the monitoring and modelling system has really improved along the years. Some efforts are needed to integrate the knowledge on transboundary air pollution and local sources. Source apportionment studies to detail the contribution of each sector are welcome in their diffusion and refinement because they can indicate solutions that can have relevant health impacts.

45. Regarding modelling of the impact of air pollution on biodiversity, the challenges with the existing monitoring are representativity of non-forest ecosystem and availability of data on biodiversity. Expansion of the ICP IM system to include more types of ecosystems should be followed by other initiatives in the same direction. For data on biodiversity, the modelling work relies heavily on national data and national modelling expertise. The newly established CDM must continue efforts to bring the outcomes of the national efforts together and, to some extent, make use of these in the work of the Convention.

46. At present stage, the ICP Materials network in sufficient to observe and assess air pollution and its effects related to the Gothenburg Protocol in the ECE region. However, regarding projections of air pollution and its effects there are currently no system in place and projections are made when asked for and relies on input data to dose-response functions from other sources.

47. There is currently very little recording of ozone impacts in the ECE region. s. Within ICP Vegetation there is an opportunity to record visible leaf-damage on crops and semi-natural vegetation. However, in reality very little data is collated. This is partly because visible leaf-damage is becoming more rare in the ECE region due to the reduction in episodic peaks of ozone, and it is the peaks that cause the most visible leaf-damage . Based on current scientific knowledge of cumulative fluxes of ozone (including from low ozone concentrations) affecting growth and flowering of crops, trees and ecosystems, a more suitable observation and assessment method for the impacts could be the use of filtered-air chambers, to filter out ambient ozone pollution over a small area to show the yield/growth

---

[15] https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report: In 2018, about 34 % of the EU-28 population in urban

benefits of cleaned air compared to ambient air. However, the cost of these facilities is very expensive and this is only currently carried out at very few institutions as part of their ongoing experiments.

48. Accurate modelling ozone impacts to vegetation requires parameterisation of the dose-response relationship for each individual species, and there are many species (both crop, tree and semi-natural vegetation) for which such information does not currently exist, even for some of the common and commercially important species This is currently limited by the availability of experimental data to parameterise both the stomatal uptake component and the yield-response component.

49. Water chemical monitoring of surface waters for air pollution responses is well-developed, but in some countries the monitoring is under threat from reductions in funding. The planned monitoring under NECD can help to sustain water chemical monitoring but monitoring of biological recovery is in many countries not very well supported, and it has not been defined as a priority under other monitoring frameworks such as the NECD. Biological monitoring should preferably be done at the same sites as where water chemical monitoring is done. In addition, Climate change might lead to more variation in surface water chemistry, and it is important to maintain sufficient sampling frequency and long-term monitoring programmes.

6. Projected future trend in methane emissions and subsequent improvements in air quality, human health effects and ecosystems impacts

50. In addition to the response by HTAP on question 3.3: Global emission scenarios for methane, NOx, NMVOC, and CO are available in the ECLIPSE-emission scenario datasets developed with the GAINS model (CIAM). They show the policy envelope between current legislation and maximum feasible reduction. These scenarios can be used to calculate the future trend in (European) background levels of ozone with models, such as the global EMEP-model and other models used by HTAP. These trends should be added to contributions from national emissions to ozone levels in European countries. The results of EMEP and/or GAINS calculations can be used to estimate trends in accumulated exceedances over ozone threshold values, and in premature mortality or expected crop damage.

E. Measured and modelled effects on natural ecosystems, materials and crops and assessment of human health effects

51. The main ozone metric recommended by ICP vegetation is now the phyto-toxic ozone dose over threshold Y (PODY). For EMEP and integrated assessment modelling purposes, two key metrics are the 3-monthly POD3-IAM-CR being used for crops and POD1-IAM-DF for deciduous forests. Model results suggest that POD1-IAM-DF has declined over the period 2000-2016 by ca. 0.7%/yr at EMEP's ozone stations, though again site-to-site variability is large, and the high O3 summers of 2003 and 2006 may account for some of this trend. For POD3-IAM-CR declines are also simulated, but trends are non-significant for the majority of sites. Two major difficulties with this type of metric though is that (a) we cannot compare with observations, and (b) the POD calculations are very sensitive to meteorology. Over the next months, MSC-W will explore the impact of the meteorological factors on the modelled POD trends. **NOTE: trend numbers are preliminary, and will likely be revised by Fall 2021**

52. The AOT40 index as used in earlier assessments is less biologically meaningful than POD, but has the advantage that we can compare modelled and measured values across the EMEP network. Mills et al. (2018) estimated the trends in 3-months and 6-months AOT40 over the period 1995-2014. They found a clearer signal of reduced levels in the 6-months AOT40 compared to 3-months AOT40 in Europe. For the latter, only 10 % of the sites showed significant decreases ($p<0.05$). Chang et al. (2017) calculated a statistically significant downward trend in the 6-months AOT40 over the period 2000-2014 for both rural and urban European sites. For the rural sites they estimated reductions in 6-months AOT40 of ca. 300-400 ppb.h/yr and less for urban sites. **Note: Based on trend calculations for the period 2005-2019, we will provide more detailed info on ozone statistics in September**.

53. **Contribution of the condensable in the PM population exposure** cannot be assessed before next year (2022). Indeed, at present the emission data reported by the countries includes condensables for some countries (& some sectors), and for some not/partly. Therefore, it is at present not possible to quantify in a consistent way across the countries the effect of condensables. Ongoing work within EMEP, CAMS, and a new project financed by Nordic Council of Ministers (led by MSC-W, with CIAM as partner) should be (partly) able to give an answer to this by spring 2022, and is expected to result in better consistency of emissions for use in EMEP modelling.

1. Observed and projected trends in vegetation risk of damage due to ozone

54. The model runs to answer this question will be completed over the coming months. ICP Vegetation are waiting for the EMEP scenario data to be finalised and distributed. This also needs the model to be run for 1990 and 2018/19 (in addition to 2030) to ensure internal consistency with the predictions of impacts. Parameterisations, dose-response relationships and critical levels for ozone are all up to date (last update of Critical Levels was 2017), meaning that no additional work is needed on this part. This question will be answered for crops, trees and semi-natural vegetation. The analysis will calculate a) impacts and b) exceedance of critical levels. Although exceedance of critical levels based on AOT40 can be calculated, the analysis will focus on critical levels based on ozone fluxes (POD) as this reflects the most recent scientific advances and knowledge. The analysis will provide a) maps and b) tables of extracted data per country.)

55. A preliminary estimate of the results shown following this analysis would be that there is a large difference in predictions depending on which metrics are used. Likely there appears to be a large reduction in effect of ozone on all vegetation types if analysis is based on AOT40 and a concentration-based analysis. Likely there would be a moderate reduction in effect of ozone on all vegetation types if analysis is based on M7 (there are no current critical levels for vegetation based on M7). Likely there would be little or no change in effect of ozone on all vegetation types since 1990 if analysis is based on ozone fluxes (POD). These changes between scenarios and differences in the extent of change between the different metrics are because the ozone profile has changed since 1990. The 'peak' concentrations have reduced, whereas the 'background' concentrations have increased. Concentration-based metrics, particularly AOT40, put greatest emphasis on peak concentrations. Scientific evidence has shown that vegetation responds to cumulative ozone uptake, reflected in the flux-based (POD) metrics, and that the response is the same when this is delivered as an 'elevated backgound' or 'episodic peak' profile[16] . Evidence has shown that impacts of ozone are observed when low to moderate ozone concentrations coincide with meteorological conditions favouring ozone uptake, whereas the concentration-based metrics do not reflect this newer evidence. This means that ozone impacts on vegetation can be found where the critical level for AOT40 is not exceeded [17] . For semi-natural vegetation, together with accurate modelling of impacts, the difference in sensitivity to ozone means that there could be changes in relative species abundance and possible impacts on biodiversity[18].

56. Although the analysis is not yet complete, an estimate based on current knowledge is that the Gothenburg Protocol will not have eliminated the negative impacts of ozone on vegetation, even by 2030. Based on current knowledge, ozone pollution is calculated to have reduced wheat grain yield by a mean of 9.9% in the northern hemisphere in 2010-2012[19]. Projections show that ozone risks to biodiversity will still occur by 2050, as ozone exposure will remain similar using RCP4.5 compared to that experienced in 2000[20]. Similarly, projections show that there will still be a significant effect of ozone on the biomass increment of trees.

---

[16] Harmens et al., 2018 doi.org/10.1016/J.ATMOSENV.2017.10.059

[17] Mills et al., 2011 doi.org/10.1111/J.1365-2486.2010.02217.X

[18] van Goethem et al., 2013 DOI: 10.1016/j.envpol.2013.02.023; Hayes et al., 2007 doi.org/10.1016/J.ENVPOL.2006.06.011; Hayes et al., 2009 DOI: 10.1016/j.envpol.2008.07.002

[19] Mills et al., 2018 doi.org/10.1111/GCB.14157

[20] Fuhrer et al., 2016 doi.org/10.1002/ECE3.2568

57. Despite a slight but significant reduction of ozone levels during the vegetative period, large-scale studies conducted at the ICP Forests plots revealed that the concentration-based Critical Levels (AOT40) have been exceeded on the majority of the investigated sites, especially in East and Southern Europe. On these sites, foliar injury attributable to ozone has been detected on several species, mostly broadleaves. No consistent ozone effect has been detected on growth and defoliation at the ICP Forests sites, regardless the ozone metric adopted. We do expect that interaction with climate change and biotic agents (pests and disease) may substantially alter the above results: this will be however dependent on site-specific condition.

2. Observed and projected trend in life years lost due to exposure to ozone, particulate matter and nitrogen dioxide

58. For particulate matter (PM2.5), mortality (premature deaths) estimates are available based on the WHO ambient air quality database; the most recent estimates are available based on 2016 data and they include DALYs estimation. There has been a trend of reduced attributable deaths driven by air pollutants decrease, but there is still peaks in some cities, for example for NO2 in areas close to traffic. New estimates will be generated later this year, as part of the SDG reporting (indicator on mortality due to air pollution). The estimates of premature mortality and years of life lost are available from the reports of the European Environment Agency. The demographic data and life expectancy data are from Eurostat and the mortality data from WHO; the exposure-response relationship and the population at risk follow recommendations from the Health Risks of Air Pollution in Europe (HRAPIE) project.

3. Observed and projected trends for other health metrics

59. With regard to other health metrics, such as morbidity, a new project has been initiated on the estimation of morbidity from air pollution and its economic costs (EMAPEC). The project is to deliver a method to estimate costs of morbidity from air pollution (for locations with the available appropriate health statistics) and morbidity-related concentration-response functions. The results are expected in 2022. The Second Clean Air Outlook includes projected trends of morbidity, with data from CIAM. Follow up action is needed to check feasibility of getting access to scenarios. This work needs to be coordinated by several TFs.

60. From the (past and future) trends in average national/urban population exposure to PM2.5 and ozone, developments of premature mortality and life years lost can be estimated by CIAM and EEA. Estimates for the non-Parties, e.g. Balkan, EECCA are likely available only early 2022; additionally the updated source-receptor relations which CIAM/MSC-W develops will be also available only February 2022 (MSC-W, completes by the end of the year 2021 and then CIAM needs time for processing and implementation – based on the discussion with MSC-W). It is expected that TFH gives additional guidance on updated relative risks and the counterfactual values to be used in modelling. Provided that an updated WHO-HRAPIE-document will become available in time (*spring 2022*) that would give guidance on the calculation method of morbidity impacts (such as asthma and sickness leave) and the health impacts of NO2-exposure (*fall 2022*). Alternatively, estimates could be based on methods used by EMRC for the Clean Air Outlook of the EU https://ec.europa.eu/environment/air/pdf/CAO2-MAIN-final-21Dec20.pdf. *See also 4.3; inclusion of condensables in PM2.5 exposure, and 6.3c influence of methane trends.*

4. Observed and projected trend in damage to materials and cultural heritage due to air pollution above threshold levels

61. When looking at observed trends, corrosion and pollution have decreased significantly since the early 1990s and a shift in the magnitude was generally observed around 1997 from a sharp decrease to a more modest decrease or to a constant level without any decrease[21]. SO_2 levels, carbon steel and copper corrosion have decreased even after 1997, which is more pronounced in urban areas, while corrosion of the other materials shows no decrease after 1997, when looking at one-year values. When looking at four-year values, however, there is a significant decrease after 1997 for zinc, which is not evident when looking at the one-year

---

[21] Tidblad et al, Materials 2017, 10, 969; doi:10.3390/ma10080969

values. There are still occurrences of corrosion values above acceptable levels at some places in Europe. For soiling, there is no decreasing trend after 1997 and consequently larger areas in Europe are above acceptable levels, so therefore the focus of future development of the programme is on exposure of new soiling materials, for example coil coated materials and stone materials. The main pollutant responsible for soiling of materials is particulate matter. For projected trends, it is possible to make an analysis based on existing dose-response functions using pollution and climate data for different scenarios. However, this information is not available at present and need to be collected for all ICPs together based on pending decisions from the working group on strategies and review and the executive body.

5. Expected impacts of new scientific findings on environmental and health effects assessments

62. The main input related to the new scientific evidence will be the publication of the new WHO global air quality guidelines, which will contain a set of updated guideline values for PM, NO2, SO2, ozone and CO. Publication of the new WHO guidelines is expected in mid-2021. Another input would be a technical report on the health effects of PAHs.

63. Main new findings regarding modelling and mapping issues are:

- N empirical Critical Loads (CLempN): The work to update CLempN is currently under progress. It will be finalised in 2022 only, but a final scientific workshop will be hold in October 2021 already. First results of this process can therefore be included in the GP report version due in February 2022.
- By providing scenario assessments of the expected state of ecosystems in the future, Dynamic Modelling complements the critical loads calculations. In the context of the GP review, Dynamic Modelling could provide outputs as what the state of ecosystems will be so that the policy will reflect not only if the air pollution is not causing further damage (non-exceedance of critical loads) but also what the state of ecosystems in any given year is expected to be. Dynamic Modelling has the potential to provide a picture of such relevant and easy to understand factors as e.g. quality of surface waters, tree health, ozone damage to crops or biodiversity in a given future year. Given that delivering such information has been so far rather underexplored in the political process, a dialogue between the GP review group and ICP M&M would be beneficial for designing how the CDM could help in the review process.

64. The focus of the new development of the program is on soiling effects on different materials. The reason is the strong link to particulate matter concentrations, where there has been no significant decreasing in soiling in the recent years. New materials assessing effects on soiling has been included in the program, for example coil coated materials and stone materials and this will result in new data on the effect of particulate matter on materials and cultural heritage.

65. The ICP Vegetation will provide a summary text with the impact of new scientific findings relevant to ozone impacts on crops and ecosystems, including the interactions with climate change and nitrogen. A brief summary of the main points (to be further updated) is included below. There are potential interactive effects between ozone pollution and nitrogen. Ozone pollution can reduce the nitrogen use efficiency of some crops e.g. wheat, soybean and rice[22] . As a result of lower nitrogen fertilization efficiency, ozone causes a risk of increased losses of nitrogen from agroecosystems, e.g. through nitrate leaching and nitrous oxide emissions. Tropospheric ozone thus has the potential to cause elevated nitrogen in streams and rivers compared to clean air conditions, but the potential magnitude of this has not been quantified. A similar pattern can be seen for semi-natural vegetation, as the stimulating effect of nitrogen on growth can be progressively lost with increasing ozone concentrations . For crops, it has only been possible to investigate changes in ozone sensitivity at different nitrogen application rates for wheat, as there is insufficient data for other crops. A comprehensive meta-analysis of the available wheat data showed that there was no significant relationship between ozone sensitivity and nitrogen application rate,

---

[22] Pleijel et al., SBD-B chapter 11, Broberg et al., 2017 DOI: 10.1016/j.scitotenv.2017.07.069) (Mills et al., 2016 doi.org/10.1016/J.ENVPOL.2015.09.038)

indicating that there is no requirement to adjust critical levels for ozone for crops according to nitrogen load (Pleijel et al., SBD-B chapter 11).

66. The relationship between ozone sensitivity and nitrogen application rate is less consistent for semi-natural vegetation. However, this heterogeneous response means that there can be changes in species composition of semi-natural vegetation communities with elevated ozone and additional nitrogen deposition co-occur . In addition, as elevated nitrogen deposition can alter species composition (notably of grasslands), this can in turn influence the ozone-sensitivity of the community, with studies suggestion that vegetation communities in pristine environments with low nitrogen deposition are most sensitive to tropospheric ozone . Current critical levels for ozone do not currently take account of the local nitrogen deposition rate.

67. There are also interactions between ozone pollution and climate change. Some interactions alter the exposure of vegetation to ozone, such as accelerated phenological development with increasing temperature resulting in bud-break earlier in the year and consequent exposure of the plant to ozone earlier in spring than current models predict[23] . Changes in meteorological conditions and soil moisture due to climate change will alter ozone fluxes to vegetation via influence on stomatal opening, however, the direction and extent of change will depend on the difference between perceived conditions and optimum conditions for each meteorological and soil moisture parameter . In addition to interactions between ozone and climate that affect exposure to ozone and fluxes of ozone, there can be additional 'non stomatal' physiological interactions affecting plant physiology with consequences that can include alterations in crop yield. Such interactions that do not involve ozone fluxes are not currently accounted for in existing models used within the Convention.

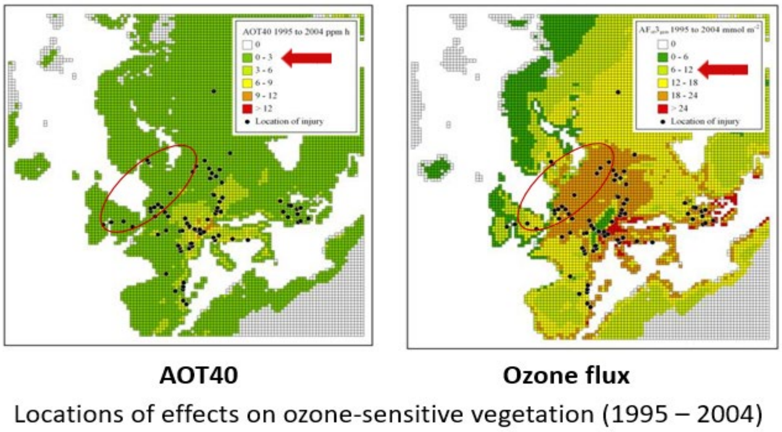


Figure B: Risk maps based on the AOT40 metric do not give a good prediction of the location of ozone impacts on crops and ecosystems, whereas risk maps based on the POD (ozone flux) metric are better at predicting the locations of ozone impacts.

68. ICP waters is currently working on effects of N deposition on surface water biology. Other topics will be discussed at the Task Force meeting (among which interactions of climate, land cover and N deposition on surface waters). ICP Waters will be able to deliver some more inputs before the summer.

69. ICP IM studies have shown that a systems approach is useful in addressing the question of future integrated impacts of climate and air pollution on ecosystem processes and biodiversity responses Simulated future soil conditions improved under projected decrease in deposition and current climate conditions: When climate change projections were included

---

[23] Calvete-Sogo et al., 2016 DOI: 10.1007/s00442-016-3628-z)
(Hayes et al., 2019 doi.org/10.1016/J.ENVPOL.2019.07.088)
Menzel et al., 2006 doi: 10.1111/j.1365-2486.2006.01193.x; SBD-B chapters 6-8)
(Hayes et al., 2019 doi.org/10.1007/S11270-018-4057-X)

pH increased in most cases, while BS and C:N increased in about half of the cases. Hardly any climate warming scenarios led to decrease in pH. Modelling results also indicated that decreases in N deposition under the CLE current legislation scenario will most likely be insufficient to allow recovery of forest understory vegetation from eutrophication. Oxidized and reduced N emission reductions would need to be considerably greater to allow recovery from chronically high N deposition (Dirnböck et al. 2018).These studies illustrate the value of long-term integrated monitoring sites for applying models that can predict soil, vegetation and species responses to multiple environmental changes.

70. The target load concept is an extension of the critical load concept of air pollution inputs to ecosystems (Posch et al. 2019). The advantage of target loads over critical loads is that one can define the deposition and the point in time (target year) when the critical (chemical) limit is no longer violated. This information on the timing of recovery requires dynamic modeling. Target loads on a large regional scale can inform effects-based emission reduction policies. The assessment of Posch et al. (2019) suggested that reductions beyond the Gothenburg Protocol are required to ensure surface water recovery from acidification by 2050.

71. In a recent study by ICP IM, Weldon and Grandin (2021) showed that epiphytic lichens which are known to be good indicators of air quality, are of limited indicative ability of recovery after large scale disturbances such as air pollution. In a twenty-year time series of the epiphytic lichen community in a forested IM catchment (mainly Norway spruce, Picea abies), only very limited recovery was detected despite a drastic decrease in sulphur deposition, from high to low levels. This has implications for the use of epiphytic lichens as indicators of improved air quality. However, we argue that monitoring of epiphytic lichens should continue as they still are good and rapid indictors of decreasing air quality.

72. An Ad-hoc Marine Group (AMG), led by Germany, was established in order to investigate options to answer the question 2.8 concerning inclusion of marine ecosystem protection. The ad-hoc group will present the issue in a presentation at the 14th Meeting of the HELDOM Working Group PRESSURE, 13 - 16 April 2021, seeking to establish a first contact." ["A concept and time schedule, which contribution can be delivered to which point in time in order to answer the question can only be provided after this first meeting with HELCOM experts."]

F. Emission reduction commitments for Parties

Assessment of the 2020 emission reduction commitments, particularly considering revised information on calculated and internationally optimized allocations of emission reductions for Parties within the geographical scope of EMEP, which use integrated assessment modelling (GAINS[2]*), including atmospheric transport models. Integrated assessment modelling is based on reducing the effects of air pollution through cost-effective optimization. Parties not covered within the scope of the GAINS modelling may also wish to provide further information to this section, as appropriate. This chapter should provide an answer on the status and barriers of meeting the 2020 emission reduction commitments in annex II to the amended Gothenburg Protocol and to whether these emission reduction commitments are adequate or not.*

Annex I Question(s) I to the preparatory document (ECE/EB.AIR/2020/3−ECE/EB.AIR/WG.5/2020/3)

- *Question 1.1 What is the status of meeting the 2020 emission reduction obligations by the Parties?*
- *Question 1.3 How do updated and most recently reported emission estimates for the base year 2005 compare to the 2005 estimates listed in tables 2–6 of annex II to the amended Protocol? For which pollutants and categories have Parties submitted an adjustment application between 2014 and 2020? What are the relative differences between reported totals and adjusted totals for these pollutants and categories for the historic years between 2010 and now?*
- *Question 1.5(e) What barriers have been identified by the Parties to meet the 2020 emission reduction obligations?*
- *Question 4.4 What will be the impact of the inclusion of condensables in reporting of particulate matter emissions for residential heating on the national emission trends and on the importance of the residential heating sector? What will be the effect of the inclusion of particles from condensables on the effectivity of abatement measures? What particulate matter emission reductions will be achieved between 2005 and latest reported year based on the inclusion of condensables in reporting of particulate matter emissions compared to its non-inclusion? What is the difference between optimized emission reduction allocations with and without particles from condensables?*

- *Question 6.5 What are the policy implications of including particles formed from condensable compounds in particulate matter -reporting? Implications include ability to report and compliance?*

Key documentation

- *TFIAM - Report meetings: https://iiasa.ac.at/web/home/research/researchPrograms/air/policy/past_meetings.html*
- *CEIP - review of adjustments: https://www.ceip.at/gothenburg-protocol/review-of-adjustments*
- *EEA - briefing: National Emission reduction Commitments Directive reporting status (2020): https://www.eea.europa.eu/publications/national-emission-reduction-commitments-directive*
- *EU - The second clean air outlook report (2021): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A3%3AFIN*
- *EU - Report on the progress made on the implementation of the NEC Directive (2020): https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593765728744&uri=CELEX:52020DC0266*
- *EU - National Air Pollution Control Programmes from EU MS (NEC Directive): https://ec.europa.eu/environment/air/reduction/NAPCP.htm*

Contribution: status as at 20 August 2021

1 Status of meeting the 2020 emission reduction commitments

73. Tables 2-6 of Annex II to the amended Gothenburg Protocol set out the emission reduction commitments for SO_2, NO_X, NH_3, VOCs and $PM_{2.5}$ for 2020 and beyond, expressed as percentage reductions from the 2005 emission levels. 34 Parties are currently listed in tables 2-6 (27 EU Member States, EU, the UK, Canada, the US, Norway, Switzerland and Belarus), of which 24 have already ratified the amended Gothenburg Protocol (status as at 20 August 2021). Belarus and 9 EU Member States are still in the process of ratification and may soon join, as possibly will other Parties, at which time emission reduction commitments for these Parties will be proposed and adopted in accordance with the procedures of Article 13 of the amended protocol. EU Member States are also bound by the 2020 emission reduction commitments under the EU NEC Directive.

74. The table below provides an overview of the current status of meeting the 2020 emission reduction commitments of the amended Gothenburg Protocol based on a comparison with the last reported emissions (2019) and 2020-2030 projections by Parties (reporting year 2021).

Party	Year of atificatio	SO_2			NO_X [a]			NH_3			VOC			$PM_{2.5}$		
		EM 2019	PROJ 2030	ERC 2020	EM 2019	PROJ 2030	ERC 2020	EM 2019	PROJ 2030	ERC 2020	EM 2019	PROJ 2030	ERC 2020	EM 2019	PROJ 2030	ERC 2020
		% emission reductions versus 2005 emission levels (green shading = meeting or overachieving ERC; yellow shading = not meeting ERC)														
Austria		58	49	26	43	69	37	-6	-19	1	31	29	21	38	46	20
Belgium		79	81	43	53	67	41	15	20	2	38	37	21	47	55	20
Bulgaria	2018	90	92	78	54	57	41	13	6	3	21	29	21	1	13	20
Croatia	2019	86	84	55	42	52	31	21	20	1	34	45	34	35	40	18
Cyprus	2019	58	97	83	39	59	44	31	32	10	42	56	45	51	70	46
Czech Republic	2017	62	72	45	44	61	35	15	8	7	20	38	18	18	54	17
Denmark	2019	60	63	35	57	73	56	16	17	24	33	23	35	40	42	33
Estonia	2019	75	78	32	44	47	18	-5	-9	1	29	32	10	55	56	15
Finland	2017	58	65	30	44	63	35	17	27	20	42	52	35	36	50	30
France		78	78	55	50	66	50	5	6	4	40	67	43	51	56	27
Germany	2017	45	60	21	33	62	39	3	16	5	25	25	13	33	41	26
Greece		86	94	74	50	65	31	15	10	7	57	63	54	46	60	35
Hungary		60	72	46	43	57	34	1	-2	10	31	33	30	5	12	13
Ireland		85	88	65	53	66	49	-5	-3	1	6	6	25	38	44	18
Italy		74	79	35	53	64	40	15	11	5	33	43	35	20	30	10
Latvia	2019	58	66	8	31	43	32	-22	-23	1	25	30	27	29	44	16
Lithuania	2019	58	62	55	22	33	48	7	8	10	18	26	32	37	42	20
Luxembourg	2019	62	71	34	67	84	43	0	-12	1	25	30	29	53	3	15
Malta	2021	99	98	77	45	48	42	29	27	4	5	33	23	47	51	25
Netherlands	2017	66	65	28	45	63	45	19	20	13	11	47	8	46	62	37
Poland		62	60	59	25	33	30	6	3	1	16	14	25	21	35	16
Portugal	2018	77	80	63	47	68	36	9	41	7	18	25	18	25	44	15
Romania	2018	84	86	77	38	42	45	17	61	13	29	24	25	7	12	28

Slovakia	2017	82	82	57	46	59	36	3	-3	15	34	43	18	51	62	36
Slovenia		89	91	63	48	65	39	11	8	1	35	45	23	35	62	25
Spain	2017	88	91	67	55	57	41	2	6	3	23	25	22	8	30	15
Sweden	2015	55	61	22	36	57	36	8	16	15	34	42	25	44	53	19
EU—27	2017	76	79	59	45	59	42	8	12	6	29	38	28	29	40	22
Belarus		44	NR	20	-4	NR	25	2	NR	7	53	NR	15	23	NR	10
Canada [b]	2017	66	68	55	29	34	35	NA	NA	NA	27	20	20	29	NE	25
Norway	2019	30	37	10	31	56	23	6	-9	8	39	48	40	37	46	30
Switzerland	2019	68	69	21	34	55	41	9	6	8	30	28	30	42	45	26
UK	2019	79	81	59	53	69	55	3	-1	8	32	37	32	17	23	30
US [b]	2017	86	NR	82	58	NR	53	NA	NA	NA	29	NR	22	17	NR	27

EM 2019 = *reported annual emission data for the year 2019 (reporting year 2021)*

PROJ 2030 = *reported WM (With Measures) emission projections for the year 2030; the reporting year is 2021, except for Austria (2019), France (2019), Ireland (2020), Portugal (2017) and Romania (2019)*

ERC 2020 = *emission reduction commitments as listed in tables 2-6 of Annex II to the 2012 amended Gothenburg Protocol.*

[a] *NO_X emissions from soils (NFR 3D category) are not included in the emission and projections totals of the EU Member States and the UK and not accounted for the purpose of complying with the GP 2020 emissions reduction commitments.*

[b] *indicative targets; the $PM_{2.5}$ target excludes open-source emissions from road dust (NFR 6A), construction operations (NFR 2A5b) and crop production (NFR 3Db-e)*

[c] *indicative targets for PEMA*

75. Key findings and conclusions

- The collective efforts of all 34 Parties have resulted in combined emission reductions between 2005 and 2019 that already exceed the combined emission reductions envisaged by the Parties' emission reduction commitments for 2020, except for $PM_{2.5}$. However, at the level of individual Parties there is a significant difference in the progress made towards meeting the emission reduction commitments.
- The majority of the 34 Parties did not yet meet their 2020 emission reduction commitments for one or more pollutants in 2019. Most recently reported emission projections based on current legislation (WM projections) for the period 2020-2030 show that in 2030, 15 out of 34 Parties will still not meet their 2020 emission reduction commitments for one or more pollutants, in particular for NH_3. Due to reductions in economic activity in 2020 related to the COVID-19 pandemic, emissions reported in 2022 for the year 2020 are likely to be much lower and show more progress in meeting reduction commitments than would be expected on the basis of reported emissions for 2019 and projections for 2020-2030, but these lower emissions should not be considered as representative of real or systematic progress to date. Normalisation may take a few years. The transport sector is/was one of the activities strongly affected by the lockdowns, resulting in reduced NO_X emissions from this activity.
- Additional policies and measures will be required for NH_3 and, to a lesser extent, VOC, NO_X and $PM_{2.5}$ in order for Parties to make faster progress towards meeting all their emission reduction commitments in 2020 and beyond. According to the latest reported WM projections, emission levels corresponding to the 2020 relative targets for NH_3, VOC, NO_X and $PM_{2.5}$ will still be exceeded in 2030 by up to 30% for several Parties.
- No Party but one will have a problem meeting its 2020 emission reduction commitment for SO_2 on time. For that Party, its national SO_2 emissions in 2020 will still exceed the allowed national total because of its current dependence on diesel and heavy fuel oil in the electricity sector. The planned switch to gas in a few years' time will sufficiently reduce its SO_2 emissions.
- 8 Parties may choose to use national emission totals calculated on the basis of fuels used (road transport) instead of fuels sold as the basis for assessing compliance with their respective emission ceilings. The need for this option has been greatly reduced with the transition to relative targets.
- Main reasons for not meeting the reduction commitments are a lack of policies and measures, higher activity levels than foreseen at the time when the emission reduction commitments were set, slow replacement of old stock and further developments of the emission inventories. In order to further reduce emissions to meet the 2020 emission reduction commitments, additional action may be needed in particular in the agricultural sector (cattle farms, manure spreading, use of inorganic fertilizers) (NH_3), the energy sector (NO_X), road transport (NO_X, VOC), shipping (NO_X), solvent use (VOC), domestic wood burning ($PM_{2.5}$ and VOC) and agricultural residue burning ($PM_{2.5}$).
- Other Parties that have not yet ratified the amended Gothenburg Protocol and for which no emission reduction commitments are proposed in tables 2-6 of Annex II to the amended Gothenburg Protocol show a mixed picture in terms of emission trends for the main pollutants between 2005 and 2019. For some of these Parties and for one or more pollutants, emissions even increased.

2 Barriers of meeting the 2020 emission reduction commitments

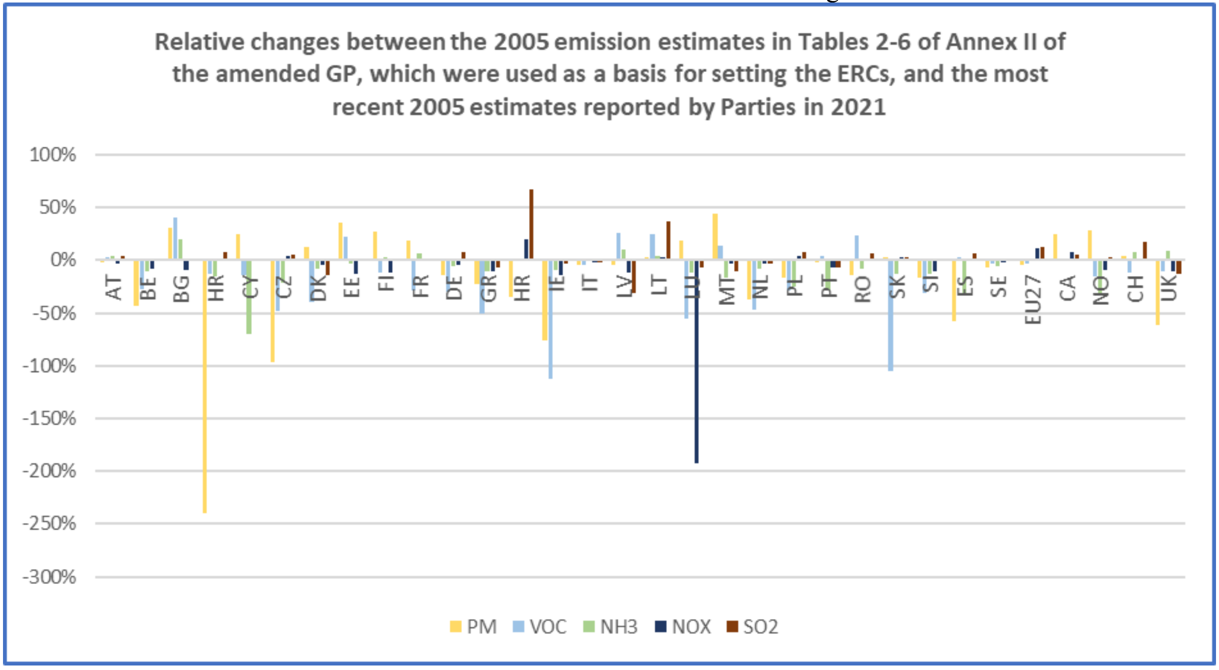
76. The Secretariat sent a letter to the Air Convention National Focal Points on 3 June 20201 requesting information by 30 September 2021 on the barriers identified by Parties to meeting their 2020 emission reduction commitments (in response to question 1.5(e)). The WGSR will then further discuss this issue at its session in spring 2022. This will provide input for the review report.

77. Key findings and conclusions

- To be completed at a later stage.

3. Updates of the base year 2005 emission estimates

78. The graph below shows how the most-up-to-date 2005 emission estimates as reported by Parties in 2021 compare to the 2005 estimates listed in tables 2-6 of Annex II to the amended Gothenburg Protocol.



79. Key findings and conclusions

- The graph above shows the many significant changes in the reported 2005 emission estimates between 2012 (for information purpose listed in tables 2-6 of Annex II to the 2012 amended Gothenburg Protocol) and 2021 (last reporting year), especially for $PM_{2.5}$ and VOC, and less so for NO_X and SO_2. Most changes remain within the range of +50% and -50% compared to the 2005 emission estimates listed in tables 2-6 of Annex II to the amended Gothenburg Protocol, but with some outliers to over 100% change.
- Comparing the 2005 emission estimates reported in 2012 with the most recently reported updates for the year 2005 (reporting year 2021) shows that the basis for setting the 2020 emission reduction commitments has significantly changed between 2012 and 2021. It underlines the importance and usefulness of moving from fixed (2010 ceilings) to relative targets (2020 emission reduction commitments).
- Relative targets are able to absorb many, but not all, of the effects of inventory developments and improvements. The transition from the 2010 fixed to the 2020 relative targets will therefore most likely also reduce the need and use of the adjustment procedure from 2022 onwards. This could mean a significant reduction in the workload for CEIP and the emission inventory review teams.

4. Use of the adjustment procedure

80. The table below shows the shares of approved adjusted emission totals in the corresponding unadjusted national emission totals as reported in 2021 from 2010 to 2019. Approved adjustments from previous years that were no longer reported in 2021 are not included in this table.

Party	Pollutant	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	NO_X	26%	28%	30%	31%	31%	30%				
France	NO_X	13%	14%	14%	15%	17%	17%	17%	16%		
Germany	NO_X	28%	29%	29%	30%	30%	29%	28%	26%	24%	23%
Luxembourg	NO_X	16%	16%	18%	20%	21%	23%	24%	24%	23%	23%

Spain	NO_X	16%	15%								
UK	NO_X	8%		8%							
Czech Republic	VOC	12%	12%	13%	13%	14%	14%	13%	13%	14%	
Denmark	VOC	28%	30%	31%	31%	33%	32%	34%	35%	36%	37%
Germany	VOC	22%	24%	25%	26%	27%	27%	27%	27%	27%	27%
Luxembourg	VOC	28%	27%	26%	27%	30%	32%	32%	32%	33%	30%
Netherlands	VOC	30%	30%	31%	29%	27%	31%	28%	27%	27%	23%
Denmark	NH_3	14%	15%	15%	16%	16%	16%	17%	18%	17%	19%
Finland	NH_3	6%	6%	6%	5%	5%	5%	5%	5%	5%	4%
Germany	NH_3	7%	8%	8%	9%	9%	9%	9%	9%	10%	10%
Netherlands	NH_3					2%	1%	2%	4%	4%	

81. Key findings and conclusions

- The mechanism to adjust national emission inventories for comparison with the emission ceilings has been widely used so far.
- A total 11 Parties submitted eligible adjustment applications in the period 2014-2021 for one or more pollutants. Adjustments of national emission inventories were submitted for NH_3, NO_X an VOC and concern adjustments to account for new emission source categories as well as significant changes in emission factors or methodologies used. The majority of the adjustment applications were submitted for the following categories: road transport, agricultural soils, manure management and cultivated crops.
- The approved adjusted emission totals represent 2 to 20% of the unadjusted national emission totals for NH_3, 10 to 30% of the unadjusted national emission totals for NO_X and 10 to 40% of the unadjusted national emission totals for VOC.
- All adjustment applications approved so far relate to adjustments to emission inventories for the purpose of assessing compliance with the 2010 fixed ceilings (provisional application since 2014). The adjustment procedure has not yet been applied with respect to assessing compliance with the 2020 emission reduction commitments. This may happen for the first time in 2022 (based on emission data reported in 2022 for the year 2020). As mentioned above, the move from fixed to relative targets is expected to reduce the need and use of the adjustment procedure from 2022 onwards. Approved adjustments to date will not be applicable for use with respect to the 2020 emission reduction commitments. New applications and reviews (based on a new reference point and including adjustments for the base year 2005) will be required for the post 2020 scheme.

5. inclusion of condensables in reporting PM emissions for residential heating

82. CIAM and TNO/CAMS started to improve the default database of condensable emissions (TNO Ref2 database). Crucial uncertainties are the number and type of appliances. Such information has to come from the Parties. Meanwhile more Parties started to report residential PM2.5 emissions with and without condensables to CEIP. This input is needed in order to properly answer question 4.4. A new initiative, funded by the Nordic Council of Ministers, will allow for a development of a new consistent set of technology specific emission factors for $PM_{2.5}$ including condensables. This work focuses also on the assessment of the efficiency of mitigation of PM emissions, when condensable PM are taken into account. Including condensables would give a more complete explanation of the population exposure to $PM_{2.5}$ and could better define the effectiveness of measures for health protection. Including condensables could shift the optimal policy strategy more into the direction of tackling residential solid fuel burning.

83. At the time when the 2020 emission reduction commitments were set (2012) many Parties did not yet include condensables in their PM reporting for residential (wood) heating:

- for some Parties, including condensables could prove to be problematic, as even with adjustment of their 2005 emission data, they would not be able to deliver the emission reduction commitment for $PM_{2.5}$, without additional measures for residential heating. The adjustment procedure could be used for this circumstance.
- for other Parties, including condensables could prove to undermine the set emission reduction commitment for $PM_{2.5}$: this would be the case if the use of wood for residential heating did not significantly increase between 2005 and 2020 and the share of old stock decreased during this period. The inclusion of condensables for this specific situation would inflate PM emissions in base year 2005 much more than in 2020 (given that the share of the condensables in PM from old stoves with poorer combustion conditions is much higher than for new stoves) (see EF in the EMEP Guidebook).

Key findings and conclusions

- To be further completed.

6. Adequacy of 2020 emission reduction commitments

To be further completed on the basis of input from CIAM/TFIAM.
To be decided whether the assessment of the adequacy of the 2020 emission reduction commitments should be dealt with in chapter VI ('Emission reduction commitments for Parties') or chapter XVI ('Progress towards achieving the objectives of the Protocol'). The adequacy of the emission reduction commitments is covered by question 3.1 which was attributed in document ECE/EB.AIR/WG.5/2021/4 (Draft annotated outline of the GP review report) to chapter XVI.

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

1.5 (a). To what extent have best available techniques and emission limit values and other technical provisions in annexes IV, V, VI, VIII, IX, X and XI been implemented by the Parties? Spring 2022l WGSR

1.5 (b). Have Parties implemented additional or newer source- oriented measures? What are the contributions of these measures? Spring 2022; WGSR

1.5(c). Have Parties implemented other (non-technical or structural) measures that contribute in meeting the 2020 emission reduction obligations? What are the expected contributions of these measures in 2020 and beyond? Spring 2022; WGSR

1.5(d). What barriers have been identified by Parties and non-Parties to implement the obligations in the technical annexes? Spring 2022; WGSR

Proposal for Parties to submit information to the Secretariat by 30 September 2021 to answer these questions. WGSR could then have an agenda item in April 2022 to discuss and provide input into the Review Document.

1.5(a), 1.5(b), 1.5(d) (TFTEI[24], TFRN[25], Parties) Spring 2022

84. The questionnaire organized by TFTEI with the support of the UNECE Secretariat was answered by many EECCA Countries as result of the 2019 Berlin meeting (see note 19) to answer the above questions. A number of barriers to implementation/ratification by EECCA Countries have been identified, along with possible actions to overcome the barriers. The joint meeting TFTEI/EECCA_CG workshop scheduled on April, 26-27, 2021, may add new elements for the evaluation. The action of TFTEI on this is limited to the EECCA countries, thanks to the long term cooperation relationship. TFTEI in NOT in the position to ask Parties what they have implemented at national level. In the past this task was carried out by the WGSR Chair with the support of the Secretariat and use of a questionnaire.

1.6(a), 1.6(b), 1.6(c), 1.6(d) (TFTEI, TFRN) Spring 2022

85. According to the revised mandate of the task force, TFTEI will perform an accurate and details analysis of the Annexes IV, V, VI, VIII, X and XI, and the associated guidance documents, in 2021, to identify the emission limit values and other technical requirements in the technical annexes, which could be potentially updated, because of the evolution of the technology since 2012. At the same time, potential adaptations of the annexes, to better address key sectors in the EECCA regions, will be investigated, along with possible gaps, complexity, excessive demanding, in collaboration with the EECCA experts (see the mentioned joint TFTEI-EECA_CG workshop), The outcome of the review will highlight the critical sections of the Annexes and associated guidance documents, along with the existence of the newest technological solutions, however, without expressing preferences or specific ELVs values.

---

[24] The Task Force on Techno-economic Issues.

[25] The Task Force on Reactive Nitrogen.

On the following page an example of outcome of the Annexes review work is reported, in form of synthesis table, concerning the Cement Production sector, (Annex V and Annex X, NOx and PM emissions from stationary sources). In the Table new/updated information is reported only.

Table – ref. ECE/EB.AIR/114 – Example of Review Outcome - Annexes V and X
Abatement technologies for NOx and PM emissions from the Cement Production sector

Page	**Reference**	**Potential update**	**Description** *(as part of the Guidance Document)*	**Potential Applicability (%)**	**Potential ELVs**
			ANNEX V		
44	Table 3 Limit values for NOx emissions released from cement clinker production General (existing and new plants): 500 mg/m3 at 10 % O2 Existing Lepol and Long Rotary Kilns in which no waste is co in-incinerated 800 mg/m3 at 10 % O2	Upgraded current abatement techniques are available Upgraded current abatement techniques are available	The techniques are advanced primary measures associated with SNCR and/or SCR The technique are advanced primary measures associated with SNCR and/or SCR	Almost 100 %. Some limitations may exist if the primary measures are not able to reach concentrations below 1000 mg/m3. Almost 100 %	200 to 450 mg/m3 as daily average 400 to 800 mg/m3 as daily average
			ANNEX X		
85	Table 3				
	Installations for the production of cement clinker in rotary kilns with capacity of > 500 t per day or in other furnaces with a capacity > 50 t/day Cement installations, kilns, mills and clinker coolers 20 mg/m3 at 10% O2	Current abatement techniques of PM well dimensioned are available	Fabric filter and ESP as well as other techniques such as wet scrubbers may reach lower concentrations	Almost 100 %.	Concentrations lower the 10 mg/m3 are achievable (daily average)

TFRN:

86. Annex IX is over 20 years old and can no-longer be considered up to date. Based on substantial progress in technical capability, availability of cost-effective measures, and recognition that measures are needed to achieve ammonia emission ceilings, a comprehensive revision of Annex IX is overdue (Relevant to paras. G-13, K-17).

87. 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[26] (Paras. G-13, K-17).

88. Although Annex IX briefly notes that "Each Party shall take due account of the need to reduce losses from the whole nitrogen cycle", no further details or requirements are provided related to the **wider nitrogen cycle**. This can be considered as a critical gap given the last decade of activity in developing joined up-perspectives and solutions across the nitrogen cycle[27] (Para. G - 13).

89. 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 (through simultaneous mitigation of nitrous oxide, di-nitrogen, nitrate and other nitrogen losses).[28] Emissions of NOx from soils are specifically excluded from the revised Gothenburg Protocol, which represents a barrier to progress in further reducing total NOx emissions, while not giving credit for progress with such measures.

90. Many parties appear not to have fully implemented the requirements of **Annex IX**. This annex is no longer state-of-the-art being over 20 years (prior to 1999). It is not technically demanding, as has been demonstrated by actions taken by a few parties. 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. The following excerpt of Annex IX is illustrative: "Within one year from the date of entry into force of the present Protocol

---

[26] 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).

[27] e.g., **The European Nitrogen Assessment**: Sources, effects and policy perspectives (eds. Sutton et al., 2011, Cambridge University Press). Includes spatial analysis of threats, damage costs and examination of solutions. http://www.nine-esf.org/node/360/ENA-Book.html

[28] **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

for it, a Party shall establish, publish and disseminate an advisory code of good agricultural practice to control ammonia emissions".

91. Although this became a requirement on 17 May 2006, engagement by the Task Force with the support of the Secretariat has shown that, even by 2020, most parties to the Protocol had not yet met this requirement[29].

92. Future review of progress on ammonia measures would benefit from annual questionnaires of the actions taken by Parties in relation to all the requirements of Annex IX.

93. Considering 'best available techniques' (Para. I-15), there are many measures available for abatement of ammonia emissions[30] that have not so far been implemented by Parties. Analysis by TFRN[31] has shown that dietary change to reduce excess intake of meat and dairy offers key a key non-technical measure, with co-benefits for health and climate. The report 'Nitrogen on the Table' showed that a halving meat and dairy intake in Europe (demitarian scenario) would reduce ammonia emissions by around 40% (without any technical measures) (See Section 5.4). It appears that Parties have net yet applied policies related to food choice as part of their ammonia emission reduction plans, although co-benefits with ambitious climate-related policies may see this change in future.

94. The **main barrier to ammonia reduction** by Parties and non-Parties (Para. K-17) appears to be lack of political willingness. A wide range of co-effective abatement methods and non-technical measures are available. The last 3 years has seen a significant change in political willingness as Parties realise that implementation of measures is needed to reach committed emission ceilings.

95. Annex IX was not updated in the amended Gothenburg Protocol of 2012. Although many options were discussed, it was not possible for the parties to agree on an amended text (hence the inclusion of Article 10.4 in the amended protocol).

96. 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. The TFRN Expert Panel on Nitrogen Budgets currently lacks resources with work conducted on a voluntary basis.

---

[29] 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

[30] See the **Guidance Document on preventing and abating ammonia emissions from agricultural sources**, originally Guidance Document V (decision 1999/1) as referred in Annex IX of the Gothenburg Protocol, which has since been revised as ECE/EB.AIR.120, adopted in 2012. Published for wider dissemination as "Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen" (eds. Bittman et al., 2014, CEH). http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/AGD_final_file.pdf

[31] **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

What barriers exist for non-Parties? (Paras. G-13, H-14, K-17)

97. The requirements of Annex IX are similar across the entire UNECE region, even though preferences for specific ammonia abatement solutions may vary across the region.

98. The Guidance Document on Integrated Sustainable Nitrogen Management includes source related measures (animal housing, manure storage and spreading, nutrient recovery methods and field application of organic and inorganic resources) and landscape / landuse related measures. Parties appear to vary in their preference for source oriented or landscape oriented measures. Potential trade-offs of certain landscape measures (e.g. impact on priority nature areas) can limit their applicability in some areas while in other contexts they can be seen as complementing source oriented measures to maximize environmental benefits.

99. Article 8 of the Gothenburg Protocol makes clear that Annex IX and ammonia measures do not apply outside the geographical area of EMEP. The Protocol therefore specifies no measures for ammonia for Parties from North America. In the past it had been asserted that ammonia was not a transboundary pollutant of concern between Canada and the United States. Further discussions are ongoing. Ammonia emissions contribute to transboundary effects and waste of nitrogen resources on local to global scales, amplifying adverse effects on health, climate and ecosystems.

Which elements of annex IX and guidance documents need to be updated? (G-13, H-14, I-15)

100. The main needs to update and extend Annex IX concern measures related to:

(a) Feeding of livestock (currently not described),

(b) Housing of cattle and storage of cattle manure (currently not described),

(c) Housing of pigs, poultry and other livestock and their associated manure storage,

(d) Processing and recovery of organic nutrient resources (currently not described),

(e) Spreading to land of solid manure and liquid manure / slurries,

(f) Spreading to land of urea, ammonium nitrate and other nitrogen containing fertilizers,

(g) Grazing of livestock and other aspects of cropping, including from agricultural soils (currently not described),

(h) 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 as nitrate and other nitrogen forms, with a goal of progressing to more circular systems with higher system-wide nitrogen use efficiency (currently not described),

(i) Measures, including ‘nature based solutions’, related to landscape and landuse structure, so far as these reduce wasted nitrogen resources and do not compromise other objectives (currently not described),

(j) Dumping and disposal of organic and inorganic nitrogen containing resources (currently not described).

101. The following guidance documents related to ammonia and the wider nitrogen cycle need to be updated as follows:

(a) The Ammonia Guidance Document (ECE/EB.AIR.120), last revised in 2012, should be updated by 2024

(b) 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

(c) The Guidance Document on National Nitrogen Budgets (ECE/EB.AIR/119), adopted by the Executive Body in 2012, should be revised by 2024.

(d) 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.

To what extent will new agricultural or integrated nutrient management policies (e.g. the European Union 'Farm to Fork' strategy and the reform of the European Union agricultural funding policies (CAP reform)) contribute to ammonia emission changes? (Section H-14, O-23)

102. Wider agricultural and integrated nutrient management policies offer great potential to reduce ammonia and wider nitrogen pollution. For example:

(a) 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.

(b) The Farm-to-Fork and Biodiversity Strategies of the European Commission embrace a goal to "reduce nutrient pollution by 50% by 2030", directly building on the Colombo Declaration.[32]

(c) 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, including Special Areas of Conservation.

(d) As focus on 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[33].

Spring 2022 - TFIAM/CIAM/TFTEI:

1. **To what extent have the measures implemented to meet the emissions reduction obligations for particulate matter contributed to reduce black carbon and polycyclic aromatic hydrocarbons emissions**

103. Additional modelling will be needed. CIAM can construct a backcasting scenario that provides information on the PM-reduction with and without compliance to emission limit values as defined in the technical annexes of the amended Gothenburg Protocol and the associated reductions of black carbon and polycyclic aromatic carbon. *For all GPG-questions on black carbon and polycyclic aromatic carbon, we assume that for modelling purposes, black carbon is represented by 'elemental carbon' and polycyclic aromatic hydrocarbons by 'organic carbon'.*

2. **Best available techniques to reduce black carbon emissions. Additional particulate matter measures that are also effective for reducing black carbon and PAH-emissions**

104. In all countries, reduction of emissions from agricultural waste burning and from residential solid fuel burning are the most effective PM-reduction measures that would also reduce emissions of black carbon. See: Prioritizing reductions of particulate matter from sources that are also significant sources of black carbon – analysis and guidance

---

[32] EU Farm-to-Fork Strategy: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/farm-fork_en Compared with the Colombo Declaration the EU Strategies include other nutrients (such as phosphorus), but by focusing only on 'pollution' do not include emissions of di-nitrogen (N_2), which is not pollution as such but is a significant waste of reactive nitrogen resources.

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

ECE/EB.AIR/WG.5/2021/8 (unece.org) , ECE/EB.AIR/2020/6 (unece.org) and: 2 (unece.org).

105. Sectoral projections of black carbon and organic carbon emissions will be made with the GAINS-model, considering existing legislation where several current important PM and BC sectors are included)e.g., transport, residential wood combustion). Development of the MTFR scenario will allow to demonstrate remaining PM2.5 and BC & OC potential and key technical measures. These will be different across the countries since potential will depend on structure of emissions, e.g., heavy reliance on solid fuels in residential sector, old fleet of diesel vehicles, or still poorly executed policies banning open burning of waste, including agricultural residue burning. While, non-technical measures offer potentially significant contribution to overall reduction their analysis will be limited to using only an alternative future scenario (i.e., strong climate mitigation, sustainable development) where certain transformation take place, including for example rapid decarbonization, structural changes in transport system, vehicle fleet electrification.

106. The above questions have found some answers in the background technical documents made available by TFTEI to WGSR, at its 58 session, in December 2020.

107. Fossil fuel consumption both in stationary and mobile sources, biomass burning are key sources of BC and associated PAHs (Polycyclic Aromatic Hydrocarbons) into the atmosphere. Gas Flaring (GF) is also an important source of BC and PM with both air quality and climate impact in the Artic regions as example. PM presents a large spectrum of components such as dust, BC, organic compounds, sulphates, nitrates, ammonium, etc… These different components may have a warming or cooling effect in the atmosphere. The reduction of BC and PAHs is linked to the reduction of PM.

108. **Residential wood burning** remains a major issue, and many efforts still need to be made to reduce emissions. The use of advanced or eco-design stoves should be promoted. The use of modern stoves implementing advanced methods to limit the emission of pollutants like catalytic combustors, wood pellets and masonry stoves enables to reach the emission standards as defined in the EU.

- Automatic fuel feeding and improvement of air staging combustion clearly improve the combustion efficiency. Low cost strategies of retrofit air injection on traditional stoves can reduce PM and BC emissions.
- Wood pellet stoves have 2 to 3 times lower PM, BC and PAH emissions than wood logs in advanced wood stoves.
- Additional strategies like Thermal Energy Storage can help to optimize the heating cycle from the start-up and the shutdown.
- Installation of an ESP (electrostatic precipitator) and the installation of a catalyst can help to reduce emissions from existing appliances.

109. The following technologies can be used[1]: New advanced stoves equipped with improved air control, reflective materials and two combustion chambers; New smart stoves with automated control of air supply and combustion, thermostatic control, Wi-Fi-connected to collect and send combustion data to the manufacturer for better service; New advanced masonry stoves, operating at high efficiencies and low emissions; New advanced pellet boilers: fully automated boilers (electronic control of air supply, lambda sensors), condensing boilers, using standardized pellets; Wood carburettor boilers using log wood or chip wood; Heat accumulating equipment with heat accumulating reducing stop/start frequencies and operation at partial load, which generates higher emissions than operation at full load; Other: flue gas recirculation, reverse combustion, gasifier. Correct installation and use of appliances, as well as maintenance and service/inspection of appliances and flue gas pipes are also essential to reduce emissions. The quality and the type of wood is also important.

110. Start-up is a critical phase with high emissions of pollutants. Currently, test procedures for delivering labels are not able to characterise real conditions of use of domestic appliances. New normalised test procedures should be developed and set-up, to better account for real utilisations of small-scale combustion appliances (starting phases, closing phases).

111. Harmonized methods to better account for the real emission factors of PM and BC would be necessary for accounting for condensables like dilution tunnels are recommended.

Road Traffic

112. PM produced by combustion emitted at the exhaust pipe are mostly fine particles below 2.5 µm and are mainly composed of carbonaceous species. PM, BC, PN, and PAH emissions are effectively reduced using tailpipe aftertreatment systems as Diesel Particulate Matter (DPF) or Gasoline Particulate Matter (GPF). Decreases from 90 to 100% are commonly observed for most particulate pollutants. Diesel particulate filters (DPFs) have been widely used in the motor vehicle industry for decades and found to be cost-effective. As an order of magnitude of $PM_{2.5}$ emission factors, changes from Conventional to Euro VI for Heavy Duty Vehicles (HDV) from 333-491 to 0.5-1.3 mg km^{-1} can be observed. The fraction of BC in PM ranges from 10 to 20% in Euro VI HDV vehicles.

113. Recent research findings show that different after-treatment technologies have an important effect on the level and the chemical composition of the emitted particles and highlight the importance of the particle filter devices condition and their regular checking to maintain the best performances.

114. Tyre and brake emissions are turning dominant sources and they are also a source of BC even if these particles are mainly in the coarse mode (diameter > 2.5 µm). There is no widely used after-treatment system to control brake, tire and road wear emissions. The choice of pad material is the main technical way to decrease emissions even some suction devices could be used to remove most particles from brakes. The behaviour of the driver is often cited as a key to reduce emissions (non-technical measure). Some companies have developed brake particles collection system that would reduce by 80% to 90 % respectively the brake mass and number emissions.

115. PM resuspension from the road should be better addressed. This emission is responsible for a large fraction of total road traffic emissions. It depends on meteorology (wind, temperature, humidity, precipitation) and the site climatology (land use in the vicinity).

Gas Flaring (GF)

116. Black carbon emissions from the oil & gas industry by Gas Flares is an important source of black carbon and particularly in areas surrounding the Artic zone. Russia, USA, Africa and some Middle East countries are among the largest emitting countries.

117. Routine flaring from a lack of gas utilisation sources is the most important and largest source of BC emissions from flaring, however, intermittent flaring and continuous flaring for operational reasons can also be significant sources. At least 90% of particulate carbonaceous species in the gas flare flue gas is made of black carbon.

118. Steam-assist Flares are clearly the most efficient in terms of soot emission reductions. However high pressure-assisted flares can be an efficient technique if water is not available on site. New model based on neural networks (advanced statistical methods) could help to better assist the flaring operations to better control soot formation.

119. The optimization of flare design and combustion conditions is an option thanks to the use of Computational Fluid Dynamic (CFD) model. Model and control systems can be used to monitor the flue gas characteristics and control the input data.

3. Appropriate definitions and calculation methods (emission factors) for black carbon and the condensable part of particulate matter

120. The joint activity (funded by the Nordic Council of Ministers) between MSC-W, TNO, NILU, SYKE, CIAM will review the Scandinavian experience and assimilate new data to establish consistent technology specific emission factors for solid particles (including BC) and total PM2.5 emissions including condensables. There will be a need for TFEIP to follow up with updating the emission inventory guidebook, and for TFTEI to update emission limit values including condensables in technical annexes.

4. Guidance documents

121. The guidance documents associated with the Annexes, are reviewed for the part of competence of TFTEI. The guidance document on “Agricultural Residue Burning” is submitted for consideration of WGSR, at its session 59th (May 2021). The development of further guidance documents might be considered, in example, for methane or shipping emissions, on the basis of the technical documents, already developed by TFTEI in 2020.

122. There is a proposal for Parties and task force chairs to give views on which guidance documents need to be updated as a priority and if there need to be any new guidance documents in response to the Review. Responses are to be sent to the Secretariat by 30 September 2021. WSGR could also take views on whether a guidance document is needed on non-technical measures. See informal document from WSGR58 re-posted for WGSR 59. [Note_on_non-technical_and_structural_measures_-201120.pdf (unece.org). Note: there is a standing mandate for TFTEI to update and assess information on technologies on a regular basis. All guidance documents should be updated on a regular basis. This is a priority question as well as a question for new documents that do not yet exist but that would be helpful in implementing the requirements of the existing protocol.

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

1. Best available emission abatement techniques and measures for the reduction of methane emissions from key sources

123. The IIASA study evaluates mitigation potential for key sources, highlighting the available measures.

124. [TFTEI] Some answers are provided in the background technical document on methane emissions from the natural gas production and distribution network and emissions from solid waste landfills, made available by TFTEI to WGSR, at its 58th session, in December 2020.

125. Methane emissions from waste landfills are the most important non-agricultural source of methane emissions in Europe and are responsible for around 20% of overall emissions. Globally, this share is assumed to be even higher. In landfills, methane is formed through anaerobic digestion of hydrocarbon waste. To avoid theses emissions the most important measure is the reduction of landfilled waste. This can be achieved through composting of biodegradable waste, more efficient separation and recycling, or incineration of non-biological hydrocarbon waste (e.g. for combined heat and power generation). For the reduction of methane emissions from existing landfills, the most relevant options are:

- Gas collection and utilization: The implementation of an active landfill gas extraction system using vertical wells or horizontal collectors is the single most important mitigation measure to reduce emissions. This gas may be further used in different manners such as electricity generation, direct gas use for heat generation, gas grid injection or flaring if further utilisation is not possible.
- Oxidation of methane in biocovers or through biofiltration based on methanotrophic organisms (bacteria) that transfer methane into CO_2 and H_2O. This requires a final soil-based biocover of the landfill.
- Landfill aeration to avoid anaerobic digestion and to enhance biological processes to inhibit methane production.

126. A further important source of methane emissions is the natural gas production and distribution network. As production technologies, compression and pressure regulation partly show regional differences, not all options listed hereafter are relevant for all countries. Furthermore, a general distinction between production, transmission and distribution to final end-users has to be made, because e.g. from an EU perspective, production and transmission mainly takes place outside of the EU (Russia as the most important natural gas supplier). Generally, these measures can be categorized as technical measures by replacing existing equipment and organizational or management measures by modifying common practices e.g.

for maintenance and inspection. In summary, the following measures have been identified to be the most relevant:

- Reduction of operating emissions: Use of low or zero emitting pneumatic and compressor systems with re-use of the gas instead of venting. This may include the replacement of centrifugal compressor seal oil systems (recover methane from seal oil), the installation of low bleed pneumatic devices, etc.
- Reduction of maintenance emissions by using mobile compressors to pump gas from a section to be vented into a neighbouring section or the use of a mobile flare unit to burn vented gas at pipeline maintenance works etc.
- Inspection and maintenance programs: Organizational measures to detect emissions earlier and stop them, also referred to as leak detection and repair (LDAR).

2. Policy implications of including particles formed from condensable compounds in particulate matter reporting

127. [TFTEI] TFTEI works in collaboration with MSC_W on deepening the technical aspects condensable part of PM. The policy implications are discussed in the frame of WGSR

3. Shipping sector

128. Projections of future emissions from international shipping in Europe have been made by the International Institute for Applied Systems Analysis (IIASA) and the Finnish Meteorological Institute (FMI). According to the FMI projections, NOx emissions from shipping in Europe will continue to decrease, despite the growth in traffic volumes (Repka et al., 2019). IIASA projects NOx emission reductions by up to 40% in 2030 and 79% in 2050, with respect to 2015 emissions (Cofala et al. 2018, their Table 5.3).

129. Based on a single model study roughly 10% of the ozone in Europe of anthropogenic origin can be attributed to international shipping (Jonson et al. 2020). Regulations of NOx emissions from shipping in emission control areas are likely to reduce ozone levels by 2030 (Jonson et al. 2019). Exceptions are regions with very high NOx levels, where reductions in NOx emissions can lead to increases in ozone during winter time. However, as ozone levels are low during winter, this will not have a major effect on exceedances of Air Quality Guidelines.

130. Cofala et al. (2018) have shown that the designation of the Mediterranean as a NOx emission control area (NECA) would be efficient in reducing PM2.5, and related premature deaths, especially in the southern parts of the ECE region. Geels et al. (2021) conclude similarly for Northern Europe that the number of premature deaths due to shipping emissions can be significantly reduced by 2050 through a heavy fuel oil ban in addition to the sulphur emission control regulations.

131. Critical loads of nitrogen depositions are exceeded in much of Europe. In particular in countries with long coastlines, a substantial portion of the nitrogen deposition is from shipping (Jonson et al. (2020) and EMEP, 2020 (their Table C.2)). Repka et al. (2021) have shown that shipping emissions contribute to critical load exceedances in land areas but that this contribution will decrease due to emission regulations, in particular in emission control areas as already implemented in the North Sea and the Baltic Sea.

I. Non-technical measures, best available techniques and energy-efficiency requirements

1.5	a. To what extent have best available techniques and emission limit values and other technical provisions in annexes IV, V, VI, VIII, IX, X and XI been implemented by the Parties? b. Have Parties implemented additional or newer source- oriented measures? What are the contributions of these measures? c. Have Parties implemented other (non-technical or structural) measures that contribute in meeting the 2020 emission reduction	TFTEI, TFEIP CIAM, TFRN, ***Parties***	Spring 2022

	obligations? What are the expected contributions of these measures in 2020 and beyond?		
3.5	c. What are the best available non-technical measures, what policy instruments are effective to trigger behavioural change and what can such measures contribute to environmental and health improvement?	TFIAM, CIAM, TFTEI	Fall 2021
4.2	d. Which additional PM-measures (technical and non-technical) are also effective for reducing BC and PAH-emissions? e. What are best available techniques to reduce BC emissions?	TFTEI, TFIAM, CIAM	Spring 2021
5.2	a. What are best available control measures to further reduce ammonia emissions? b. Which elements of annex IX and guidance documents need to be updated?	TFRN	Spring 2021
5.4	a. What is the potential for dietary change? b. What environmental and health benefits are associated with dietary change? c. What policy instruments are available to change diets?	TFRN, WGE	Spring 2022
6.3	a. What are the (best) available emission abatement techniques and measures for the reduction of methane emissions from key sources?	TFTEI, TFRN, TFIAM, WGSR, WGE	Spring 2021 (a., b.) Spring 2022

1.5b Technical and non-technical measures implemented by the parties.

132. A questionnaire might be helpful to get the information needed. This was last done by the Task Force on Reactive Nitrogen on national ammonia code in May 2018. At the time, not many Parties were complying with their commitments.

Options to further reduce emissions can be found in:

Code of good practice for solid fuel burning and small combustion installations, 2019: https://www.unece.org/fileadmin/DAM/env/documents/2019/AIR/EB/ECE_EB.AIR_2019_5-1916518E.pdf

Guidance document on emission control techniques for mobile sources, 2016: https://www.unece.org/fileadmin/DAM/env/documents/2016/AIR/Publications/ECE_EB.AIR_138_En.pdf)

IIASA report on measures to address air pollution from agricultural sources, 2017: https://iiasa.ac.at/web/home/research/researchPrograms/air/policy/SR11-AGRICULTURE-FINAL.pdf

3.5 Best available non-technical measures, effective policy instruments to trigger behavioural change and their contribution to environmental and health improvement

133. Implementation of emission limit values (ELVs) is not always sufficient to meet national emission reduction obligations or air quality targets. In such cases, additional actions in the form of “non-technical” measures could be considered, at the national or local level. This could include encouraging a faster substitution of old and polluting technologies by new and cleaner technologies, facilitating the use of cleaner fuels or feedstocks, or stimulating a greener behaviour of consumers. The latter could include a modal shift from private to public transport, dietary changes or domestic energy saving. Sometimes such measures prove to be more efficient and less costly than implementing stricter ELVs.

134. Such additional measures are not included in the technical annexes of the protocol and are for that reason sometimes referred to as ‘non-technical’, voluntary, innovative or non-regulatory measures, although in reality these can still have highly technical components. For example, in the case of building insulation, solar energy, product and process redesign or advanced public transport systems. Examples of measures with almost no technical component include improved maintenance routines, reducing indoor temperature, obeying speed limits and turning off the lights when leaving the room. Examples of hybrid measures or solutions are motion-activated light switches, cruise control functionalities in vehicles, or even changes in purchase behaviour from standard technologies to environmental-friendly technologies.

135. Given that narrow or potentially misleading interpretation of ‘non-technical measures’, the broader term ‘structural measures or structural changes’ may be more appropriate when we refer to measures that are additional to the end-of-pipe techniques prescribed in the technical annexes to the protocol. The common feature of structural changes is that they cannot easily be implemented via permitting of specific activities. They often require a combination of actions by various players in the production chain, as well as by consumers.

136. Shifting car mobility to more active mobility (walking, cycling and public transport use) as well as changing diets (less meat, more vegetables) could have multiple benefits for environment and individual health. Pricing, regulation and infrastructural measures (fewer parking places and car lanes, better facilities for cycling and fast public transport) proved to be effective in several cities. Such measures are also the subject of work under the Expert Panel on Clean Air in Cities.
CIAM analysis of dietary (low meat) and improved nitrogen use efficiency measures showed significant environmental and health benefits due to reduced air pollution at a regional scale and also climate co-benefits owing to reduction of methane emissions; such measures are part of the clean air portfolio in Amann et al (2020).

137. The COVID-19 induced lockdown periods taught us some relevant lessons on the impact of reduced car use and the shift to walking and cycling. A big uncertainty is which of the behavioural changes will have a lasting effect after the pandemic. There is a potential for negative feedbacks on air quality if more people will avoid public transport and use cars instead and move to larger dwellings. Additionally, the actual impacts on air quality will depend on the indicator, i.e., reduced NO_2 concentrations but not so clear picture for PM concentrations and even increase in ozone. There is a need to complement the information on non-technical measures with information on policy instruments that will be effective to implement this group of measures (e.g. regulation, economic instruments, infrastructural investments, nudges, etc). See: Note_on_non-technical_and_structural_measures_-201120.pdf (unece.org)

4.2 Best available non-technical measures to reduce PM, BC and PAH emissions

138. Behavioural changes to reduce PM can be triggered by ad hoc guidance documents like the Code of good practice for wood-burning and small combustion installations. The effectiveness and costs of non-technical and structural measures are currently analysed in several countries, e.g. Sweden, Italy, Portugal, UK, Germany[3], Ireland, Belgium, the Netherlands as well as the European Commission’s Joint Research Centre.
139. The draft TFIAM/TFTEI Guidance Document on Prioritization of PM sources (ECE_EB.AIR_WG.5_2021_8-2102625E.pdf (unece.org) identifies as the main PM-measures that also significantly reduce BC (and PAH) emissions:

- Residential burning of coal and wood
- Open field (agricultural) residue burning
- Scrapping old diesel vehicles & old NRMM
- Industrial emissions (coke ovens, flaring in refineries)
- Cooking (meat frying, BBQs)

140. For domestic wood burning (a coherent package of) ‘non-technical’ measures are likely to be more effective and suitable than technical measures for the reduction of emissions: for instance: (i) scrapping or mandatory replacement programs to accelerate the removal or replacement of old and polluting stock, (ii) bans, (iii) installation and regular maintenance schemes, (iv) encouraging good burning practices, (v) energy renovation (reducing heat demand), etc. All these measures will likely be more effective than retrofitting the existing stock with a catalyst or an ESP (technical measure). See the new code of good practice for solid fuel burning (TFTEI).

5.2a Best available non-technical measures to reduce ammonia

141. TFRN: 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.

142. 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.

143. 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"[34] by 2030, saving US$100 billion per year globally[35], as embraced as part of national action plans under the Colombo Declaration[36].

144. 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.[37] Although **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. This highlights the need for coordinated reduction of NH_3 and NO_x emissions from agricultural soils, especially, since this could facilitate simultaneous reduction of nitrous oxide (N_2O) emissions, di-nitrogen (N_2) emissions, and nitrate (NO_3^-) and other reactive nitrogen leaching within the context of more efficient management of the nitrogen cycle.

145. 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)[38]. That directive describes both emission reduction commitments for years between 2020-2030 and after 2030, relative to 2005 (Annex II, Table B) and a set of specific measures for ammonia emission reduction (Annex III, part 2).[39]

146. 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.

147. Concerning revision of Annex IX, the **"Top Five" priority areas for ammonia emission abatement** were identified by TFRN (ECE/EB.AIR/WG.5/2011/16; considering availability across UNECE region, cost, contribution to emission reduction and capacity building):

148. Low-emission application of manures and fertilizers to land, including:

(a) Low emission application of slurry and solid manure from cattle, pigs and poultry. Available measures included immediate or fast incorporation into the soil, trailing hose, trailing shoe and other band spreading and injection methods, and slurry dilution via irrigation;
(b) Low-emission application of urea fertilizers. Available measures included immediate or fast incorporation into the soil, coated pellets, urease inhibitors and fertilizer substitution;

---

[34] 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)

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

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

[37] 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

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

[39] 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

2. Animal feeding strategies to reduce nitrogen excretion. Available measures included: (a) low-protein phase feeding on pig and poultry farms; and (b) low-protein supplement feeding of cattle during housing, and improved nitrogen and grazing management of grazed grassland targeted to improve nitrogen use efficiency;
3. Low emission techniques for all new stores for cattle and pig slurries and poultry manure. Available measures include covers on all new slurry tanks, use of floating covers or slurry bags, prohibition of the building of new open slurry lagoons and keeping stored poultry manure dry;
4. Strategies to improve nitrogen use efficiencies and reduce nitrogen surpluses. The priority target was to establish nitrogen balances on demonstration farms or through on-farm demonstration, as a basis to monitor improvements in nitrogen use efficiency. That priority would develop capacity across the UNECE region for wider use of nitrogen budgeting approaches after 2020;
5. Low emission techniques in new and largely rebuilt pig and poultry housing. Available measures included improved building designs, reducing the area of manure exposed to the air, keeping poultry litter dry and chemical scrubbing of exhaust air.

149. Since this list is now 10 years old, these priorities should be reviewed based on evolution of costs, innovation and policy experience.

5.4 Potential and benefits of dietary change

150. For agriculture a behavioural 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.

151. TFRN: **What is the potential for dietary change?**
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%.[40] 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.

What environmental and health benefits are associated with dietary change?
152. 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 2021 providing further details for Question 5.4. (http://www.clrtap-tfrn.org/content/epnf#Publications). The EPNF work so far depended fully on in-kind contribution of the experts; for the contribution to the GP revision document, funds for a workshop might be necessary.

c. What policy instruments are available to change diets?
153. A large number of policies to shift food demand exist (i.e. Food Based Dietary Guidelines; public procurement; food labeling; school and other education programs; marketing policies; food standards etc.), which, however, need to scale up to be more effective, and be integrated into comprehensive (food system) policy packages.

154. Also see the draft Ammonia Assessment report:

---

[40] **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

ECE_EB.AIR_WG.5_2021_7-2102624E.pdf (unece.org)

6.3 Best available measures to reduce methane

155. Methane concentrations have been increasing at a rate of about 6 ppb per year in 2007-2013 and accelerating to 10 ppb per year during 2014-2018 (Dlugokencky, E. (2020). Trends in Atmospheric Methane. NOAA Earth Systems Research Laboratory www.esrl.noaa.gov/gmd/ccgg/trends_ch4/)
Approximately half of global methane emissions are anthropogenic, with the anthropogenic methane emissions being generally better constrained than natural emissions by both bottom- up and top-down methods (Saunois et al. The Global Methane Budget 2000–2017 Earth Syst. Sci. Data, 12, 1561–1623, 2020 https://doi.org/10.5194/essd-12-1561-2020). There is no single projected future trend in methane emissions; the RCP and SSP scenarios span a wide range, depending on assumptions of socioeconomic development and mitigation levels. Methane emissions decrease (compared with the present day) in baseline versions of SSPs 1 and 2, and increase in baseline versions SSPs 3, 4, and 5. In the earlier RCP scenarios, methane emissions increase in RCP 8.5 and decrease or stay roughly constant in all three other scenarios. Trends in projected emissions from the energy and agricultural sectors dominate the projected future trends in methane emissions. Scenarios in which methane emissions decrease can be characterised either by a phasing out of reliance on fossil fuels or stronger mitigation measures. Scenarios in which methane emissions increase are characterised by increasing unmitigated emissions primarily from the energy and/or agricultural sectors.

156. Butler et al. (Butler, T., Lupascu, A., and Nalam, A.: Attribution of ground-level ozone to anthropogenic and natural sources of nitrogen oxides and reactive carbon in a global chemical transport model, Atmos. Chem. Phys., 20, 10707–10731, https://doi.org/10.5194/acp-20-10707-2020, 2020) recently estimated that methane oxidation contributes to 40% of the annual average present-day northern hemisphere concentration of ground-level ozone.

157. In Europe, changes in emissions outside Europe and global methane concentrations will largely drive future annual average O_3 levels. Without additional controls, global methane emissions are expected to grow, increasing O_3 mortality in Europe in 2050 by up to 8,000 additional premature deaths compared to 2010 levels. Implementation of mitigation policies, largely outside of Europe, can decrease methane emissions overall and decrease O_3 mortality in Europe by up to 2000 premature deaths per year compared to 2010 levels, a difference of 10,000 deaths per year between the highest and lowest global CH4 emissions scenarios. In North America, the difference between the highest and lowest global CH4 emissions scenarios corresponds to a difference of up to 5,000 deaths per year in 2050. The sectors with substantial mitigation potential are fossil fuel production, waste and wastewater management, and agriculture, with the largest emissions in China, followed by Latin America, Africa, India, and North America (vanDingenen, R., Crippa, M., Maenhout, G., Guizzardi, D. and Dentener, F. (2018) *Global trends of methane emissions and their impacts on ozone concentrations.* Publications Office of the European Union, Luxembourg, https://ec.europa.eu/jrc/en/publication/global-trends-methane-emissions-and-their-impacts-ozone-concentrations).

158. The costs and effects of methane measures can be found in:
Höglund-Isaksson, L., Gomez-Sanabria, A., Klimont, Z., Rafaj, P., & Schöpp, W. (2020). Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the GAINS model. Environmental Research Communications, (https://doi.org/10.1088/2515-7620/ab7457),

159. Several specific abatement options, including non-technical measures, are listed in the Global Methane Assessment, UNEP/CCAC (2021)
https://wedocs.unep.org/bitstream/handle/20.500.11822/35917/GMA_ES.pdf.
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

160. Maximum feasible technical abatement measures could reduce projected methane emissions in 2050 by around 50% (or 30% compared to the 1990 level). Measures that would not entail additional costs of more than 20 euro per ton of CO2-eq would enable to keep emissions at the 1990 level. Effective measures vary across regions. In Europe the most effective measure would be reduce emissions from landfills. In Russia and other EECCA countries abatement measures in the oil production sector could give a significant contribution in reducing methane emissions, while in North America abatement of emissions from unconventional gas production have the greatest potential. Further methane emission reduction would require tackling its largest remaining source: cattle. Technical measures to reduce emissions from cattle are limited. Options to reduce methane emission via changes in cattle feed are limited. Ambitious targets to reduce methane would require reduced meat and dairy consumption.

What are the (best) available emission abatement techniques and measures for the reduction of methane emissions from agriculture?

161. Considering agricultural sources, several measures are available reduce CH_4 emissions from enteric fermentation. 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.

162. Overall feeding a diet with more starch and less fibres not only produce less methane per kg feed Dry Matter, but also form a basis for higher feed intake and higher production per animal and hence will be the most efficient way to reduce the methane production per kg of meat or milk produced.[41]

163. Mitigation of CH_4 emissions from manure is also a tool that contributes to CH_4 emission mitigation. No single option appears to provide a simple and lasting solution so, a combination of different techniques seems to be the most appropriate and effective path. A summary of interactions between ammonia and methane mitigation has been provided previously by TFRN.[42]

164. 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.[43] 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.[44]

b. What is the contribution of implemented and new climate measures on the reduction of methane emissions?

165. There is potential for interaction between climate related measures on methane, nitrous oxide and ammonia. Examination of such relationships would require additional resources. For example, intensification of livestock management with indoor controlled controlled ventilation systems may provide opportunities for feeding and environmental regimes that reduce methane emission and reduce nitrous oxide emissions (by limiting grazing). However, such practices risk substantially increasing ammonia levels unless a commitment is made to use ambitious technologies to control ammonia emission from housing, manure storage and land-spreading of manure.

d. How could methane be addressed in a future instrument?

---

[41] 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

[42] http://www.clrtap-tfrn.org/content/methane-and-ammonia-air-pollution

[43] 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

[44] Cowan N., Bhatia A., Drewer J., Sutton M. et al. (under review)

166. It would be possible to specify emission limit values for methane and develop an annex of mandatory measures in agriculture. Resources would be needed to develop such an approach. All source sectors should be considered.[1]

---

[1] Note 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)

[3] https://www.umweltbundesamt.de/publikationen/oekonomische-instrumente-in-der-luftreinhaltung (a summary is available in English)

J. Flexibility provisions

167. Description of the complexity of the amended Gothenburg Protocol and its main barriers to ratification. Assessment of the adequacy and effectiveness of current flexibility provisions to facilitate further ratifications. Proposals for alternative solutions and new approaches, with pros and cons, to overcome barriers and increase ratification.

168. There is an informal document on flexibility provisions for the WGSR59 meeting. There will be a proposal to take general comments on the informal document on flexibility provisions, discuss the possibility for an informal session in Spring 2022 and continue discussion on this topic during the Review. Parties and non-Parties could send comments on the informal document on flexibility provisions to the secretariat by 15 July 2021.

K. Convention Parties that are not parties to the Protocol

1.5 (d) What barriers have been identified by Parties and non-Parties to implement the obligations in the technical annexes? **Spring 2022; WGSR**

169. Proposal for non-Parties to submit information to the Secretariat by 30 September 2021 to answer this question. WGSR could then have an agenda item in April 2022 to discuss and provide input into the Review Document. Clarify non-Parties are only to answer 1.5(d) and Parties 1.5 (a-e).

Fall 2021/spring 2022 - TFEIP/TFIAM/CIAM:

1. Key sectors with large emission reduction potential in EECCA/SEE

170. CEIP (Fall 2021) – major emitting sectors based on current emission reporting or current implementation in GAINS, if other data missing. CIAM (Spring 2022) – MTFR for future scenario defining mitigation potential and identifying key sectors. For item 3.1 c & e – see chapter on progress towards achieving objectives.

L. Canada and the United States of America

171. This section recognizes that the amended Gothenburg Protocol includes a number of commitments for parties outside the geographical scope of EMEP, which in most cases includes Canada and the United States of America, unless otherwise specified. It also recognizes that Canada and the United States are bilaterally addressing cross-border air pollution under the Canada-United States Air Quality Agreement, which includes commitments by both countries to reduce emissions of sulphur dioxide, nitrogen oxides, and volatile organic compounds. Although the review report will integrate inputs from Canada and the United States of America into the relevant chapters/sections, as appropriate to national circumstances, this section will include all other relevant information.

172. Canada and the United States of America have ratified the 1999 Gothenburg Protocol (in November 2004 and December 2018 for the United States and Canada respectively) and its 2012 amendments (in January 2017 and November 2017 for the United States and Canada respectively), and have, upon ratification, submitted their respective emission reduction commitments to annex II and relevant emission limit values into annexes IV, V, VI, VIII, X and XI. Canada and the United States of America have a long history of bilateral cooperation on transboundary air pollution through the 1991 Canada-United States Air Quality Agreement. The two countries plan to undertake a review of the effectiveness of the agreement in terms of meeting its environmental objectives as well as its sufficiency in addressing transboundary air pollution. The scope and content of the review are being finalized. It is expected to focus on issues covered by the Air Quality Agreement including acid rain and ozone and their transboundary impacts, while discussions are underway on how and whether to address fine particulate matter, as well as other appropriate additional topics. The work schedule for the review of the Air Quality Agreement is underway with a tentative completion date in 2022.

173. Ammonia is not covered by the Air Quality Agreement, but it is also of concern in Canada and the United States of America as atmospheric ammonia is a key precursor to the formation of fine particulate matter and contributes to acid deposition and eutrophication. Additional assessments are needed to quantify the impacts. Discussions are ongoing.

174. Canada and the United States are planning to develop an informal technical document in 2022 to further detail efforts in North America to address transboundary air issues to accompany the formal review report.

M. Hemispheric transport

175. Description of the role of hemispheric transport. Assessment of current and future contributions of emission sources outside the ECE region to ecosystems and health impacts in the ECE region. Assessment of emission reduction potentials outside the ECE region. Special focus on ozone and particulate matter (black carbon) and their precursors.

Preliminary contribution: QuestionsForGPReview210228.pdf (kaskada.tk)

Topic 1: Contribution of hemispheric transport to observed trends in air quality and its impacts, and future projections

176. The hemispheric contribution to ground-level ozone is larger than the hemispheric contribution to PM or its components due to ozone's longer atmospheric lifetime. The concentration of ozone experienced at any given location is the combination of ozone and ozone precursors transported from distant sources on hemispheric to regional scales and, depending on the photochemical regime, local photochemical ozone production or local ozone loss due to titration with NO. Reduction in emissions of ozone precursors in the UNECE region has led to a reduction in peak, short-term ground-level ozone concentrations associated with local photochemical production, especially in the summertime. Reduction of NOx emissions has also led to a reduction in the titration of ozone by NO, leading to higher concentrations of ground-level ozone, especially between autumn and spring, at nighttime, and in Europe. Both effects have increased the relative influence of background ozone, including ozone from hemispheric transport, on local concentrations of ozone experienced in urban areas of the UNECE region, but especially in Europe.

177. Peak ground-level ozone levels in Europe and North America have decreased strongly since 2000, but trends for annual average ozone levels are mixed, with increases at some sites and decreases at others. Average ozone levels in the free troposphere above Europe and North America, as measured by aircraft, have continued to increase, In other parts of the world, both peak levels and annual average levels of ground-level ozone have continued to increase, as have ozone levels aloft as measured by aircraft.

178. The mixed or weak trends in annual average ozone levels belie opposing trends in different seasons. In Europe, in winter (DJF) and spring (MAM) some sites have experienced weak increasing trends and others weak decreases. In summer (JJA), however, most

European sites have had strong decreases over the period 2000-2014. In autumn (SON), most sites have seen no trend or a weak decrease. In North America, winter (DJF) ground-level ozone levels strongly increased over the period 2000-2014 and summer (JJA) levels strongly decreased. Trends in spring and autumn were mixed with many sites showing no significant trends. (Chang 2017).

179. This observed trend in ground-level ozone and its impacts cannot be explained completely by precursor emission trends in Europe and North America. Downward trends of ozone precursor emissions in Europe and North America since around 1990 appear to be at least partially offset by increasing NOX and VOC emissions outside the UNECE region and increasing CH4 emissions globally.

180. The contribution of anthropogenic emission sources outside the UNECE region to PM species and their associated impacts within the UNECE region is negligible compared with the impact of local anthropogenic sources. Wildfires and wind-blown dust emanating from outside the UNECE, however, do influence PM levels and deposition in the UNECE region and are sensitive to changes in climate.

181. The absolute contribution of NOX and VOC emissions outside the UNECE region to annual average ground-level ozone in Europe and North America is not expected to change significantly under a business as usual scenario to 2050. Expected increases in global CH4 are expected to more than offset projected reductions of NOX and VOC emissions in Europe and at least partially offset reductions of NOX and VOC emissions in North America.

182. If NOx and VOC emissions were reduced everywhere by the same percentage, the emission reductions outside of Europe would have a bigger impact on European ozone levels than the emission reductions within Europe. In North America, equal percentage emission reductions of NOX and VOC outside of North America would contribute significantly to decreases of ozone in North America, but not more than the equal percentage emission reductions in North America itself.

Topic 2: Projected trends in methane, contribution to ground-level ozone, and mitigation potential

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

184. Ozone formation is strongly influenced by the atmospheric methane burden, with model studies consistently showing that higher mixing ratios of methane lead to higher background mixing ratios of ground-level ozone.

185. Due to the long lifetime of methane in the atmosphere, methane is well mixed. Decreases in surface ozone arising from methane emission control are largely independent of source location, but the local response to global methane reduction is stronger in locations where local NOx emissions are high. Equal emission reductions in any given regions will lead to the same reductions in global background ground-level ozone.

186. The fossil fuel (production and distribution) and waste sectors have the highest technical potential for reduction of methane emissions. The agricultural sector is a major source of methane emissions but has a low technical potential for reductions in methane emissions.

187. Outside the UNECE region there is currently potential for reducing methane emissions from the waste sector in China and the fossil fuel sector in the Middle East.

Topic 3: Projected trends in international shipping, contribution to ground-level ozone and N deposition, and mitigation potential

188. NOx emissions from international shipping on the global seas are projected to remain approximately constant or decrease slightly in absolute terms over the 21st century, depending on assumptions about growth in international trade and the use of emission control technology. The share of global shipping NOx as a proportion of global anthropogenic NOx emissions (currently at about 30%) is projected to vary between 10% and 60%, by the end of the century depending on the effectiveness of land-based NOx emission control.

189. Projections of the future effects of shipping on air quality in Europe has focused on the human health impact of PM2.5 from SOx and NOx emissions over European seas. Projections of the impact of global shipping NOx on baseline ground level ozone and N deposition in the UNECE region are currently lacking. Models show low agreement on the present-day effects of shipping NOx on ground-level ozone, but do agree that extra-regional sources account for up to half of N deposition in coastal regions, strongly indicating a role for shipping NOx.

190. Due to the short lifetime of NOx, it seems likely that reduction of emissions of ship NOx near coastlines has a high potential to reduce N deposition. There are some indications that the global springtime maximum in intercontinental transport of ozone is influenced by shipping NOx emitted over the high seas, but further model studies are needed to determine the strength of this influence.

Topic 4: Sufficiency of atmospheric modelling for understanding hemispheric transport of air pollution, and the main requirements for improving simulation of hemispheric transport

191. Multi-model intercomparisons show a very large spread in simulated surface ozone, which has not improved over the last decade despite higher spatial resolution and other model developments. As an ensemble, global models tend to overestimate available surface observations.

192. The source/receptor relationships for ground-level ozone from the HTAP2 multi-model exercise were not significantly different from those of the HTAP1 exercise, despite developments in individual models and closer harmonisation of the model inputs.

193. Global models disagree strongly on the magnitude of the pre-industrial to present-day trend in ground-level ozone, and tend to underestimate the magnitude of the observed trend. Projection of the contribution of hemispheric background ozone to the attainment of future targets using current models remains highly uncertain.

194. Regional ozone models generally performed better in comparison to observations than did global ozone models, which generally have lower spatial resolution than regional models. However, the best performing global models compared better to observations than did the worst performing regional models.

195. Technical challenges for improved global simulations of ground-level ozone for the UNECE region include more accurate simulation of the global methane lifetime, better resolution of the NOx chemistry of ship exhaust plumes, and better representation of ozone deposition to vegetation.

196. Model intercomparison studies such as HTAP, CCMI, and AerChemMIP exercises play a vital role in assessing the adequacy of state-of-the-art emission inventories, global models, and measurement data for informing the Convention on the impacts of extra-regional emission sources on ozone impacts in the UNECE region.

197. In addition to model development, ongoing provision of high-quality emission inventories and expansion of the global network of ozone observations for model evaluation are required.

N. Integrated multi-pollutant multi-effect approach

Fall 2021 - CIAM:

198. The GAINS model has been continuously updated including revisions of key assumptions about installation structure (especially in residential sector), emission factors, cost coefficients. A larger systematic update of the GAINS framework has been released in Spring 2021 where several updates were introduced, including: allocation of wood and coal combustion in the residential sector into urban and rural population, new waste management sector allocating waste generation and management activities into urban/rural population, possibility to include explicit representation of high emitting vehicles. Further updates will

be performed in 2021 in collaboration with MSC-W, including extension of the GAINS Europe domain to cover the whole extended EMEP domain; this will encompass also additional model capacity through so called Primary Particulate Matter (PPM) tracking, enabling downscaling beyond 10x10km, sectoral transfer coefficients allowing for improved source attribution (e.g., cities) and potentially adjusting for significant spatial shifts (due to improved data or mitigation efforts) in source distribution. Furthermore, GAINS will include consistent inclusion of condensables, new data for selected EECCA, West Balkan, Turkey (both past and future) based on the ongoing activities within EU and World Bank projects.

O. Synergies and interactions with other policy areas

6.3 (b) What is the contribution of implemented and new climate measures for reduction of methane? Spring 2021; TFIAM lead with TFTEI and TFRN

TFIAM/CIAM will present on air and climate synergies, including methane. See also 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

6.3 (d) Addressing methane in a future instrument Spring 2022; WGSR lead

- WGSR could discuss options to address, activities to focus on, but not on the technical aspects
- Likely link to discussion on International Forum for Collaboration on Air Pollution
- Potentially discuss progress and how to include methane

1. Impact of climate and energy measures on emissions reductions in the long term. Impact of new policies and measures on biodiversity, bioeconomy, circular economy, nitrogen management, etc.

199. For the EU as whole a 2050-scenario including climate policy is available, but country specific data are still confidential. Lessons (or indicative answers) on the impact of climate policy could be drawn from the EU-wide analysis (as already available in the 2nd Clean Air Outlook study for the EU), single country analysis when the EU-data is released, or from analyses made by (some) individual countries. Qualitative answers on the potential contribution to reducing ammonia emissions of promoting the bioeconomy and circular economy as well as integrated nitrogen management, will be formulated in co-operation with TFRN. Studies presented at TFIAM48 reconfirm the potential co-benefits for air quality of reaching the 2 degrees climate target (Task Force on Integrated Assessment Modelling - TFIAM - IIASA). The Task Force noted that these co-benefits will not be enough for reaching the long-term objectives of the Air Convention. Remaining nitrogen problems would require additional action. An integrated design of climate and air quality policy is needed to deal with policy trade-offs: fuel switch for climate reasons should not worsen (local or regional) air quality, and air pollution strategies should aim to be at least climate neutral. GAINS analyses[45] showed that a wider perspective on air pollution control (considering more than end-of-pipe measures and involving policies aimed at various sustainable development goals including also measures in agriculture addressing reduced meat consumption and improving nitrogen use efficiency) would be needed to reach WHO air quality targets. This also confirms the need for an integrated approach to air pollution taking into account other environmental issues.

2. Contribution of implemented and new climate measures on the reduction of methane emissions

---

[45] Amann M et al. (2020) Reducing global air pollution: the scope for further policy interventions. Phil. Trans. R. Soc. A 378: 20190331. http://dx.doi.org/10.1098/rsta.2019.0331

200. A peer-reviewed studies are available by IIASA[46] and JRC (Rita van Dingenen, et al) on emission trends (including climate policy) and available additional measures to reduce methane emissions. Current policy focusses on emission reduction from waste and gas exploration. Gas recovery from landfills and reduced use of fossil fuels are important measures. Additional measures would have to focus on emissions from cattle, with a combination of changes in cattle feed, as well as reduced livestock and reduced meat consumption, as the technical potential to reduce methane emissions seems low.

3.5(a) (CIAM, TFIAM, TFTEI)

[TFTEI] the work carried out by TFIAM (lead body) in collaboration with TFTEI on cost of inaction will provide elements to answer the question

6.3(b) (TFIAM, TFTEI)

[TFTEI] The effects of the implemented measures are mainly matter of Integrated Assessment Modelling. Additional elements may come from background studies like that carried out by TFTEI, mentioned above

P. Progress towards achieving the objectives of the Protocol

Fall 2021 - CIAM/TFIAM, TFTEI, CEIP, TFRN:

1. The latest emission projections by Parties compared with the latest GAINS -scenarios, taking into account recent climate, energy and agricultural policies, new source legislations and latest updated emission inventories

201. For EU-countries, an updated set of GAINS-scenarios including existing policies as well as National Air Pollution Control Programmes (NAPCP) has been developed for the baseline scenario and a scenario with climate policies; these are available in: https://ec.europa.eu/environment/air/pdf/CAO2-MAIN-final-21Dec20.pdf. Comparable analyses for non-EU countries are dependent on the completeness of national projections delivered to CEIP and the updated GAINS scenarios for these countries. Model calculations for EU-countries show that full implementation of emission limit value regulations would enable parties to meet national emission reduction obligations for SO2, NOx, NMVOC and PPM2.5, assuming an average lifetime of existing installations and vehicles. Slower than average replacement could be a reason to miss the deadline. Many parties have difficulties to meet the ammonia reduction obligation, even with implementation of emission limit values for new large stables (https://iiasa.ac.at/web/home/research/researchPrograms/air/policy/past_meetings.html.

2. Will the Protocol obligations be met based on latest emission projections?

202. The latest CAO2 analysis for EU countries shows that all countries will meet the 2005-2020 reduction obligations for SO2. Four out of 27 countries will only meet the 2020 obligation for NOx a few years later (among which France and Germany), two countries will meet the NMVOC target later than 2020 and seven countries will meet the primary PM2.5 obligation only after 2020 (without correcting for condensable PM-emissions). The NH3 obligation seems to be the most challenging one: ten countries will miss the 2020-target. Even with additional measures in the NAPCP and additional climate policies up to 2030, Denmark, Estonia, Finland, Ireland, Latvia and Lithuania will not meet the ammonia obligation. Also see: Assessment report on ammonia ECE_EB.AIR_WG.5_2021_7-2102624E.pdf (unece.org), in French: ECE/EB.AIR/WG.5/2021/7 (unece.org) and in

---

[46] 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

Russian: ECE/EB.AIR/WG.5/2021/7 (unece.org); and: Ammonia_inf_doc_for_WGSR58__note_from_TFRN__TFIAM_.pdf (unece.org).

3. The optimized emission reduction obligations, given the updated emission inventories and projections and the same gap-closure ambitions as used in the preparation of the amended Gothenburg Protocol

203. Preliminary optimization calculations for 2020 and 2030 are planned to be made *late 2021* depending on the availability of updated emission inventories (for 2005) and projections for non-EU countries. Final optimization calculations are planned for *spring 2022*, including the sensitivity for including condensable PM-emissions, NOx and NMVOC from agricultural land, and deposition reduction targets for marine ecosystems (provided that credible targets are made available in time by the WGE). CIAM could recalculate ambition scenarios as used in 2011. Alternatively CIAM might explore what emission reductions would be needed for attainment of critical loads and levels and the WHO air quality guidelines.

4. Are emission reduction obligations adequate for meeting long term environmental and health protection targets of the protocol? E.g. what will be the outcomes for health risks from ozone and particulate matter and for nitrogen deposition in 2030 and 2050

204. With updated relative risk factors from TFH, updated critical load maps from CCE and updated damage functions for vegetation of ozone fluxes from ICP-Vegetation GAINS could estimate the remaining risks for health, ecosystems and crops, assuming 1) full implementation of the 2020 emission reduction obligations; 2) emission projections for 2030 based on national air pollution control programmes, and possibly: 3) tentative emission projections for 2050 assuming implementation of climate policies (currently only available for the EU as a whole). For non-EU countries that ratified the protocol similar projections exist in GAINS. GAINS will look at the share of ecosystems with exceedances of critical loads and excess ozone in countries and the remaining health risks. Deposition and air quality data from the three scenarios will also be shared with WGE-groups to further analyse the impacts for specific end points, such as biodiversity. Based on current difficulties and slow progress in reduction of ammonia emissions, the exceedance of nitrogen critical loads would likely stick out at as a remaining challenge, and probably also the high share of secondary aerosols (e.g., ammonium-nitrate) in population exposure to PM2.5.

5. The estimated reductions based on the best available emission projections for non-Parties to the revised protocol. Will these reductions contribute to meeting long term environmental and health protection targets?

205. In the absence of the harmonized projections for the non-parties to the Protocol (non-EU West Balkan and EECCA) several alternative sources will be used and implemented in GAINS; these include EU project on West Balkan and EECCA and the IEA/FAO projections. CEIP and TFTEI will be involved to get a most up-to-date picture of current legislation and actual current implementation of abatement technologies. Bilateral communication with the parties involved will depend on available co-funding and time (and should probable be postponed to the revision phase of the protocol. Uncertainties about the actual implementation of measures will probably remain significant. Based on the emission projections impacts for health and ecosystems will be estimated. CIAM/IIASA will develop emission trends for all species. CIAM/IIASA and MSC-W will jointly (in parallel) calculate the concentration and deposition as well as perform assessment of environmental impacts and distance to environmental and health targets.

6. Will implementation of best available techniques and emission limit values and other technical provisions be adequate for meeting long term environmental and health protection targets of the protocol beyond 2020?

206. CIAM/IIASA will develop the MTFR scenario considering the BAT and ambitious ELVs as defined in the technical annexes. IIASA and MSC-W will perform concentration and deposition calculation evaluating health and environmental impacts.

7. Contribution to meeting environmental and health protection targets if non-Parties to the revised protocol implemented best available techniques and the emission limit values and other technical provisions set in the technical annexes

207. CIAM is currently updating (best available) emission projections for several EECCA- and west-Balkan countries, including Turkey, for both current legislation and with maximum feasible technical measures. Based on these projections, an assessment will be made of the remaining risks for health and ecosystems. CEIP and TFTEI will be involved to get a most up-to-date picture of applicable technologies and their potential in the concerned countries. Based on the emission projections impacts for health and ecosystems will be estimated.

Fall 2022 - TFIAM/CIAM , TFTEI:

8. The costs of additional measures in the region that would not exceed the external costs of inaction, with due consideration of synergies and other interactions with and more cost-effective measures potentially available in other policy areas. In which sectors can such be found?

208. A TFIAM/TFTEI-report on the Costs of Inaction will be available in the coming months. See informal document: Cost_of_inaction_TFIAM_two_pager.pdf (unece.org). Identification of cost-effective actions to reduce ammonia emissions will be identified with TFRN. There are opportunities to reduce the costs of (end-of-pipe) abatement measures when air quality policy can be combined with policy measures to reduce the use of fossil fuels, the number of car kilometres driven and the production and consumption of meat and dairy. GAINS costs will be updated with the latest data from TFTEI and TFRN. The GAINS model will provide an optimized (either at the ECE level or country level) portfolio of additional measures whose cost will not exceed the cost of inaction at the regional or country level. The scenario will consider the synergies with other policies including climate targets as well as nitrogen use efficiency improvements. GAINS costs will be updated with the latest data from TFTEI and TFRN. The GAINS model will provide an optimized (either at the ECE level or country level) portfolio of additional measures whose cost will not exceed the cost of inaction at the regional or country level. The scenario will consider the synergies with other policies including climate targets as well as nitrogen use efficiency improvements.

Fall 2022: TFIAM/EPCAC:

9. Are additional local air quality measures sufficient and cost-effective to reduce health risks or strive towards WHO air quality guideline values (or to strive towards updated WHO values, if available on time)?

209. Local traffic measures are effective to reduce the health burden for people living along busy roads that are exposed to high pollution levels. Further, with local permitting of installations and equipment use, cities can stimulate early replacement of old installations, wood stoves and non-road mobile machinery in favour of newer ones, that comply with stricter emission limit values. In many cities (not only in Europe, but all over the world), to reduce the average exposure of the urban populations as a whole. Even in large cities like Berlin and London, there is a large regional and transboundary contribution to the concentration of particulate matter at traffic stations. Long-range transport of fine particulate matter, NO_2 and ozone contribute significantly to local air quality and related impacts on health and ecosystems. WHO guideline values could not be achieved unless those sources outside the city itself were also addressed, emphasizing the need for a multiscale governance approach. Nevertheless it is clear that all cities were net exporters of pollution (Task Force on Integrated Assessment Modelling - TFIAM - IIASA).

3.1 (CIAM, TFIAM, TFTEI, TFRN, TFEIP)

[TFTEI] The effects of the measures and other instruments (e.g. ELVs) are mainly matter of Integrated Assessment Modelling. CIAM could provide input on the effects of best available technology implemention in *spring 2022.*

3.5(a), 3.5(b), 3.5(c) (CIAM, TFIAM, TFTEI)

Work on the costs of inaction is carried out by TFIAM (lead body) in collaboration with TFTEI. Elements are provided by the upcoming Costs of Inaction (IVL), the EEA-report (INERIS/EMRC) on damage estimates of emissions and the OECD-report (The Economic Benefits of Air Quality Improvements in Arctic Council Countries | en | OECD).

3.6 (TFIAM)

Input on effective local measures is expected from the Expert Panel on Clean Air in Cities, the JRC, and several national experts including those from Italy and the UK.

4.2(a), 4.2(b), 4.4 (TFTEI, CIAM, TFIAM)

[TFTEI] The effects of the implemented measures on black carbon and PAH are mainly matter of Integrated Assessment Modelling. TFTEI contributes with the background technical documents on the abatement technologies. CIAM will include projections on elemental carbon and organic carbon in scenarios for current legislation and maximum technical feasible reductions.

Q. Additional policy issues: Note: this section no longer exists in the Draft Review. Condensables is currently in III and VI.E. GPG needs to discuss where information on the other articles will be included.

210. Assessment of adequacy and suitability of key articles (including but not limited to objectives in article 2, reporting provisions in article 7, review provisions in article 10, adjustment provisions in article 13, and amendments procedures in article 13bis) of the amended Gothenburg Protocol. Assessment of the need and best approach to include methane in a future instrument. Description of the policy implications of including condensable particles in reporting of emissions of particulate matter.

6.2 (a) Are key articles on inter alia objectives, reporting obligations and amendments still fit for purpose? **Fall 2022; WGSR Lead**

211. Proposal to collect preliminary views from Parties by 30 September 2021 and make clear that it concerns an evaluation of current articles, and whether or not they are effective to meet the objective of the Protocol and not yet in the context of a possible revision. The GPG will then make proposals in Draft 2 of the Review based on any views received. The following articles could be reviewed:

-Article 1. Any new/modified definitions?
-Article 2. Is 1. (a)-(f) sufficient to meet the objective?
-Article 3. Is implementation of the basic obligations sufficient to meet the objective of the Protocol? (Annex I answers will help inform)
-Article 4. Exchange of Information
-Article 5. Public Awareness
-Article 6. Strategies, Policies, Programmes, Measures and Information
-Article 7. Reporting
-Article 8. Research, Development and Monitoring
-Article 12. Annexes (TFTEI and TFRN Review) Others?
-Article 13. Adjustments

6.2(b) Do articles 4 (exchange of information) and 8 (research and development) adequately address international cooperation and integrated environmental policy as indicated in the LTS for 2020-2030 and beyond? **Fall 2022; WGSR lead**

212. Proposal for parties and subsidiary bodies to send in views on these Articles by 30 September 2021 to the Secretariat.

6.5: Policy Implications for condensables; **May 2021; WGSR lead with EMEP/WGE**

213. Include a paragraph in the draft review that gives an update/discussion from May WGSR59 (Section F. para 12 of outline).

- Basic science questions need answered first before policy discussions begin
- Not all information will be available for discussion in May – will just give an update on progress
- Need additional clarity on what policy implications would be if condensables are included in emissions inventories and projections, it would be useful to list those issues more clearly

R. Conclusions

214. Description of main review findings and conclusions on the adequacy of the obligations and the progress made towards the achievement of the objectives of the amended Gothenburg Protocol. Recommendations for next steps and further work.

Sources (to be further converted to footnotes)

TFIAM references on trends in urban air quality

Degrauewe, B., Pisoni, E., Peduzzi, E., De Meij, A., Monforti-Ferrario, F., Bodis, K., Mascherpa, A., AstorgaLlorens, M., Thunis, P and Vignati, E., Urban NO2 Atlas, EUR 29943 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-10386-8, doi:10.2760/43523, JRC118193

P. Thunis, B. Degraeuwe, E. Pisoni, M. Trombetti, E. Peduzzi, C.A. Belis, J. Wilson, E. Vignati, Urban PM2.5 Atlas - Air Quality in European cities, EUR 28804 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-73876-0, doi:10.2760/336669, JRC108595

Kiesewetter et al. (2013) Modelling compliance with NO2 and PM10 air quality limit values in the GAINS model. TSAP Report #9. IIASA/JRC/INERIS. March 2013. https://iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP-Report-_9-v1_final-MA.pdf

Kiesewetter and Amann (2014) Urban PM2.5 levels under the EU Clean Air Policy Package. TSAP Report #12. IIASA. Oct. 2014. https://iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP_12_final_v1.pdf

ICP Waters references

Velle et al. 2016. Biodiversity of macro-invertebrates in acid-sensitive waters: trends and relations to water chemistry and climate. ICP Waters report 127/2017. NIVA report 7077-2016.

Garmo, Ø.A., De Wit, H.A. and Fjellheim, A. 2015. Chemical and biological recovery in acid-sensitive waters: trends and prognosis. ICP Waters report 119/2015. NIVA report 6847-2015.

ICP Forests references

ICP Forests Brief No. 4 (2020). Increased evidence of nutrient imbalances in forest trees across Europe forests.

Johnson et al. (2018). The response of soil solution chemistry in European forests to decreasing acid deposition. Global Change Biology 24:3603–3619.

Jonard et al. (2015). Tree mineral nutrition is deteriorating in Europe. Global Change Biology 21, 418–430.

Waldner et al. (2015). Exceedance of critical loads and of critical limits impacts tree nutrition across Europe. Annals of Forest Science 72:929–939.

Araminiene et al. (2019). Trends and inter-relationships of ground-level ozone metrics and forest health in Lithuania. Science of the Total Environment 658, 1265-1277.

De Marco et al. (2017). Ozone exposure affects tree defoliation in a continental climate. Science of the Total Environment 596-597, 396-404.
Etzold et al. (2020). Nitrogen deposition is the most important environmental driver of growth of pure, even-aged and managed European forests. Forest Ecology and Management 458.
Ferretti et al. (2020). In: FOREST EUROPE, 2020: State of Europe's Forests 2020.
Ferretti et al. (2018). Scarce evidence of ozone effect on recent health and productivity of alpine forests—a case study in Trentino, N. Italy. Environmental Science and Pollution Research 25 (9), 8217–8232.
ICP Forests Brief 3 (2018). Ozone concentrations are decreasing but exposure remains high in European forests

ICP IM references

Dirnböck, T. 2018. Currently legislated decreases in nitrogen deposition will yield only limited plant species recovery in European forests. Environmental Research Letters 13 (2018) 125010. DOI: https://doi.org/10.1088/1748-9326/aaf26b

Forsius, M., et al. 2020. Assessing critical load exceedances and ecosystem impacts of anthropogenic nitrogen and sulphur deposition at unmanaged forested catchments in Europe. Science of The Total Environment 753: 141791. https://doi.org/10.1016/j.scitotenv.2020.141791

Grennfelt, P., Engleryd, A., Forsius, M., Hov, Ø., Rodhe, H. and Cowling. E. 2020. Acid rain and air pollution– 50 years of progress in environmental science and policy. Ambio 49: 849–864. https://doi.org/10.1007/s13280-019-01244-4

Holmberg, M. et al. 2018. Modelling study of soil C, N and pH response to air pollution and climate change using European LTER site observations. Science of the Total Environment 640–641: 387–399. https://doi.org/10.1016/j.scitotenv.2018.05.299

Kulmala, M. 2018. Build a global Earth observatory. Nature 553: 21–23. https://media.nature.com/original/magazine-assets/d41586-017-08967-y/d41586-017-08967-y.pdf

Posch, M. et al. 2019. Dynamic modeling and target loads of sulfur and nitrogen for surface waters in Finland, Norway, Sweden, and the United Kingdom. Environmental Science & Technology 53(9): 5062-5070. https://doi.org/10.1021/acs.est.8b06356

Vuorenmaa, J. et al. 2018. Long-term changes (1990–2015) in the atmospheric deposition and runoff water chemistry of sulphate, inorganic nitrogen and acidity for forested catchments in Europe in relation to changes in emissions and hydrometeorological conditions. Science of the Total Environment 625: 1129–1145. https://doi.org/10.1016/j.scitotenv.2017.12.245

Vuorenmaa, J. et al. 2020. Long-term changes in the inorganic nitrogen output in European ICP Integrated Monitoring catchments – an assessment of the impact of internal nitrogen-related parameters and exceedances of critical loads of eutrophication, in Kleemola and Forsius, eds., 29th Annual Report 2020: Convention on Long-range Transboundary Air Pollution, International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems, Reports of the Finnish Environment Institute, pp. 35–45.

Weldon, J. 2018. Post disturbance vegetation succession and resilience in forest ecosystems – a literature review, in Sirpa Kleemola and Martin Forsius, eds., 27th Annual Report 2018: Convention on Long-range Transboundary Air Pollution. International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems, Reports of the Finnish Environment Institute, No. 20 (Helsinki, 2018), pp. 39-52, available at http://hdl.handle.net/10138/238583

Weldon, J. and Grandin, U. 2021. Weak recovery of epiphytic lichen communities in Sweden over 20 years of rapid air pollution decline. The Lichenologist 53: 203-213. https://doi.org/10.1017/S0024282921000037