Convention on Long-range Transboundary Air Pollution

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Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe

STATUS REPORT 1/2021

Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components

Status Report 1/2021

msc-w & ccc & ceip

EMEP Report 1/2021
Date: September 3, 2021

METEOROLOGISK INSTITUTT
Norwegian Meteorological Institute

Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components

EMEP/MSC-W:	Hilde Fagerli, Svetlana Tsyro, David Simpson, Ágnes Nyíri, Peter Wind, Michael Gauss, Anna Benedictow, Heiko Klein, Alvaro Valdebenito, Qing Mu, Eivind Grøtting Wærsted, Jonas Gliß, Hans Brenna, Augustin Mortier, Jan Griesfeller
EMEP/CCC:	Wenche Aas, Anne Hjellbrekke, Sverre Solberg, Kjetil Tørseth, Karl Espen Yttri
EMEP/CEIP:	Katarina Mareckova, Bradley Matthews, Sabine Schindlbacher, Bernhard Ullrich, Robert Wankmüller
CCE/UBA:	Thomas Scheuschner
TNO:	Jeroen J.P. Kuenen,

EMEP Status Report 2021; September 3, 2021

ISSN 1504-6109 (print)
ISSN 1504-6192 (on-line)

Executive Summary

This report presents the EMEP activities in 2020 and 2021 in relation to transboundary fluxes of particulate matter, photo-oxidants, acidifying and eutrophying components, with focus on results for 2019. It presents major results of the activities related to emission inventories, observations and modelling. This year, special attention has been given to the trends in air pollution during the last decades, in support of the Gothenburg Protocol review.

Measurements and model results for 2019

In the first chapter, the status of air pollution in 2019 is presented, combining meteorological information and emissions with numerical simulations using the EMEP MSC-W model together with observed air concentration and deposition data.

Altogether 33 Parties reported measurement data for 2019, from 168 sites in total. Of these, 120 sites reported measurements of inorganic ions in precipitation and/or main components in air; 73 of these sites had co-located measurements in both air and precipitation. The ozone network consisted of 138 sites, particulate matter was measured at 78 sites, of which 50 performed measurements of both PM_{10} and $PM_{2.5}$. In addition, 56 sites from 21 Parties reported at least one of the components required in the advanced EMEP measurement program (level 2). However, only a few sites provided a complete level 2 program, i.e. only 12 sites have implemented all the required aerosol parameters.

In 2019, the mean daily maximum O_3, SOMO35 and AOT40 all show a distinct gradient with levels increasing from north to south, a well established feature for ozone reflecting the dependence of ozone on the photochemical conditions. The geographical pattern in the measured values is fairly well reflected by the model results for all these three metrics. Peak levels of surface O_3 were high in 2019, and this was linked to extreme heat waves in June and July. The national temperature records were broken in France, United Kingdom and Germany this year, and associated with these episodes very high ozone levels were observed. Some stations registered the highest peak ozone levels since the mid 1990s. Many countries reported levels above EU's information threshold (180 μg m^{-3}) and some even above the alert threshold (240 μg m^{-3}). This confirms the strong link between weather conditions and surface ozone and is a signal that future climate change could have a substantial influence on the frequency and intensity of ozone episodes in Europe.

Overall, the year 2019 was quite moderate with respect to PM air pollution in Europe, which was due to a mild winter and excessive precipitation in the cold seasons (especially autumn) in many parts of Europe.

The results from the EMEP MSC-W model simulations and the observations show general increases in the annual mean levels of PM_{10} and $PM_{2.5}$ over land from north to south. The regional background PM_{10} concentrations are below 5 μg m^{-3} in Northern Europe (also below 5 μg m^{-3} for $PM_{2.5}$), increasing to 15 μg m^{-3} (10 μg m^{-3} for $PM_{2.5}$) further south. The annual mean PM_{10} is in excess of 20 μg m^{-3} in the Po Valley and in Cyprus. The observations also show PM_{10} concentrations above 20 μg m^{-3} in Slovakia. $PM_{2.5}$ concentrations are below 10 μg m^{-3} over most of the EMEP domain, and between 10 and 15 μg m^{-3} in parts of the Benelux region, Poland, Hungary and some Balkan countries. Furthermore, the model calculates high PM_{10} for the regions east of the Caspian Sea and over the southern Mediterranean, with annual mean concentrations in excess of 50 μg m^{-3} due to windblown dust from arid soils and deserts. There is a good general agreement between the modelled and observed distributions of annual mean PM_{10} and $PM_{2.5}$.Overall, the model underestimates the observed annual mean of PM_{10} by 12% and $PM_{2.5}$ by 13% .

Model results and EMEP observational sites show that the annual mean regional background PM_{10} concentrations were below the EU limit value of 40 μg m^{-3} for all of Europe in 2019. The model calculates annual mean PM_{10} above the WHO recommended Air Quality Guideline (AQG) of 20 μg m^{-3} for only small regions in the Po Valley and western Turkey. The highest observed annual mean PM_{10} concentration, exceeding the AQG of 20 μg m^{-3} , was registered at two Slovakian and one Greek site. Further, the joint model and observational results show that annual mean regional background $PM_{2.5}$ concentrations in 2019 were below the EU limit value of 25 μg m^{-3} (except in the Po Valley according to the model). However, there were observed cases of exceedance of the WHO AQG value of 10 μg m^{-3} (for $PM_{2.5}$) at nine sites.

A lot of rain in November-December combined with the mild winter temperatures resulted in the absence of major PM episodes in 2019 typical for Europe in winters. Overall, the number of days with PM exceedances, observed and modelled for EMEP sites for 2019, was the smallest in the last decade. PM_{10} daily concentrations in excess of 50 μg m^{-3} were observed at 31 out of 67 sites in 2019, but no violation of the PM_{10} EU limit value (more than 35 exceedance days) were registered. Still, 12 sites had more than 3 exceedance days, i.e. exceeded the limit recommended by the WHO AQG. Regional background $PM_{2.5}$ concentrations exceeded the WHO AQG recommended limit of 25 μg m^{-3} at 37 out of 51 stations in 2019. Among those, the number of exceedance days was more than 3 at 21 sites. Most of the exceedances registered at the central European sites occurred in winter and spring, while rather few exceedances occurred in the autumn of 2019. By contrast, at the Mediterranean sites the exceedances were more frequent in summer. PM exceedances simulated by the EMEP MSC-W model correspond in general quite well with the EMEP observations, with some tendency of underestimating the occurrence of exceedances for Central European sites, while overestimating those for some of the Mediterranean sites, which are heavily influenced by desert dust.

Status of emission reporting

In 2021, 48 out of 51 Parties (94%) submitted emission inventories to the EMEP Centre on Emission Inventories and Projections (CEIP), and 42 Parties reported black carbon (BC) emissions. As 2021 is a reporting year for large point sources (LPS) and gridded emissions, 32 Parties reported information on LPS, while 26 Parties reported gridded data. The quality of reported emission data differs significantly across countries, and the uncertainty of the data is considered to be relatively high.

After the first round of submissions in 2017, 2021 was the second year for which EMEP countries were obliged to report gridded emissions in $0.1^{\circ}\times0.1^{\circ}$ longitude/latitude resolution. Until June 2021, 34 of the 48 countries which are considered to be part of the EMEP area reported sectoral gridded emissions in this resolution. For remaining areas, missing emissions are gap-filled and spatially distributed using expert estimates.

Estimates of PM emissions, as currently provided by Parties, have a number of major uncertainties, and there is a clear need for clarification and standardisation of the methods used to define and report PM emissions. Previous work has clearly shown that the definitions behind national emission estimates are inconsistent in their treatment of condensable organics: some countries explicitly do not include condensables in their PM inventories, some likely include condensables and for some it is mixed or unclear.

The treatment of condensable organics in emission factors is best known for the emissions from the energy sector and road transport, while it is less clear for small-scale combustion, which is one of the sources where the largest impact on the emission factor occurs.

To improve the quality of the input data for air quality models, and following a decision of the EMEP Bureaux, the group of experts at the expert workshop on condensable organics hosted by MSC-W in 2020 agreed on the following approach: 1) in year one (2020) use the so-called REF2 emission data provided by TNO, which include condensable organics, as an initial estimate for residential combustion emissions and 2) in subsequent years these top-down estimates should be increasingly replaced by national estimates.

Therefore, in 2021, CEIP in co-operation with TNO prepared a list of Parties where it could be assumed with a good degree of certainty that the condensable component is mostly included in PM emissions for GNFR sector C (small-scale combustion). For these Parties the reported PM emissions were used, while for other Parties the TNO REF2.1 data were used for GNFR sector C. The resulting GNFR C dataset was combined with official EMEP emissions into the so-called EMEPwREF2.1C emission dataset. This emission dataset has been used in the assessment of the air quality situation in Europe and the source receptor calculations for 2019 made this year.

Trends in air pollution 2000-2019

In December 2019, the Executive Body launched the review of the Gothenburg Protocol as amended in 2012. In order to support the review and assess the progress made towards achieving the environmental and health objectives of the Protocol, we present an assessment of the trends in air pollution in Europe for the period 2000–2019, based on long term observational data from the EMEP network as well as on EMEP MSC-W model calculations. We analyze trends in air concentrations for ozone, sulfur dioxide, particulate matter (and their species; sulfate, nitrate, ammonium, elemental carbon and organic carbon), oxidized and reduced nitrogen as well as wet deposition of sulfur and nitrogen species. In addition, we present trends in some indicators of health and vegetation risk (SOMO35, exceedances of WHO guideline values for $PM_{2.5}$ and PM_{10}, AOT40 for forests and crops, and exceedances of critical loads for acidification and eutrophication for every 5th year since 2000). Unfortunately, the EMEP observational network is dominated by sites in the western part of the EMEP domain and has hardly any coverage in the EECCA countries. Therefore, the assessment discussed below is only valid for a part of the EMEP domain. Furthermore, the developments of emissions in the western and eastern parts of the EMEP domain have followed different patterns, with clear decreases of most pollutants in the western countries, but more stable (albeit gradually decreasing for most pollutants) in the eastern part of the domain over the 2000–2019 period. Thus, the trends in the eastern part of the EMEP domain are expected to be different than those presented here for the western part of the domain. Note also that many of the emission time series for the eastern countries have been partially or fully replaced with independent emission estimates due to quality issues or lack of reported data and thus are considered to be uncertain. Furthermore, for the different components analyzed, the number of observational sites available and the geographical coverage differs. Thus, the trends for the different components are not fully consistent.

Sulfur

The SO_x emissions in the EU27+UK+EFTA countries have declined by more than 80% the last two decades. The decrease is reflected in both the observed and modelled trends for all the atmospheric sulfur components. The average total reductions in observations for the last 20 years (2000–2019) are 74% for SO_2, 61% for SO_4^{2-} in aerosols and 60% for wet deposition of sulfur, respectively, while the reductions in model calculations are somewhat larger: 97%, 72% and 81%, respectively.

Oxidized nitrogen

We find that oxidized nitrogen in precipitation and in air (NO_2, HNO_3, NO_3^- aerosol and the sum of HNO_3 and NO_3^- aerosol) has been decreasing since 2000. However, the reductions in the observations for NO_2 (24%) and for wet deposition of oxidized nitrogen (26%) are smaller than in model calculations (42% for NO_2 and 40% for wet deposition of oxidized nitrogen). Similar results are found for other oxidized nitrogen components, although the difference between model results and observations is smaller (e.g. observed NO_3^- is reduced by 38% and in modelled by 47%). The reductions in observations are also significantly smaller than the changes in reported emissions of NO_2 (-48% for EU27+UK+EFTA countries) for 2000–2019.

It is not clear why the reductions in the reported emissions of oxidized nitrogen (and sulfur) and the trends calculated by the model are larger than those seen in the observations, but it might potentially indicate that the emission reductions reported are somewhat optimistic for some countries.

Reduced nitrogen

For reduced nitrogen, the observations and the model calculations confirm that only very small reductions of ammonia emissions have been achieved in the 2000–2019 period. Both observations and model calculations find very few significant trends in wet deposition of reduced nitrogen. On the contrary, total ammonium (NH_3 + NH_4^+) in air has decreased by about 27% in observations and by 25% in model calculations, with many more sites showing statistically significant trends. These changes are larger than the reduction in ammonia emissions for EU27+UK+EFTA countries (12%) for 2000–2019. The reduction for ammonium aerosols is even larger, around 49%, both in observations and model calculations. Very few sites have long term time series of ammonia in air (8 sites), and for very few of those sites the changes are statistically significant. However, on average, the changes in observed and calculated concentrations are positive.

These large differences between the changes found for the different reduced nitrogen components can be explained by the interaction of ammonia with the sulfur and oxidized nitrogen components. It can be noted that the results imply that the contribution of ammonia emissions to aerosols has been largely reduced during the 2000–2019 period, due to the impact of SO_x and NO_x emission reductions.

EC and OC

For EC and OC we have calculated observed and modelled trends for 15 sites across Europe for the period 2010–2019. A reduction of ca. 4.5 %/yr in observed EC was found, and a similar reduction was found for OC in the winter months (when OC is expected to be most sensitive to primary anthropogenic emissions rather than to OA associated with biogenic sources). These trends suggest that abatement measures are having some success in reducing both EC and OC in Europe, especially in wintertime. Trends in summertime OC were much less clear in both the model and observations, almost certainly due to the increased impact of biogenic sources. The model reproduced observed EC values and trends quite well, but underpredicted OC, both in terms of absolute values and trends. This underprediction is at least partly due to the omission of condensable organics in the reported emissions from many countries. Organic aerosol comprises a major fraction of $PM_{2.5}$, but major efforts are needed to separate and understand its natural and anthropogenic components, in order to get a quantitative overview of the abatable fractions.

PM_{10} and $PM_{2.5}$

For PM_{10} and $PM_{2.5}$, statistically significant downward trends are identified for the majority of the sites for the period 2000–2019. During this 20-year period, observed PM_{10} concentrations decreased by 35% (37% in model simulations) on average. The average observed decrease of $PM_{2.5}$ was 46% (48% estimated by the model). The smaller reductions in PM_{10} than in $PM_{2.5}$ can be explained by the larger contribution of natural aerosols (i.e. sea salt and windblown dust) in the coarse fraction of PM_{10}.

PM is a complex pollutant, consisting of aerosol species both emitted directly and formed from gaseous precursors. Reduction in the secondary inorganic aerosols (SO_4^{2-}, NO_3^- and NH_4^+) components contributed substantially to the PM_{10} and $PM_{2.5}$ decreases in 2000–2019. The contribution from EC and OC is more difficult to quantify due to the lack of observation in the 2000s. However, as described in the previous subsection, considerable reductions in EC and wintertime OC have been found for the 2010–2019 period. The model reproduce the observed relative PM trends well, but underestimates the absolute levels and trends, at least partly due to the lack of condensable organics in the reported emissions from many countries.

The number of EMEP sites, at which annual mean PM_{10} and $PM_{2.5}$ concentrations exceeded WHO AQG[1] recommended levels, decreased in the period 2001–2019. It should be pointed out that these results cannot be considered very robust as the number of sites with exceedances is small.

[1]AQG = Air Quality Guidelines. The recommended levels are 20 and 10 $\mu g\,m^{-3}$ for PM_{10} and $PM_{2.5}$, respectively

Ozone

Trends in six annual percentiles of daily maximum O_3 as well as three aggregated metrics (AOT40 for crops, AOT40 for forests and SOMO35) were calculated for the period 2000–2019. For the high percentiles as well as for the three aggregated metrics both the model values and the observations show a decrease during this period when averaged over the stations. The observations show a mean decrease of 0.5-1.5 %/yr relative to 2000 over this 20 years period for the three aggregated metrics while the model calculates somewhat larger reductions, of the order of 0.9-2 %/yr. For the 99th percentile of the annual daily maximum values, corresponding to the 4th highest ozone concentration, the mean of the observed and modelled values agree very well for sites north of 49°N, both showing a reduction of the order of 0.5 %/yr relative to 2000. For sites south of 49°N the observations show a similar relative reduction on average, whereas the model calculates stronger reductions. Comparisons of the observed and modelled absolute concentration levels of O_3 reveal that the model underpredicts the high percentile and overpredicts the AOT40 levels. The underprediction increases with higher percentiles and is strongest for sites south of 49°N. The modelled downward trend in the high percentiles is, however, of the same order if comparing absolute levels. For SOMO35, the trend in the model values agrees well with the observed levels.

Exceedances of critical loads

The exceedances (AAE) of critical loads have been calculated for the years 2000, 2005, 2010, 2015 and 2019 based on the $0.1° \times 0.1°$EMEP MSC-W calculations discussed in this report. The critical loads for eutrophication are exceeded in practically all countries in all years. The share of ecosystems where the critical load for eutrophication is exceeded decreases relatively slowly, starting at 76.4% in 2000 and ending at 65.5% in 2019. The European average AAE is about 452 eq ha^{-1} yr^{-1} (2000) and 276 eq ha^{-1} yr^{-1} (2019). The highest exceedances of critical loads are found in the Po Valley in Italy, the Dutch-German-Danish border areas and in north-eastern Spain.

By contrast, critical loads of acidity are exceeded in a much smaller area. Hotspots of exceedances can be found in the Netherlands and its border areas to Germany and Belgium, and some smaller maxima in southern Germany and Czechia, whereas most of Europe is not exceeded. Acidity exceedances occur on 16.2% (2000) and 5.0% (2019) of the ecosystem area and the European average AAE is about 133 eq ha^{-1} yr^{-1} (2000) and 25 eq ha^{-1} yr^{-1} (2019).

Model improvements

The EMEP MSC-W model code has been upgraded in a number of ways. A 19-sector emissions system (GNFR-CAMS) was introduced into the code. Emissions for soil NO, DMS, and aircraft were updated using results from the CAMS_81 project. The fine/coarse fractions for sea-salt and nitrate were modified. Emissions and the chemical mechanism were adapted to explicitly track GNFR sector C emissions. Revised global monthly emission factors were produced, and use of a global time-zone map introduced. The planetary boundary layer schemes (Kz and Hmix methods) were changed. The local fraction methods were extended, and code for the many configuration options was simplified.

Development in the monitoring programme

There are large differences between Parties in the level of implementation of the monitoring programme, as well as significant changes in the national activities during the period 2010–2019. With respect to the requirement for level 1 monitoring, 35% of the Parties have had an improvement since 2010, while 37% have reduced the level of monitoring. For level 2 monitoring there has been a general positive development, but only a few sites have a complete measurement program.

The complexity of data reporting has increased in recent years, and it is therefore now mandatory for the data providers to use the submission and validation tool when submitting data to EMEP to improve the quality and timeliness in the data flow.

Acknowledgments

This work has been funded by the EMEP Trust Fund.

The development of the EMEP MSC-W model has also been supported by the Nordic Council of Ministers, the Norwegian Space Centre, the Norwegian Ministry of Climate and Environment and Copernicus Atmosphere Modelling Service (CAMS) projects.

The work on condensable organics was partly funded by the Norwegian Ministry of Climate and Environment.

The work of TNO was partly funded by the Copernicus Atmosphere Monitoring Service (CAMS), in particular the Contracts on emissions (CAMS_81) and policy products (CAMS_71).

The work presented in this report has benefited largely from the work carried out under the four EMEP Task Forces and in particular under TFMM.

A large number of co-workers in participating countries have contributed in submitting quality assured data. The EMEP centers would like to express their gratitude for continued good co-operation and effort. The institutes and persons providing data are listed in the EMEP/CCC's data report and identified together with the data sets in the EBAS database. For the work presented on trends in EC/OC and chemical composition we would like to express our gratitude to Laurent Poulain and Noemi Perez for their extra effort to report data from Melpitz and Montseny respectively

For developing standardized methods, harmonization of measurements and improving the reporting guidelines and tools, the close co-operations with participants in the European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases (ACTRIS) as well as with the Scientific Advisory Groups (SAGs) in WMO/GAW are especially appreciated.

Chris Heyes and Zig Klimont from EMEP CIAM/IIASA are acknowledged for provision of emission data and helpful discussions and advice.

The Working Group on Effects and its ICPs and Task Forces are acknowledged for their assistance in determining the risk of damage from air pollution.

The computations were partly performed on resources provided by UNINETT Sigma2 - the National Infrastructure for High Performance Computing and Data Storage in Norway (grant NN2890k and NS9005k). IT infrastructure in general was available through the Norwegian Meteorological Institute (MET Norway). Furthermore, the CPU time granted on the supercomputers owned by MET Norway has been of crucial importance for this year's source-receptor matrices. The CPU time made available by ECMWF to generate meteorology has been important for both the source-receptor and status calculations in this year's report.

Contents

CHAPTER 1

Introduction

1.1 Purpose and structure of this report

The mandate of the European Monitoring and Evaluation Programme (EMEP) is to provide sound scientific support to the Convention on Long-range Transboundary Air Pollution (LRTAP), particularly in the areas of atmospheric monitoring and modelling, emission inventories, emission projections and integrated assessment. Each year EMEP provides information on transboundary pollution fluxes inside the EMEP area, relying on information on emission sources and monitoring results provided by the Parties to the LRTAP Convention.

The purpose of the annual EMEP status reports is to provide an overview of the status of transboundary air pollution in Europe, tracing progress towards existing emission control Protocols and supporting the design of new protocols, when necessary. An additional purpose of these reports is to identify problem areas, new aspects and findings that are relevant to the Convention. This year, special attention has been given to the trends of air pollution, supporting the review of the Gothenburg Protocol.

The present report is divided into four parts. Part I presents the status of transboundary air pollution with respect to acidification, eutrophication, ground level ozone and particulate matter in Europe in 2019. Part II summarizes the work on trends performed to support the review of the Gothenburg Protocol, while Part III deals with technical developments going on within the centres.

Appendix A in Part IV contains information on the national total emissions of main pollutants and primary particles for 2019, while Appendix B shows the emission trends for the period of 2000-2019. Country-to-country source-receptor matrices with calculations of the transboundary contributions to pollution in different countries for 2019 are presented in Appendix D.

Appendix E describes the country reports which are issued as a supplement to the EMEP status reports.

Model evaluation against all EMEP observations is visualized online at `https://aeroval.met.no/evaluation.php?project=emep`. This online information is complemented by numerical fields and other information on the EMEP website. The reader is encouraged to visit the website, `http://www.emep.int`, to access this additional information.

1.2 Definitions, statistics used

For sulfur and nitrogen compounds, the basic units used throughout this report are μg (S or N)/m^3 for air concentrations and mg (S or N)/m^2 for depositions. Emission data, in particular in some of the Appendices, is given in Gg (SO_2) and Gg (NO_2) in order to keep consistency with reported values.

For ozone, the basic units used throughout this report are ppb (1 ppb = 1 part per billion by volume) or ppm (1 ppm = 1000 ppb). At 20°C and 1013 mb pressure, 1 ppb ozone is equivalent to 2.00 μg m^{-3} .

A number of statistics have been used to describe the distribution of ozone within each grid square:

Mean of Daily Max. Ozone - First we evaluate the maximum modelled concentration for each day, then we take either 6-monthly (1 April - 30 September) or annual averages of these values.

SOMO35 - The Sum of Ozone Means Over 35 ppb is the indicator for health impact assessment recommended by WHO. It is defined as the yearly sum of the daily maximum of 8-hour running average over 35 ppb. For each day the maximum of the running 8-hours average for O_3 is selected and the values over 35 ppb are summed over the whole year.

If we let A_8^d denote the maximum 8-hourly average ozone on day d, during a year with N_y days (N_y = 365 or 366), then SOMO35 can be defined as:

$SOMO35 = \sum_{d=1}^{d=N_y} \max\big(A_8^d - 35 \text{ ppb}, 0.0\big)$

where the `max` function evaluates $\max(A-B, 0)$ to $A-B$ for $A > B$, or zero if $A \leq B$, ensuring that only A_8^d values exceeding 35 ppb are included. The corresponding unit is ppb.days.

POD$_Y$ - Phyto-toxic ozone dose, is the accumulated stomatal ozone flux over a threshold Y, i.e.:

$$\text{POD}_Y = \int \max(F_{st} - Y, 0)\, dt \tag{1.1}$$

where stomatal flux F_{st}, and threshold, Y, are in nmol m^{-2} s^{-1}. This integral is evaluated over time, from the start of the growing season (SGS), to the end (EGS).

For the generic crop and forest species, the suffix gen can be applied, e.g. POD$_{Y,gen}$ is used for forests. POD was introduced in 2009 as an easier and more descriptive term for the accumulated ozone flux ($AF_{st}Y$ was used previously). See also Mills et al. (2011a,b, 2018) and LRTAP (2017).

AOT40 - is the accumulated amount of ozone over the threshold value of 40 ppb, i.e..

$AOT40 = \int \max(O_3 - 40 \text{ ppb}, 0.0)\, dt$

where the `max` function ensures that only ozone values exceeding 40 ppb are included. The integral is taken over time, namely the relevant growing season for the vegetation concerned, and in some daytime period. The corresponding unit are ppb.hours (abbreviated to ppb.h). The usage and definitions of AOT40 have changed over the years though, and also differ between UNECE and the EU. LRTAP (2017) give the latest definitions for UNECE work, and describes carefully how AOT40 values are best estimated for local conditions (using information on real growing seasons for example), and specific types of vegetation. In the EU approaches, O_3 concentrations are taken directly from observations (at typically ca. 3 m height), or grid-average 3 m modelled values. In the Mapping Manual (LRTAP 2009) approaches, there is a strong emphasis on estimating AOT40 using ozone levels at the top of the vegetation canopy. Since O_3 concentrations can have strong vertical gradients, this approach leads to lower AOT40 estimates than with the EU approach.

The EMEP MSC-W model now generates a number of AOT-related outputs, in accordance with the recommendations of LRTAP (2017), but in this report we will concentrate in this report on four definitions, derived from either 'EU' approach or 'UNECE' approaches:

AOT40c - AOT40 calculated using EU criteria, from modelled (3 m) or observed ozone, for the assumed crop growing season of May–July. Here we use the EU definitions of day hours as 08:00–20:00.

AT40f - AOT40 calculated using EU criteria from modelled 3 m ozone, or observed ozone, for the assumed forest growing season of April–September. Here we use the EU definitions of day hours as 08:00–20:00.

AOT40$_f^{uc}$ - AOT40 calculated for forests using estimates of O_3 at forest-top (uc: upper-canopy). This AOT40 is that defined for forests by LRTAP (2009), but using a default growing season of April-September.

AOT40$_c^{uc}$ - AOT40 calculated for agricultural crops using estimates of O_3 at the top of the crop. This AOT40 is close to that defined for agricultural crops by LRTAP (2009), but using a default growing season of May-July, and a default crop-height of 1 m.

For AOT40$_f^{uc}$and AOT40$_c^{uc}$only daylight hours are included, and for practical reasons we define daylight in the model outputs as the time when the solar zenith angle is equal to or less than 89°. (The proper UNECE definition uses clear-sky global radiation exceeding 50 W m^{-2} to define daylight, whereas the EU AOT definitions use day hours from 08:00-20:00.).

In practice, it is very difficult to convert measured O_3 from an EMEP observation site to the UNECE AOT40 values, since there are no data with which is to estimate the vertical gradient to get to upper-canopy O_3. Therefore, in the comparison of modelled and observed AOT40s in Ch 2 and Ch 4, we have used the EU AOT definitions, since this approach is readily applicable to observed as well as modelled values. We do, however, present source-receptor calculations for the UNECE metrics $AOT40_f^{uc}$ and $AOT40_c^{uc}$ in Appendix D.

The AOT40 levels reflect interest in long-term ozone exposure which is considered important for vegetation - critical levels of 3 000 ppb.h have been suggested for agricultural crops and natural vegetation, and 5 000 ppb.h for forests (LRTAP 2009). Note that recent UNECE workshops have recommended that AOT40 concepts are replaced by ozone flux estimates for crops and forests (see also LRTAP 2017).

Furthermore, this report includes concentrations of particulate matter (PM). The basic units throughout this report are μg m^{-3} for PM concentrations and the following acronyms are used for different components to PM:

POA - primary organic aerosol - which is the organic component of the PPM emissions (defined below). (POA is in this report assumed to be entirely in the particle phase, see Fagerli et al. (2020).)

SOA - secondary organic aerosol, defined as the aerosol mass arising from the oxidation products of gas-phase organic species.

SIA - secondary inorganic aerosols, defined as the sum of sulfate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+). In the EMEP MSC-W model SIA is calculated as the sum: SIA= SO_4^{2-} + NO_3^-(fine) + NO_3^-(coarse) + NH_4^+.

SS - sea salt.

MinDust - mineral dust.

PPM - primary particulate matter, originating directly from anthropogenic emissions. One usually distinguishes between fine primary particulate matter, $PPM_{2.5}$, with aerosol diameters below 2.5 μm and coarse primary particulate matter, PPM_{coarse} with aerosol diameters between 2.5 μm and 10 μm.

PM$_{2.5}$ - particulate matter with aerodynamic diameter up to 2.5 μm. In the EMEP MSC-W model, $PM_{2.5}$ is calculated as $PM_{2.5}$ = SO_4^{2-} + NO_3^-(fine) + NH_4^+ + $SS_{2.5}$ + MinDust(fine) + SOA(fine) + $PPM_{2.5}$ + 0.13 $\cdot$ NO_3^-(coarse) + PM25water. (PM25water = PM associated water).

PM$_{\text{coarse}}$ - coarse particulate matter with aerodynamic diameter between 2.5μm and 10μm. In the EMEP MSC-W model PM_{coarse} is calculated as PM_{coarse} = 0.87 $\cdot$ NO_3^-(coarse)+ SS(coarse) + MinDust(coarse) + PPM_{coarse}.

PM$_{10}$ - particulate matter with aerodynamic diameter up to 10 μm. In the EMEP MSC-W model PM_{10} is calculated as PM_{10} = $PM_{2.5}$ + PM_{coarse}.

SS$_{10}$ - sea salt aerosol with diameter up to 10 μm.

SS$_{2.5}$ - sea salt aerosol with diameter up to 2.5 μm.

In addition to bias, correlation and root mean square the statistical parameter, index of agreement, are used to judge the model's agreement with measurements:

IOA - The index of agreement (IOA) is defined as follows (Willmott 1981, 1982):

$$IOA = 1 - \frac{\sum_{i=1}^{N}(m_i - o_i)^2}{\sum_{i=1}^{N}(|m_i - \bar{o}| + |o_i - \bar{o}|)^2} \tag{1.2}$$

where $\bar{o}$ is the average observed value. Similarly to correlation, IOA can be used to assess agreement either spatially or temporally. When IOA is used in a spatial sense, N denotes the number of stations with measurements at one specific point in time, and m_i and o_i are the modelled and observed values at station i. For temporal IOA, N denotes the number of time steps with measurements, while m_i and o_i are the modelled and observed value at time step i. IOA varies between 0 and 1. A value of 1 corresponds to perfect agreement between model and observations, and 0 is the theoretical minimum.

1.3 The EMEP grid

At the 36^{th} session of the EMEP Steering Body the EMEP Centres suggested to increase spatial resolution and projection of reported emissions from 50×50 km^2 polar stereographic grid to 0.1°×0.1° longitude-latitude grid in a geographic coordinate system (WGS84). The EMEP domain shown in Figure 1.1 covers the geographic area between 30°N-82°N latitude and 30°W-90°E longitude. This domain represents a balance between political needs, scientific needs and technical feasibility. Parties are obliged to report gridded emissions in this grid resolution from year 2017.

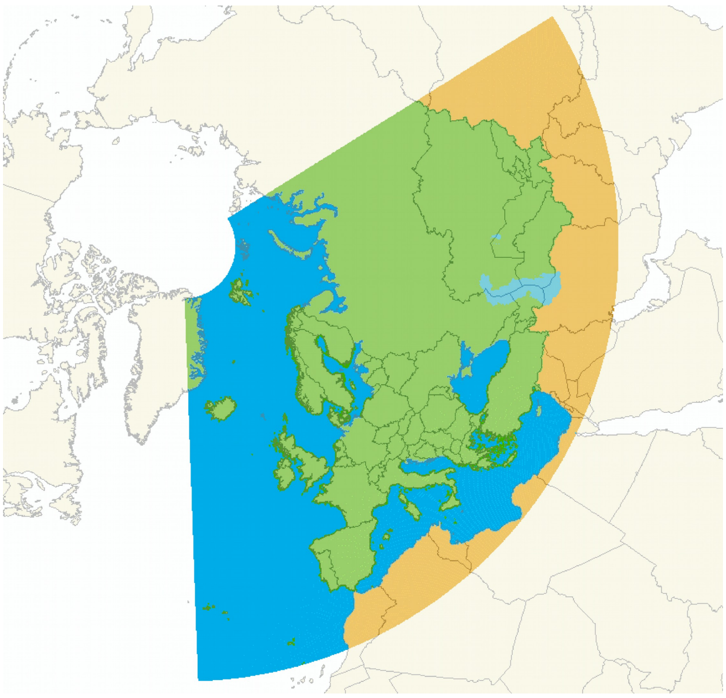

Figure 1.1: The EMEP domain covering the geographic area between 30°N-82°N latitude and 30°W-90°E longitude.

The higher resolution means an increase of grid cells from approximately 21500 cells in the 50×50 km^2 grid to 624000 cells in the 0.1°×0.1° longitude-latitude grid.

1.3.1 The reduced grid: EMEP0302

For practical purposes, a coarser grid has also been defined. The EMEP0302 grid covers the same region as the 0.1°×0.1° longitude-latitude EMEP domain (Figure 1.1), but the spatial resolution is 0.3° in the longitude direction and 0.2° in the latitude direction. Each gridcell from the EMEP0302 grid covers exactly 6 gridcells from the 0.1°×0.1° official grid.

Table 1.1: Country/region codes used throughout this report.

Code	Country/Region/Source	Code	Country/Region/Source
AL	Albania	IS	Iceland
AM	Armenia	IT	Italy
AST	Asian areas	KG	Kyrgyzstan
AT	Austria	KZ	Kazakhstan
ATL	N.-E. Atlantic Ocean	LI	Liechtenstein
AZ	Azerbaijan	LT	Lithuania
BA	Bosnia and Herzegovina	LU	Luxembourg
BAS	Baltic Sea	LV	Latvia
BE	Belgium	MC	Monaco
BG	Bulgaria	MD	Moldova
BIC	Boundary/Initial Conditions	ME	Montenegro
BLS	Black Sea	MED	Mediterranean Sea
BY	Belarus	MK	North Macedonia
CH	Switzerland	MT	Malta
CY	Cyprus	NL	Netherlands
CZ	Czechia	NO	Norway
DE	Germany	NOA	North Africa
DK	Denmark	NOS	North Sea
DMS	Dimethyl sulfate (marine)	PL	Poland
EE	Estonia	PT	Portugal
ES	Spain	RO	Romania
EU	European Union (EU28)	RS	Serbia
EXC	EMEP land areas	RU	Russian Federation
FI	Finland	SE	Sweden
FR	France	SI	Slovenia
GB	United Kingdom	SK	Slovakia
GE	Georgia	TJ	Tajikistan
GL	Greenland	TM	Turkmenistan
GR	Greece	TR	Turkey
HR	Croatia	UA	Ukraine
HU	Hungary	UZ	Uzbekistan
IE	Ireland	VOL	Volcanic emissions

1.4 Country codes

Several tables and graphs in this report make use of codes to denote countries and regions in the EMEP area. Table 1.1 provides an overview of these codes and lists the countries and regions included.

All 51 Parties to the LRTAP Convention, except two, are included in the analysis presented in this report. The Parties that are excluded of the analysis are Canada and the United States of America, because they lie outside the EMEP domain.

1.5 Other publications

A list of all associated technical reports and notes by the EMEP centres in 2021 (relevant for transboundary acidification, eutrophication, ozone and particulate matter) follows at the end of this section.

Peer-reviewed publications in 2020

The following scientific papers of relevance to transboundary acidification, eutrophication, ground level ozone and particulate matter, involving EMEP/MSC-W and EMEP/CCC staff, have become available in 2020:

Amann, M.; Kiesewetter, G.; Schöpp, Wolfgang; Klimont, Zbigniew; Winiwarter, Wilfried; Cofala, Janusz; Rafaj, Peter; Hoglund-Isaksson, Lena; Gomez-Sabriana, Adriana; Heyes, Chris; Purohit, Pallav; Borken-Kleefeld, Jens; Wagner, Fabian; Sander, Robert; Fagerli, Hilde; Nyiri, Agnes; Cozzi, Laura; Pavarini, Claudia. Reducing global air pollution: The scope for further policy interventions: Achieving clean air worldwide. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences2020; 378.(2183) DOI: 10.1098/rsta.2019.0331

Blechschmidt, Anne-Marlene; Arteta, Joaquim; Coman, Adriana; Curier, Lyana; Eskes, Henk; Foret, Gilles; Gielen, Clio; Hendrick, François; Marécal, Virginie; Meleux, Frédérik; Parmentier, Jonathan; Peters, Enno; Pinardi, Gaia; Piters, Ankie J.M.; Plu, Matthieu; Richter, Andreas; Segers, Arjo; Sofiev, Mikhail; Valdebenito, Alvaro; Van Roozendael, Michel; Vira, Julius; Vlemmix, Tim; Burrows, John P.. Comparison of tropospheric NO2 columns from MAX-DOAS retrievals and regional air quality model simulations. Atmospheric Chemistry and Physics ; 2020; 20 p. 2795-2823 DOI: 10.5194/acp-20-2795-2020

Collaud Coen, M., Andrews, E., Alastuey, A., Arsov, T. P., Backman, J., Brem, B. T., Bukowiecki, N., Couret, C., Eleftheriadis, K., Flentje, H., Fiebig, M., Gysel-Beer, M., Hand, J. L., Hoffer, A., Hooda, R., Hueglin, C., Joubert, W., Keywood, M., Kim, J. E., Kim, S.-W., Labuschagne, C., Lin, N.-H., Lin, Y., Lund Myhre, C., Luoma, K., Lyamani, H., Marinoni, A., Mayol-Bracero, O. L., Mihalopoulos, N., Pandolfi, M., Prats, N., Prenni, A. J., Putaud, J.-P., Ries, L., Reisen, F., Sellegri, K., Sharma, S., Sheridan, P., Sherman, J. P., Sun, J., Titos, G., Torres, E., Tuch, T., Weller, R., Wiedensohler, A., Zieger, P., and Laj, P. Multidecadal trend analysis of in situ aerosol radiative properties around the world. Atmos. Chem. Phys., 20, 8867–8908, 2020. DOI: 10.5194/acp-20-8867-2020

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Etzold, Sophia; Ferretti, Marco; Reinds, Gert-Jan; Solberg, Svein; Gessler, Arthur; Waldner, Peter; Schaub, Marcus; Simpson, David; Benham, Sue; Hansen, Karin; Ingerslev, Morten; Jonard, Mathieu; Karlsson, Per Erik; Lindroos, Antti-Jussi; Marchetto, Aldo; Manninger, Miklos; Meesenburg, Henning; Merilä, Päivi; Nöjd, Pekka; Rautio, Pasi; Sanders, Tanja GM; Seidling, Walter; Skudnik, Mitja; Thimonier, Anne; Verstraeten, Arne; Vesterdal, Lars; Vejpustkova, Monika; de Vries, Wim. Nitrogen deposition is the most important environmental driver of growth of pure, even-aged and managed European forests. Forest Ecology and Management ; 2020; 458; p. 1-13 DOI: 10.1016/j.foreco.2019.117762

Flechard, Chris R.; Ibrom, Andreas; Skiba, Ute; de Vries, Wim; Van Oijen, Marcel; Cameron, David R.; Dise, Nancy B.; Korhonen, Janne; Buchmann, Nina; Legout, Arnaud; Simpson, David; Sanz, Maria J.; Aubinet, Marc; Loustau, Denis; Montagnani, Leonardo; Neirynck, Johan; Janssens, Ivan A.; Pihlatie, Mari; Kiese, Ralf; Siemens, Jan; Francez, Andre-Jean; Augustin, Jurgen; Varlagin, Andrej; Olejnik, Janusz; Juszczak, Radoslaw; Aurela, Mika; Berveiller, Daniel; Chojnicki, Bogdan H.; Dämmgen, Urich; Delpierre, Nicolas; Djuricic, Vesna; Drewer, Julia; Dufrene, Eric; Eugster, Werner; Fauvel, Yannick; Fowler, David; Frumau, Arnoud; Granier, Andre; Gross, Patrick; Hamon, Yannick; Helfter, Carole; Hensen, Arjan; Horvath, Laszlo; Kitzler, Barbara; Kruijt, Bart; Kutsch, Werner; Lobo-do-Vale, Raquel; Lohila, Annalea; Longdoz, Bernard; Marek, Michal V.; Matteucci, Giorgio; Mitosinkova, Marta; Moreaux, Virginie; Neftel, Albrecht; Ourcival, Jean-Marc; Pilegaard, Kim; Pita, Gabriel; Sanz, Francisco; Schjoerring, Jan K.; Sebastià, Maria-Teresa; Tang, Y. Sim; Uggerud, Hilde Thelle; Urbaniak, Marek; van Dijk, Netty; Vesala, Timo; Vidic, Sonja; Vincke, Caroline; Weidinger, Tamas; Sechmeister-Boltenstern, Sophie; Butterbach-Bahl, Klaus; Nemitz, Eiko; Sutton, Mark A.. Carbon–nitrogen interactions in European forests and semi-natural vegetation – Part 1: Fluxes and budgets of carbon, nitrogen and greenhouse gases from ecosystem monitoring and modelling. Biogeosciences ; 2020; 17; p. 1583-1620 DOI: 10.5194/bg-17-1583-2020

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Jonson, Jan Eiof; Gauss, Michael; Schulz, Michael; Jalkanen, Jukka-Pekka; Fagerli, Hilde. Effects of global ship emissions on European air pollution levels. Atmospheric Chemistry and Physics 2020; 20, p. 11399–11422, DOI: 10.5194/acp-20-11399-2020

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Associated EMEP reports and notes in 2021

Joint reports

Transboundary particulate matter, photo-oxidants, acidification and eutrophication components. Joint MSC-W & CCC & CEIP Report. EMEP Status Report 1/2021

EMEP MSC-W model performance for acidifying and eutrophying components, photo-oxidants and particulate matter in 2019. Supplementary material to EMEP Status Report 1/2021

Assessment of transboundary pollution by toxic substances: Heavy metals and POPs. Joint MSC-E & CCC & CEIP & INERIS Report. EMEP Status Report 2/2021

CCC Technical and Data reports

Anne-Gunn Hjellbrekke. Data Report 2019. Particulate matter, carbonaceous and inorganic compounds. EMEP/CCC-Report 1/2021

Anne-Gunn Hjellbrekke and Sverre Solberg. Ozone measurements 2019. EMEP/CCC-Report 2/2021

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Sverre Solberg, Anja Claude and Stefan Reimann. VOC measurements 2019. EMEP/CCC-Report 4/2021

CEIP Technical and Data reports

Sabine Schindlbacher, Bradly Matthews and Bernhard Ullrich. Uncertainties and recalculations of emission inventories submitted under CLRTAP, Technical Report CEIP 1/2021

Bradley Matthews and Robert Wankmueller. Part I: Main pollutants , Particulate Matter and BC (NOx, NMVOCs, SOx, NH3, CO, PM2.5, PM10, PMcoarse, BC), Technical Report CEIP 2/2021

Katarina Mareckova, Marion Pinterits, Bernhard Ullrich, Robert Wankmueller, Thomas Bartmann and Sabine Schindlbacher. Inventory Review 2021, Technical Report CEIP 3/2021

Katarina Mareckova, Robert Wankmueller, Marion Pinterits, Bernhard Ullrich and Sabine Schindlbacher. Methodology report, Technical Report CEIP 4/2021

MSC-W Technical and Data reports

Heiko Klein, Michael Gauss, Ágnes Nyíri, Svetlana Tsyro and Hilde Fagerli. Transboundary air pollution by sulfur, nitrogen, ozone and particulate matter in 2019, Country Reports. EMEP/MSC-W Data Note 1/2021

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Part I

Status of air pollution

CHAPTER 2

Status of transboundary air pollution in 2019

Svetlana Tsyro, Wenche Aas, Sverre Solberg, Anna Benedictow and Hilde Fagerli

This chapter describes the status of transboundary air pollution in 2019. A short summary of the meteorological conditions is presented, the EMEP network of measurement and the EMEP MSC-W model set up is briefly described. Thereafter, the status of air pollution in 2019 is discussed.

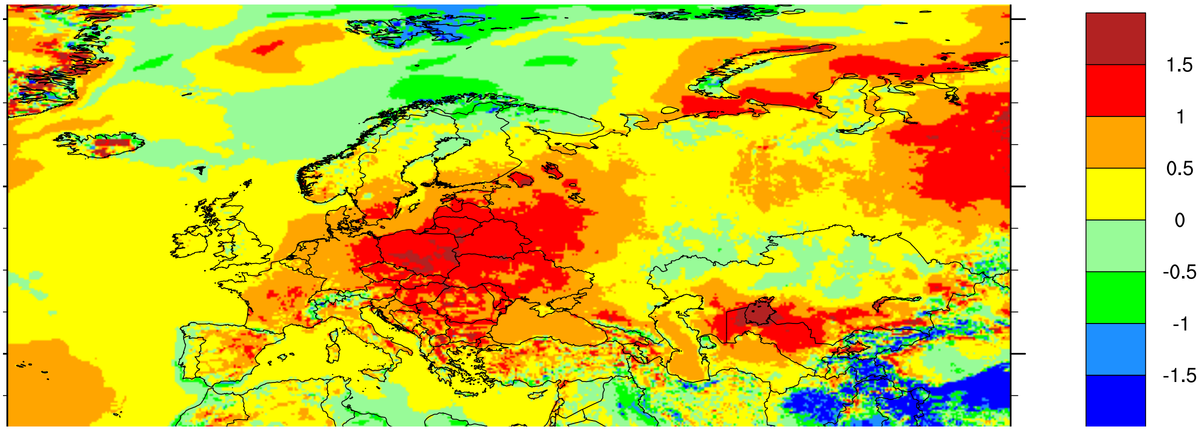
2.1 Meteorological conditions in 2019

Air pollution is significantly influenced by both emissions and weather conditions. Temperature and precipitation are particularly important factors. A short summary describing the situation in 2019 with respect to these two parameters, based on NWP model results and as reported by the meteorological institutes in European and EECCA countries, is given below.

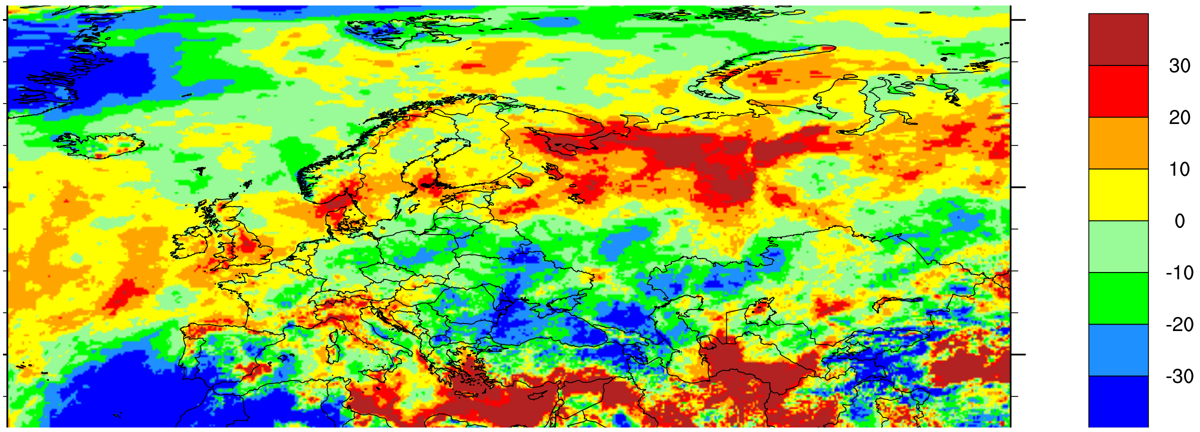
The meteorological data to drive the EMEP MSC-W air quality model have been generated by the Integrated Forecast System (IFS) model of the European Centre for Medium-Range Weather Forecasts (ECMWF), hereafter referred to as the ECMWF-IFS model. In the meteorological community the ECMWF-IFS model is considered state-of-the-art, and MSC-W has been using this model in hindcast mode to generate meteorological reanalyses for the year to be studied. IFS Cycle 46r1 is the version used for the year 2019 model runs. In the following section, temperature and precipitation in 2019 are compared to the 2000-2018 average based on the same ECMWF-IFS model setup. Meteorological data for the years 2000 to 2018 have been derived from the IFS Cycle 40r1 version.

2.1.1 Temperature and precipitation

The global mean temperature in 2019 was reported by the World Meteorological Organisation (WMO 2020) as the second or third highest on record. In Europe, the annual mean temperature for 2019 was the highest on record according to Copernicus[1] and October 2018 to September 2019 was the second warmest over land north of 60°N since records began in 1900 (Arctic Report Card 2019 Overland et al. 2019. Global precipitation anomalies in 2019 were reported by the WMO (WMO 2020) and despite some seasonal local extreme precipitation events with heavy rainfall in eastern Norway, north-east Italy, south-east Spain, Ukraine and northern European Russia, and drought in the Iberian Peninsula, Moldova and Latvia, 2019 was overall a normal year in much of Europe according to Copernicus[2] and BAMS (Regional climates 2019, Bissolli et al. 2020).



(a) Δtemperature at 2m (2019-climavg)



(b) Δprecipitation (2019-climavg)

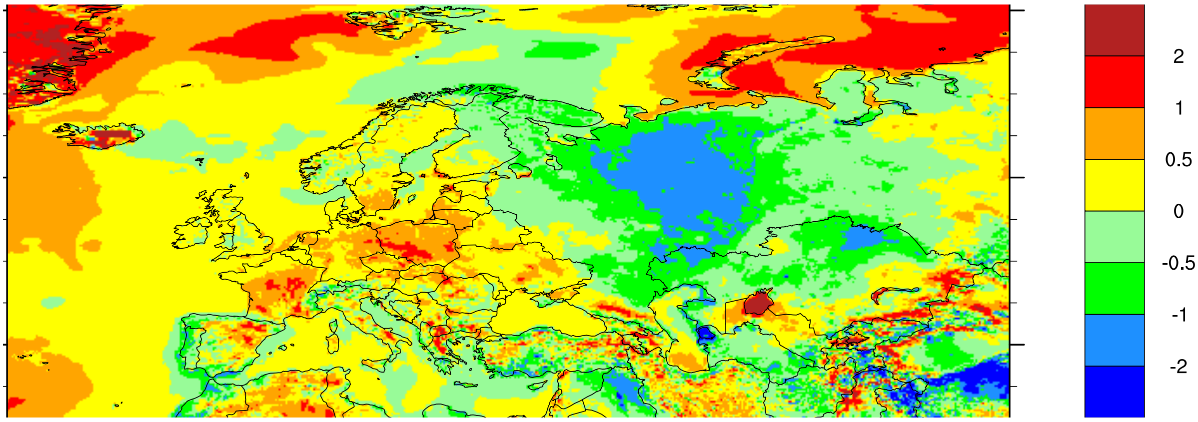
Figure 2.1: Meteorological conditions in 2019 compared to the 2000-2018 average (climavg) for: a) Annual mean temperature at 2m [K] and b) Annual precipitation [%]. The meteorological data have been calculated with the ECMWF-IFS model.

In Figure 2.1a higher temperatures in 2019 compared to the 2000-2018 average are seen over central and south-eastern Europe, and slightly lower temperatures in northern and south-western Europe, northern and southern European Russia and Turkmenistan. Many countries reported that 2019 was the warmest year on record, particularly Poland (since 1781) and Lithuania (since 1778), but also Ukraine (since 1881), Belarus (since 1945), Hungary (since 1901), Bulgaria (since 1930), Romania (since 1961) and Serbia (since 1951).

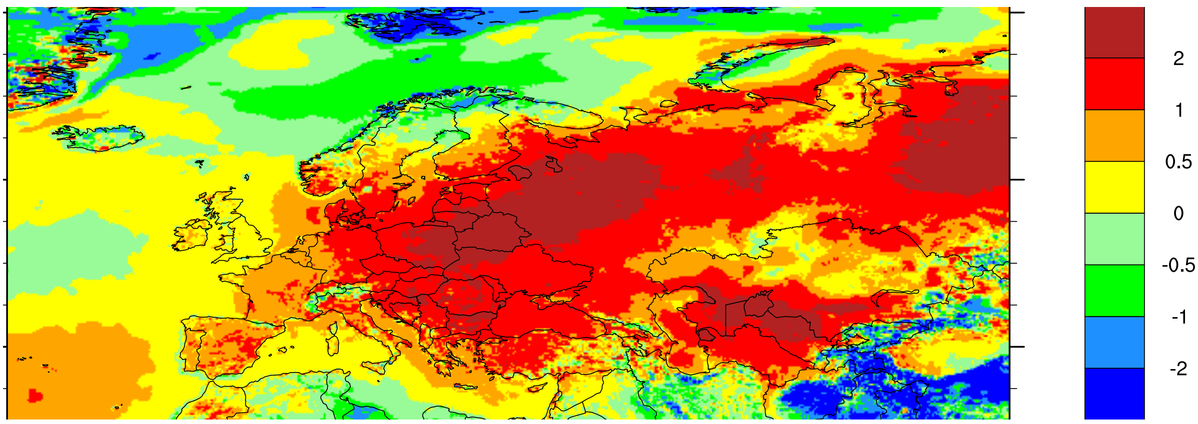
[1] `https://climate.copernicus.eu/ESOTC/2019/european-temperature`

[2] `https://climate.copernicus.eu/ESOTC/2019/european-wet-and-dry-conditions`

Compared to the 2000-2018 average, precipitation in 2019 (Figure 2.1b) shows higher amounts than normal in northern European Russia, parts of the Nordic countries, UK and Ireland, Bay of Biscay coastal regions as well as central and southeastern Mediterranean countries. Below average precipitations are shown in central and eastern Europe, southern European Russia, South Caucasus, Tajikistan, Kyrgyz Republic, Iberian Peninsula, Iceland and Svalbard.



(a) Δtemperature at 2m (AprSep 2019-climavg)

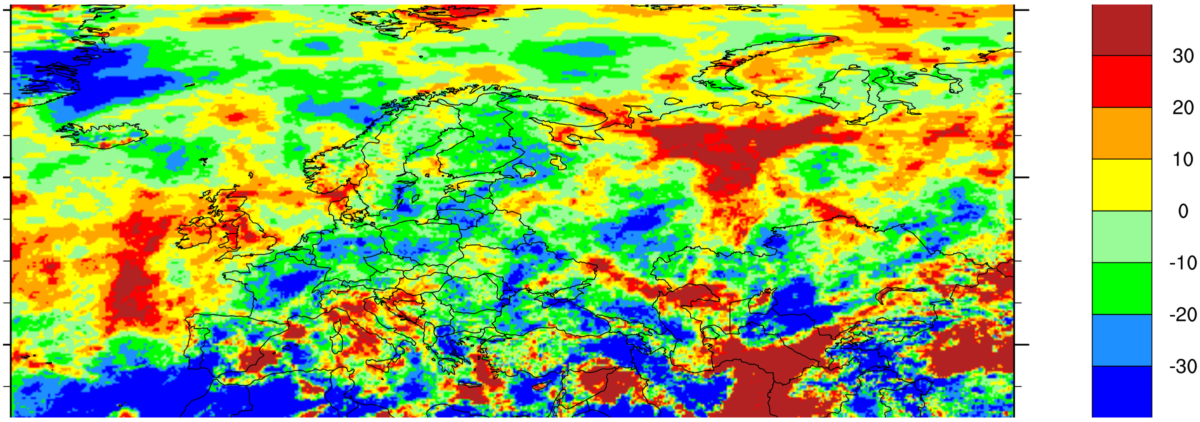


(b) Δtemperature at 2m (OctMar 2019-climavg)

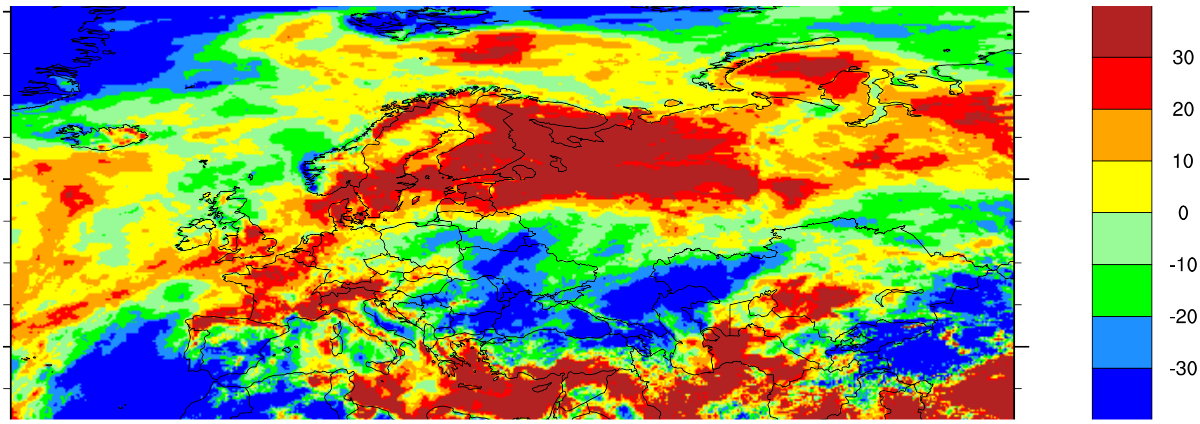
Figure 2.2: Meteorological conditions in 2019 compared to the 2000-2018 average (climavg) for: a) Summer (April-September) temperature [K], b) Winter (January-March and October-December) temperature [K]. The meteorological data have been calculated with the ECMWF-IFS model.

Figure 2.2 shows the temperatures in 2019 compared to the 2000-2018 average in Europe for the summer months (April through September) and the winter months (October through December and January through March). Summer was warm overall in central and southern Europe, and cold in European Russia, see Figure 2.2a. Spring was variable throughout Europe, April was warm and the second warmest month on record in Norway and Finland. On the contrary, May was colder than normal for most countries in Europe, in Slovenia the coldest on record, except in southern and western parts of the Iberian Peninsula where a heatwave occurred in mid-May. Slovakia and Czechia reported their warmest summer, and second warmest in Hungary, Austria, Slovenia and Italy and third warmest in Belgium, Luxembourg, France, Germany and Switzerland. June was the warmest month on record in many western and central European countries, and in Ukraine and Georgia records were broken. There were two distinct heatwaves for June and July across western and central Europe. In contrast, August was colder than normal in European Russia.

As shown in Figure 2.2b winter temperatures were higher than the 2000-2018 average in virtually all of Europe. Winter temperatures were particularly high in eastern Europe including Russia. The first months of 2019 was overall mild in Europe and Ireland reported their warmest winter on record, particularly February was exceptionally warm. In the Iberian Peninsula, central- and eastern Europe also March was warmer than usual. The year ended extremely mild in central-east and southeastern Europe, and European Russia. Czechia, Slovakia, Hungary, Croatia, Serbia and Greece reported their warmest autumn on record. It was the warmest October in Belarus and third warmest in Georgia, the warmest November in Romania and second warmest December in European Russia.



(a) Δprecipitation (AprSep 2019-climavg)



(b) Δprecipitation (OctMar 2019-climavg)

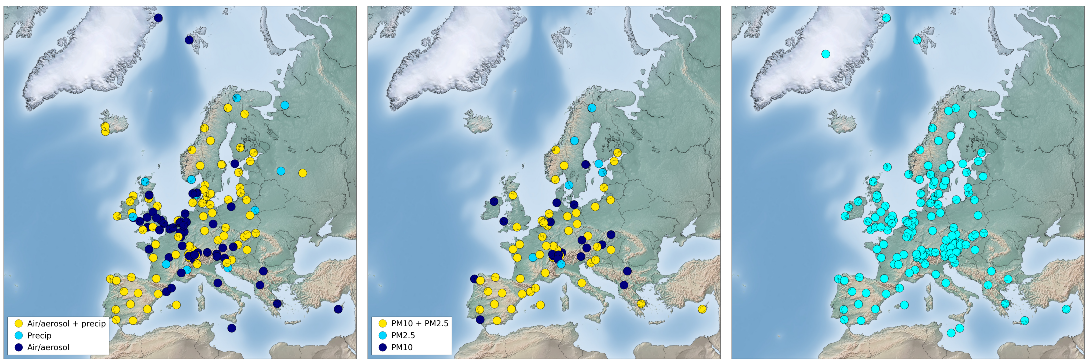
Figure 2.3: Meteorological conditions in 2019 compared to the 2000-2018 average (climavg) for: a) Summer (April-September) precipitation [%], b) winter (January-March and October-December) precipitation [%]. The meteorological data have been calculated with the ECMWF-IFS model.

For April through September (Figure 2.3a) shows that Europe in general had much less precipitation in 2019 than the 2000-2018 average, with the exception of UK, Ireland, southern Norway and the central Mediterranean countries. In Latvia and Belarus, April was the driest month on record, and also European Russia, Germany, Czechia and northern parts of Poland was extremely dry. In spring, parts of France and the Iberian Peninsula was much drier than normal, but wet in Scandinavia, Italy and the northern Balkans, and Slovenia reported its wettest May on record. Summer was overall very dry in most of Europe, except for the eastern Mediterranean, the United Kingdom and southern Norway. Autumn continued with dry conditions in eastern Europe, Turkey and southwestern Iberia, while central and western Europe received above-normal precipitation. Eastern Norway was extremely wet while western Norway was very dry. Denmark reported its wettest autumn on record and in southeastern Spain local extreme precipitation totals due to heavy rain were reported for September.

As shown in Figure 2.3b the 2019 winter months (January-March and October-December) precipitation were wetter than the 2000-2018 average in most of Europe, except for drier conditions in western Norway, southern Iberian Peninsula, southeastern Europe, southern European Russia, South Caucasus, Kyrgyz Republic and Tajikistan. January was wetter than normal in central Europe, European Russia, Greece, Moldova and Spain. However in Spain it was the driest February in the twenty-first century, and also Germany, Belarus and Hungary received very little precipitation for this month. Spain, Portugal, Hungary, Romania, Ukraine and Moldova was also drier than normal in March, but northern European Russia broke records with wettest month. Turkey was wetter than normal in September, while Moldova was drier. For November the Alps recorded substantial snow amounts with new records in Switzerland, while it was still dry in Moldova. December was very wet in northern European Russia, Finland and southern Turkey, but abnormally dry in Macedonia and Bulgaria. For October, November and December, south Caucasus was extremely dry and in Georgia the snowcover for December was record low.

2.2 Measurement network 2019

In 2019, a total of 33 Parties reported measurement data of inorganic components, particulate matter and/or ozone to EMEP from altogether 168 sites, which are the relevant components for level 1 sites (UNECE 2019). All the data are available from the EBAS database (`http://ebas.nilu.no/`) and are also reported separately in technical reports by EMEP/CCC (Hjellbrekke 2021, Hjellbrekke and Solberg 2021). Figure 2.4 shows an overview of the spatial distribution of the sites reporting data for inorganic ions in air and precipitation, particulate matter and ozone in 2019.



(a) Inorganic compounds (b) PM mass concentration (c) Ozone

Figure 2.4: EMEP measurement network for level 1 components in 2019.

120 sites reported measurements of inorganic ions in precipitation and/or main components in air. However, not all of these measurements were co-located, as illustrated in Fig-

ure 2.4. There were 73 sites with measurements in both air and precipitation. Ozone was measured at 138 EMEP sites. The number of sites is marginally lower than in 2018.

There were 78 sites measuring either PM_{10} or $PM_{2.5}$ mass. 50 of these sites measured both size fractions, as recommended in the EMEP Monitoring strategy (UNECE 2019). The stations measuring EMEP level 2 variables are shown in Figure 6.2 in Ch 6.1, along with a discussion on compliance with the monitoring obligations and the development of the programme during the last decade.

2.3 Setup for EMEP MSC-W model runs

The EMEP MSC-W model version rv4.42 has been used for the 2019 runs. The horizontal resolution is $0.1° \times 0.1°$, with 20 vertical layers (the lowest with a height of approximately 50 meters).

Meteorology, emissions, boundary conditions and forest fires for 2019 have been used as input. Meteorological data have been derived from ECMWF-IFS(cy46r1) simulations (see Ch 2.1). The land-based emissions have been derived from the 2021 official data submissions to UNECE CLRTAP (Pinterits et al. 2021), as documented in Ch 3. In the Base run for pollution assessments and the source-receptor runs included in this report, the officially submitted PM_{10} and $PM_{2.5}$ emissions from residential combustion (GNFR sector C) were partly substituted by an emission data set provided by TNO for 2015 (the so-called REF2.1 scenario used in the Copernicus Atmosphere Monitoring Service contract CAMS50-II), see Ch 3.3 The data set by TNO represents the best-to-date available estimate of residential combustion emissions of PM, accounting for condensable organics in a consistent way.

Emissions from international shipping within the EMEP domain are derived from the CAMS global shipping emissions (Granier et al. 2019), developed by the Finnish Meteorological Institute (FMI). The forest fires emissions are taken from The Fire INventory from NCAR (FINN) (Wiedinmyer et al. 2011), version 5. For more details on the emissions for the 2019 model runs see Ch 3 and Appendix A.

2.4 Air pollution in 2019

2.4.1 Ozone

The ozone observed at a surface station is the net result of various physio-chemical processes: surface dry deposition and uptake in vegetation, titration by nearby NO_x emissions, regional photochemical ozone formation and atmospheric transport of background ozone levels, each of which may have seasonal and diurnal systematic variations. Episodes with elevated levels of ozone are observed during the summer half year when certain meteorological situations (dry, sunny, cyclonic stable weather) promote the formation of ozone over the European continent.

There were four main ozone episodes in Europe in 2019 that occurred around days 23-28 in each of the months April, June, July and August and at a varying degree in different parts of the continent. Details for the first three of these episodes are discussed below. Extreme levels of ozone even exceeding EU's alert threshold of 240 μg m^{-3} were observed in several countries as explained in more detail below.

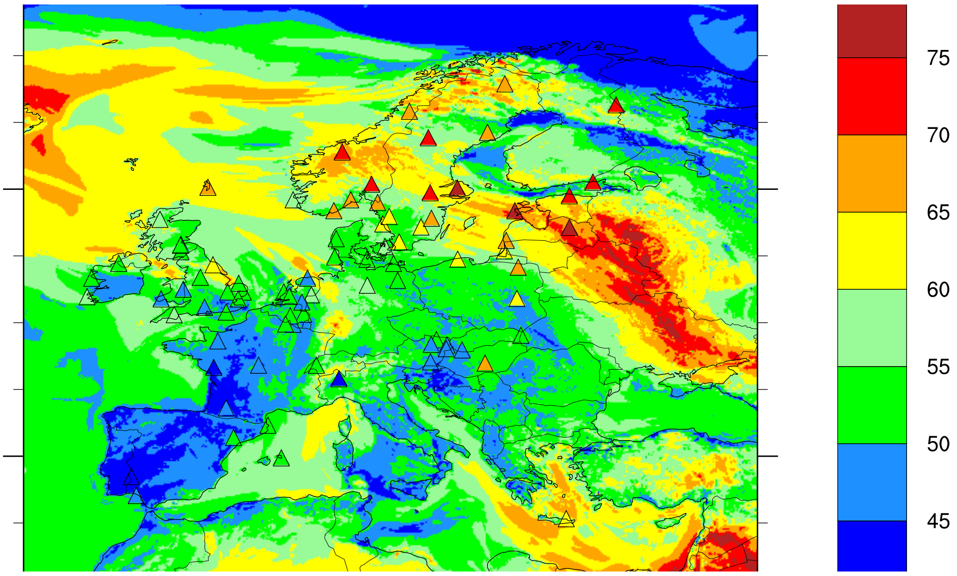


Figure 2.5: Modelled and measured daily max ozone [ppb] 24 April 2019.

The April episode was linked to a blocking high pressure located over western parts of Russia and Belarus, setting up southeasterly winds bringing warm and dry continental air masses northwards particularly to the Baltic countries, Scandinavia and parts of the UK. At 25 April Northern Norway registered the second highest surface ozone level (82 ppb) since the start of the monitoring in 1990. Likely, agricultural fires in East Europe (Ukraine and Russia) contributed to the peak ozone levels. The modelled and observed daily maximum ozone levels for 24 April are shown in Figure 2.5.

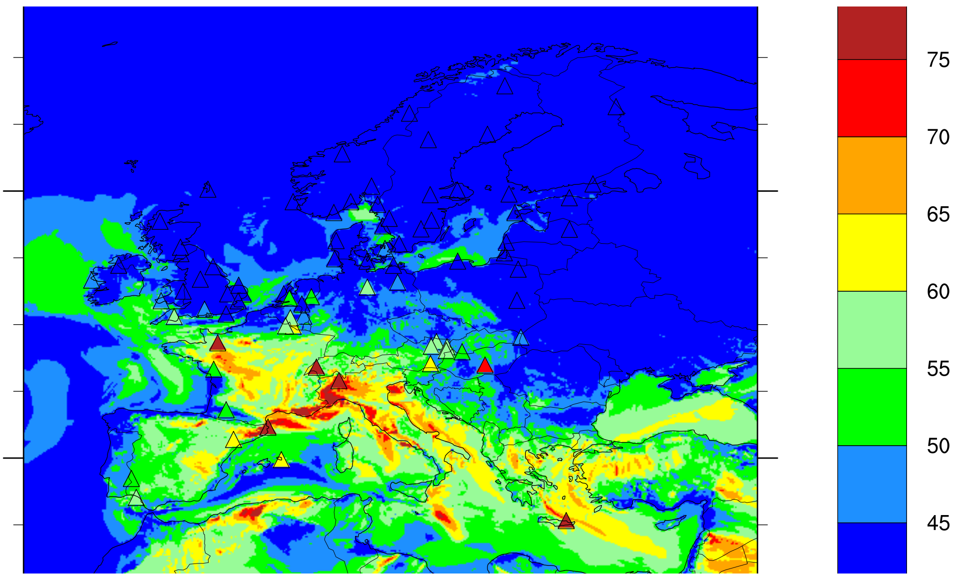


Figure 2.6: Modelled and measured daily max ozone [ppb] 28 June 2019.

June 2019 was the warmest June on record, globally as well as for Europe (Bissolli et al. 2020). During 26-28 June a persistent high pressure over central Europe brought very hot air masses into central and western parts of the continent. In Germany, temperatures just below 40 °C was observed and in France 13 stations surpassed France's 2003 records, exceeding a temperature of 44.1 °C. Surface ozone levels above EU's information threshold (180 μg m^{-3}) were observed in many countries during this period. At Ispra in Italy an extreme level of 142 ppb (285 μg m^{-3}) was reported on 28 June, breaking EU's alert threshold of 240 μg m^{-3}. Figure 2.6 shows the modelled and observed daily maximum ozone levels for 28 June.

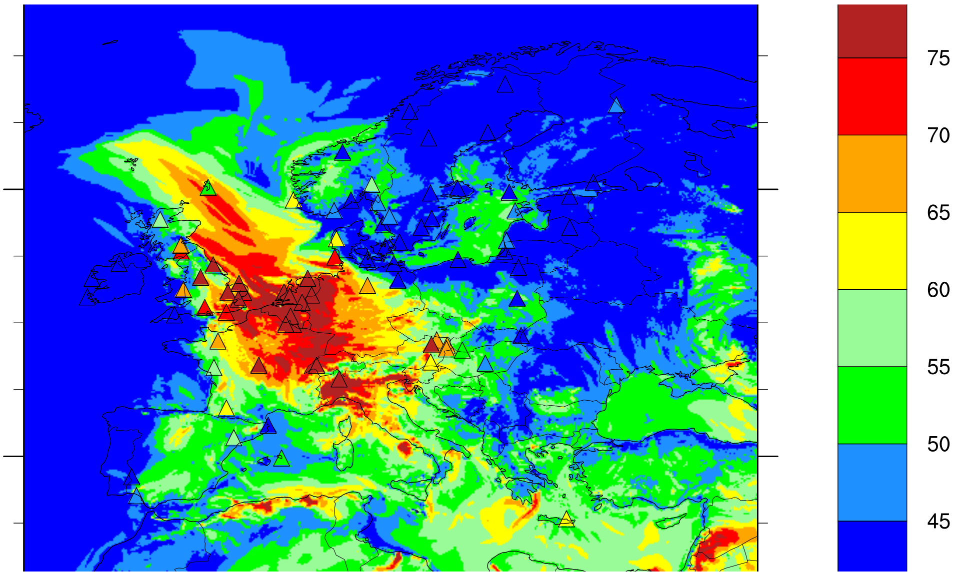
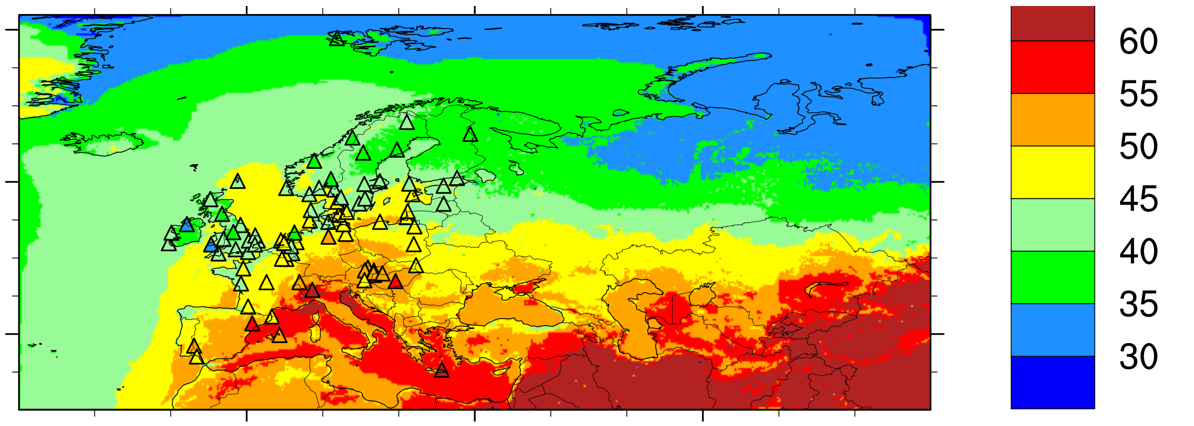


Figure 2.7: Modelled and measured daily max ozone [ppb] 25 July 2019.

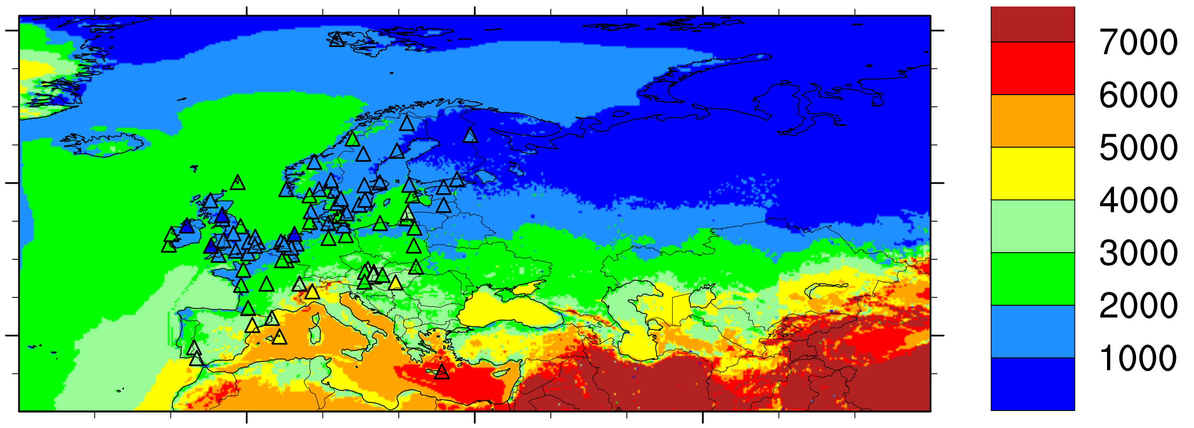
One month later, during 24-26 July a new and even more intense (albeit shorter) heat wave struck central and northwestern part of Europe, and national temperature records were set in the UK and Germany (38.7 °C in the UK and 40.5 °C in Germany). Along with this heat wave, peak ozone levels were measured. In the UK, an hourly maximum level of 119 ppb (238 μg m^{-3}) was observed at Sibton 25 July, the highest level measured at this site since 1996. At Vredepeel in the Netherlands, the ozone levels peaked at 127 ppb (254 μg m^{-3}) on the same day and thereby broke EU's alert threshold. The extent of the ozone episode on 25 July is seen on Figure 2.7, showing the modelled and observed values.

For the year 2019 as a whole, Figure 2.8 shows various modelled ozone metrics with the corresponding measured metrics based on the EMEP measurement sites plotted on top of the maps. Only stations located below 500 metres above sea level were used in this comparison to avoid uncertainties related to the extraction of model data in regions with complex topography. Figure 2.8 shows a) maxO3 (= mean of the daily max ozone concentration) for the 6-month period April-September, b) SOMO35 (= Sum of Ozone Means Over 35 ppb), c) AOT40 for forests (= Accumulated Ozone exposure over a Threshold of 40 ppb) for the 6-month period April-September using the hours between 08 and 20, and Figure 2.9 shows POD_1 for forests (= Phytotoxic Ozone Dose above a threshold 1 mmol m^{-2}). Figure 2.9 shows only modelled POD_1 since measurements could not be calculated from the ozone monitoring data directly and could not be included.

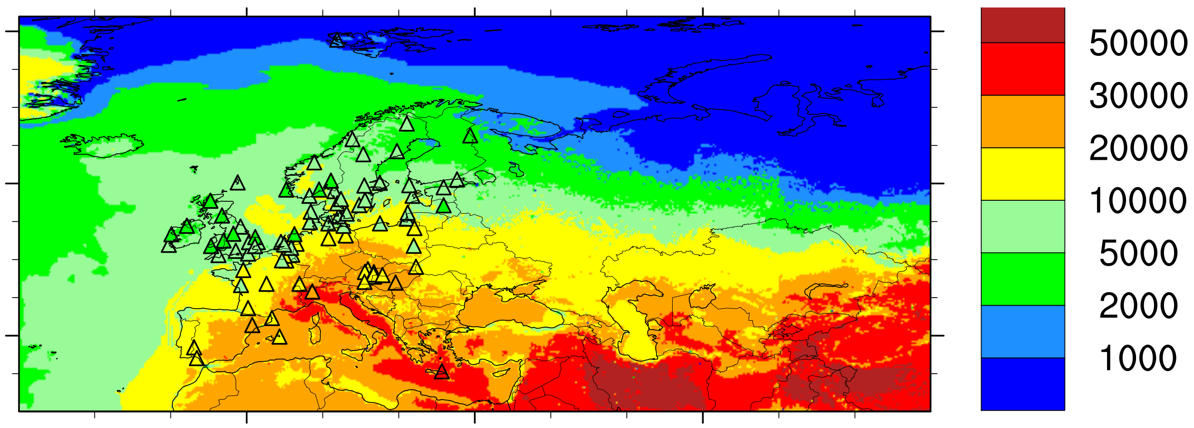
These plots indicate good agreement between these modelled and measured ozone metrics in general. The model and the measurements show an increasing gradient to the southeast as expected which reflects the strong dependency between surface ozone, temperature and solar radiation.



(a) maxO3



(b) SOMO35



(c) AOT40

Figure 2.8: Model results and observations at EMEP stations (triangles) for mean of daily maximum ozone concentrations (a) ([*ppb*], Apr-Sep), SOMO35 (b) [*ppb.d*] and AOT40 for forests (c) [*ppb.h*] in 2019. Only data from measurement sites below 500 m a.s.l. are shown.

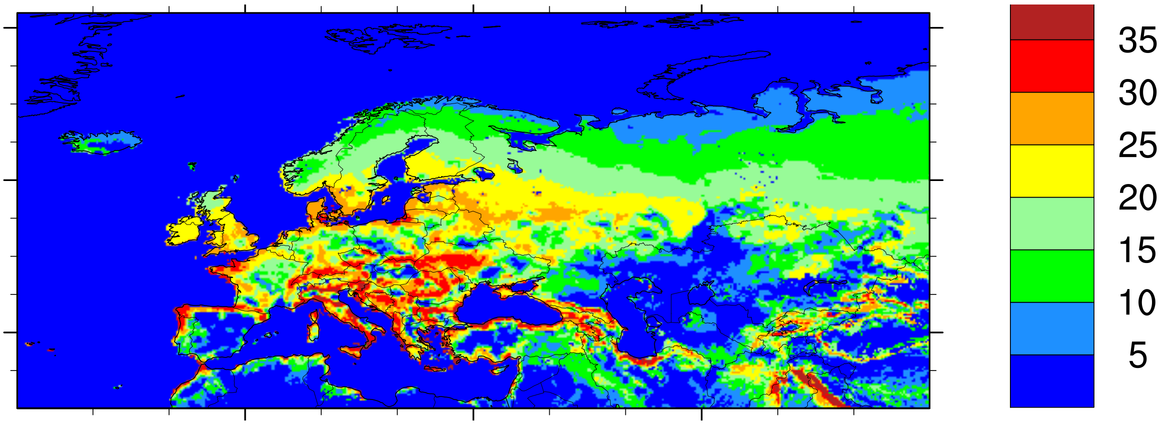


Figure 2.9: Model results of POD_1 for forests $[mmolm^{-}2]$ in 2019.

It should be noted that the O_3 metrics such as AOT40 are very sensitive to the calculation of vertical O_3 gradients between the middle of the surface layer and the 3m height used for comparison with measurements (Tuovinen et al. 2007) and thus more difficult to compare with measurement data than, e.g., the mean daily maximum. Indeed, the formulation we use (Simpson et al. 2012) is probably better suited to a lowest model layer of 90m thickness (since we equate the centre of this, ca. 45m, with a 'blending-height') than to a lowest model layer of 50m thickness (as used throughout this report). The modelled POD_1 pattern differs from the other metrics reflecting the influence of additional parameters such as plant physiology, soil moisture etc., and is a metric more indicative of the direct impact of ozone on vegetation than, e.g., AOT40. The POD_1 field could, however, not be validated by the EMEP ozone measurement data alone.

SOMO35 is an indicator for health impacts recommended by WHO, and the results given in Figure 2.8 indicate that the health risk associated with surface ozone increased towards southern Europe. Highest levels are seen in the Mediterranean area and Northern Italy. SOMO35 is a health risk indicator without any specific threshold or limit value.

AOT40 and POD_1 are indicators for effects on vegetation. UNECE's critical level for forests based on the 6-months AOT40 value is 5000 ppb hours, and the results shown in Figure 2.8 indicate that this level was exceeded in most of Europe in 2019 although the model tends to overestimate the AOT40 values somewhat. In parts of central and south Europe the critical level was exceeded by a very large margin (20000 ppb hours and more). During dry periods, plants will reduce or close their stomata as a response to soil water deficit, which in turn will lead to reduced uptake of ozone. Parts of the reason for the elevated atmospheric concentrations of ozone (and the high AOT40 levels) could thus be explained by the reduced uptake in vegetation.

On the contrary, POD_1 takes into account this soil moisture deficit, giving an estimate of the actual flux of ozone into the plants. It is interesting to see the substantial difference in the geographical pattern of AOT40 and POD_1 in Figures 2.8 (c) and 2.9. Whereas AOT40 shows a north-south gradient with peak values over southern/central parts of the continent, POD_1 is highest along the coast and shows a minimum in central parts of Europe just where high values of AOT40 are seen. This reflects the importance of the soil moisture effect for these two metrics for ozone damage to vegetation. For POD_1 the limit value depends on the species and Mills et al (2011) give a value of 4 mmol m^{-2} for birch and beech and 8 mmol m^{-2} for Norway spruce. The results in Figures 2.8 (c) and 2.9 indicate that both these limit values were exceeded in most of Europe. The modelled levels of POD_1 could, however, not be validated by observations.

Surface ozone levels and the associated metrics were fairly high in 2019 which partly could be explained by several heat waves striking the continent in the summer half year. This is an indication of the strong link between climate and surface ozone and raises the issue of climate induced changes of ozone in the years to come. A main question is to what extent such changes will outweigh the benefits of reduced ozone precursors emissions.

2.4.2 Particulate matter

Maps of annual mean concentrations of PM_{10} and $PM_{2.5}$ in 2019, calculated by the EMEP MSC-W model, are presented in Figure 2.10. The figures also show annual mean PM_{10} and $PM_{2.5}$ concentrations observed at the EMEP monitoring network, which are represented by colour triangles overlaying the contours of the modelled concentration fields.

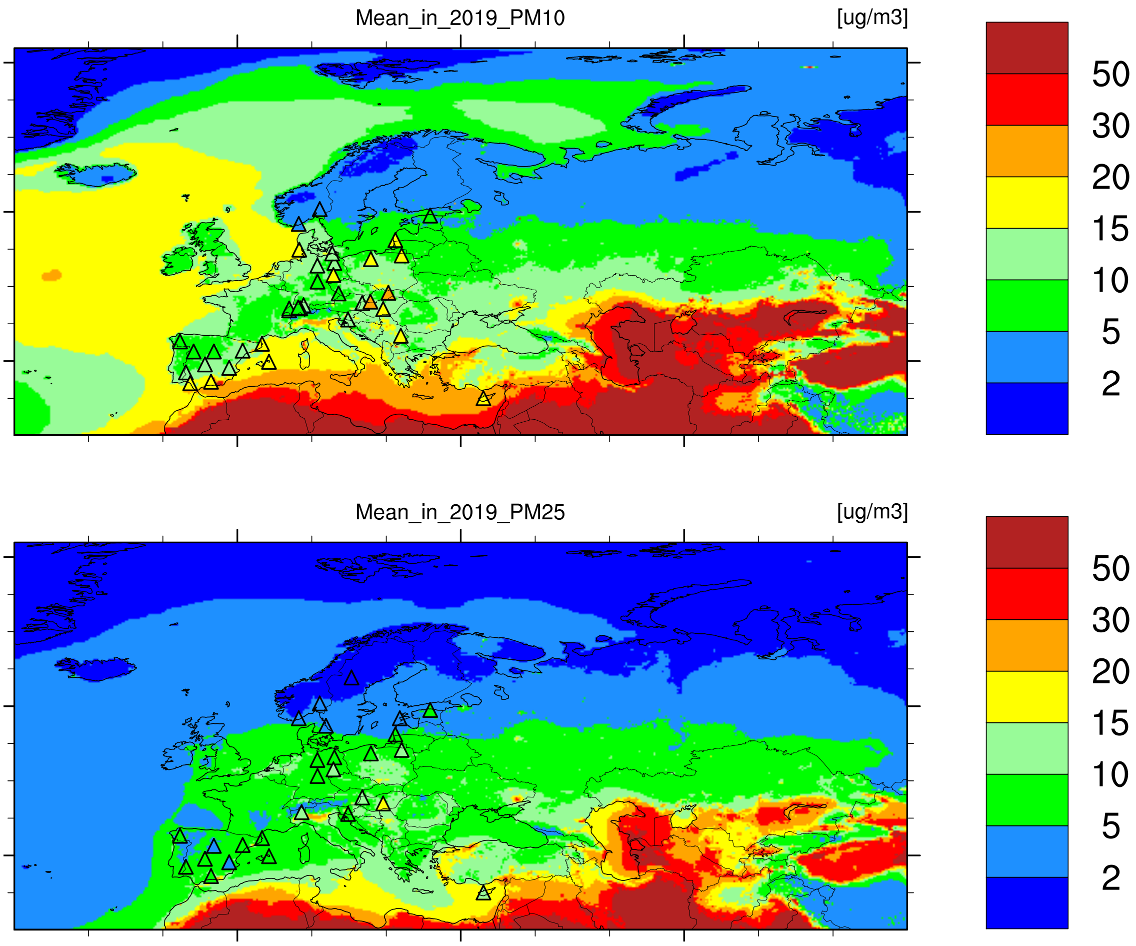


Figure 2.10: Annual mean concentrations of PM_{10} and $PM_{2.5}$ in 2019: calculated with the EMEP MSC-W model (colour contours) and observed at EMEP monitoring network sites (colour triangles). *Note: Observations include hourly, daily and weekly data.*

The model results and the observations are well in agreement regarding the geographical distribution of the annual mean levels of PM_{10} and $PM_{2.5}$, showing their general increase over land from north to south. The concentrations are below 2-5 $\mu g\ m^{-3}$ in Northern Europe, increasing to 5-15 μg m^{-3} in the mid-latitudes and further south, $PM_{2.5}$ levels being somewhat lower than those of PM_{10}. Figure 2.10 displays fairly homogeneous modelled levels of regional background PM over most of Central and Western Europe, with PM_{10} in excess of 20 μg m^{-3} in the Po Valley and on Cyprus. The observations also show PM_{10} concentrations above 20 μg m^{-3} in Slovakia. $PM_{2.5}$ concentrations are below 10 μg m^{-3} over most of EMEP domain (except the most south/southeastern regions), or otherwise between 10 and 15 μg m^{-3} in parts of Benelux, Poland, Hungary and some Balkan countries. The only site with observed annual mean PM_{10} above 15 μg m^{-3} (namely 16.3 μg m^{-3}) was Hungarian K-Puszta. Furthermore, the model calculates high PM for the regions east of the Caspian Sea (parts of Kazakhstan, Uzbekistan, Turkmenistan) and over the southern Mediterranean, with annual mean concentrations in excess of 50 μg m^{-3}. These high PM concentrations are due to windblown dust from the arid soils and deserts of Central Asia, though the precision of the calculated values still cannot be verified due to the lack of observations in these regions.

There is a good agreement between the modelled and observed distributions of annual mean PM_{10} and $PM_{2.5}$, with correlation coefficients of 0.60 and 0.72, respectively. Overall, the model underestimates the observed annual mean of PM_{10} by 12% and $PM_{2.5}$ by 13% (see also Table F:1 in Appendix F). A more detailed comparison between model and measurements for the year 2019 can be found at `https://aeroval.met.no/evaluation.php?project=emep&exp_name=2021-reporting`.

Overall, the year of 2019 was quite moderate with respect to PM air pollution in Europe, which was due to dominating meteorological conditions that year. It was relatively warm across the EMEP area (Figure 2.1), in particular in the cold half-year (Figure 2.2). Mild winter conditions would mean less need for residential heating, resulting in lower emissions from this sector. Moreover, stagnant air conditions (with temperature inversion, low wind speed and thin mixing layer), typically causing elevated pollution levels, are less frequent in warm winters. Also, the spring/summer period was relatively warm (except from Russia, Kazakhstan, Finland, most of Sweden, Spain and Portugal). During those months, the higher temperatures would enhance evaporation of semi-volatile inorganic and organic aerosols (SIA and SOA), though the more efficient oxidation contributes to secondary aerosol formation. Furthermore, the year 2019 was relatively dry over most of Europe (except in the south and parts of Scandinavia), in EECCA countries, and most of Russia (except for the northern regions), as shown in Figure 2.1. However, the amount of precipitation was also relatively large in the cold half-year in Denmark, France, the UK and parts of Germany (Figure 2.3). As documented in Tarrason et al. (2020), the wet end of the year in western and southern Europe was the most prominent feature of precipitation in 2019, with November being particularly extreme, both in terms of the total rainfall amounts and the number of days with heavy rainfall. As wet scavenging is the main PM removal mechanism, this, combined with the mild winter temperatures, resulted in the lower levels of PM pollution in winter 2019 over most of Europe.

Figure 2.11 presents the relative anomalies of mean PM_{10} and $PM_{2.5}$ concentrations in 2019 relative to 2000-2018 averages, based on the 2000-2019 trend runs performed with the EMEP MSC-W model using a consistent emission data-set based on officially submitted data, as documented in Ch 4. In order to look at the sole effect of meteorological conditions on PM pollution, also the 2019 run used here is based on the reported emissions and thus different from the 2019 Status run (in which TNO's emissions for residential combustion are used, as documented in Ch 2.3). Figure 2.11 shows that the PM pollution in 2019 was relatively moderate, with annual mean concentrations being 5-20% lower than the 2000-2018 averages over most of the EMEP domain, and 20-35% lower compared to the 18-year average in Central

Europe and over vast areas in the N/NE of Russia. Only along NW/N coasts in Fennoscandia, parts of Spain and some south-eastern regions (parts of Turkey, the Caucasus region and Central Asian countries), PM_{10} and $PM_{2.5}$ levels in 2019 were higher relative to the 2000-2018 averages.

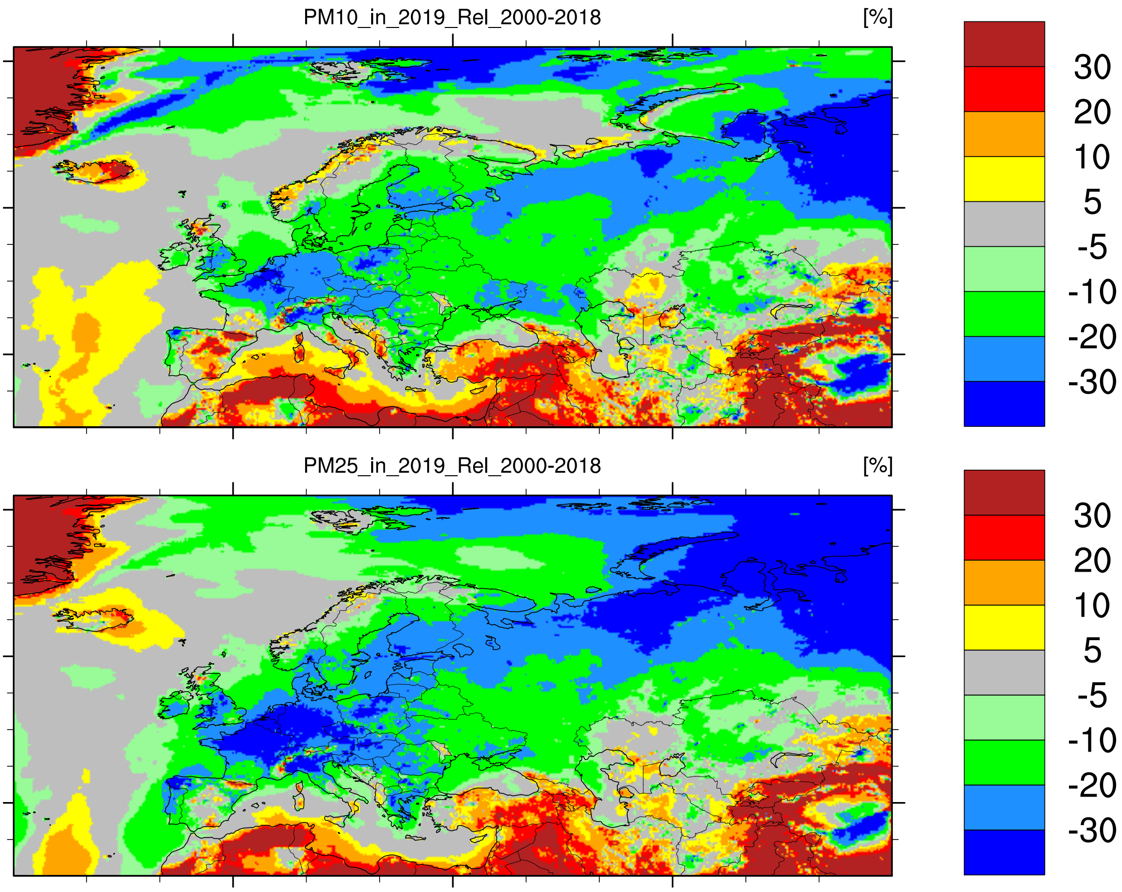


Figure 2.11: Relative anomalies of mean PM_{10} and $PM_{2.5}$ in 2019 from the 2000-2018 mean.

Exceedances of EU limit values and WHO Air Quality Guidelines in 2019

In this section we compare PM_{10} and $PM_{2.5}$ exceedances of EU critical limits and WHO recommended Air Quality Guidelines (WHO 2005), calculated by the EMEP MSC-W model, with those measured at EMEP sites. The EU limit values (Council Directive 1999/30/EC) for PM_{10} are 40 μg m^{-3} for the annual mean and 50 μg m^{-3} for the daily mean concentrations, with the daily limit not to be exceeded more than 35 times per calendar year (EU 2008). For $PM_{2.5}$, the annual mean limit value of 25 μg m^{-3} entered into force on 01.01.2015.

The Air Quality Guidelines (AQG) recommended by WHO (WHO 2005) are:

- for PM_{10}: 20 μg m^{-3} annual mean, 50 μg m^{-3} 24-hourly (99th perc. or 3 days per year)
- for $PM_{2.5}$: 10 μg m^{-3} annual mean, 25 μg m^{-3} 24-hourly (99th perc. or 3 days per year)

The EU limit values for protection of human health from particulate matter pollution and the WHO AQG for PM should apply to concentrations for zones or agglomerations, in rural and urban areas, which are representative for exposure of the general population. PM_{10} and $PM_{2.5}$ concentrations calculated with the EMEP MSC-W model on the 0.1°× 0.1° grid cannot reproduce urban hotspot levels, but give a reasonable representation of PM levels occurring in rural and, to some extend, in urban background areas.

Model results and EMEP observational data show that the annual mean PM_{10} concentrations were below the EU limit value of 40 $\mu g\ m^{-3}$ for all of Europe in 2019 (Figure 2.10). The model calculates annual mean PM_{10} above the WHO recommended AQG of 20 $\mu g\ m^{-3}$ for only small regions in the Po Valley and western Turkey. The highest observed annual mean PM_{10} concentrations, exceeding the AQG of 20 $\mu g\ m^{-3}$, were registered at Slovakian sites (24 $\mu g\ m^{-3}$ at SK0004 and 23 $\mu g\ m^{-3}$ SK0007) and Greek GR0001 (23 $\mu g\ m^{-3}$, 58% data coverage only). Further, the observations and model results show that annual mean $PM_{2.5}$ concentrations (Figure 2.10) in 2019 were below the EU limit value of 25 $\mu g\ m^{-3}$ (except in the Po Valley according to the model). However, there were observed cases of exceedance of the WHO AQG value of 10 $\mu g\ m^{-3}$ by annual mean $PM_{2.5}$ at nine sites (including GR0001 with 57% data coverage), with the highest values at the Hungarian site HU0004 with 16 $\mu g\ m^{-3}$, followed by German DE0044 with 14 $\mu g\ m^{-3}$ and Italian IT0004 with 13 $\mu g\ m^{-3}$.

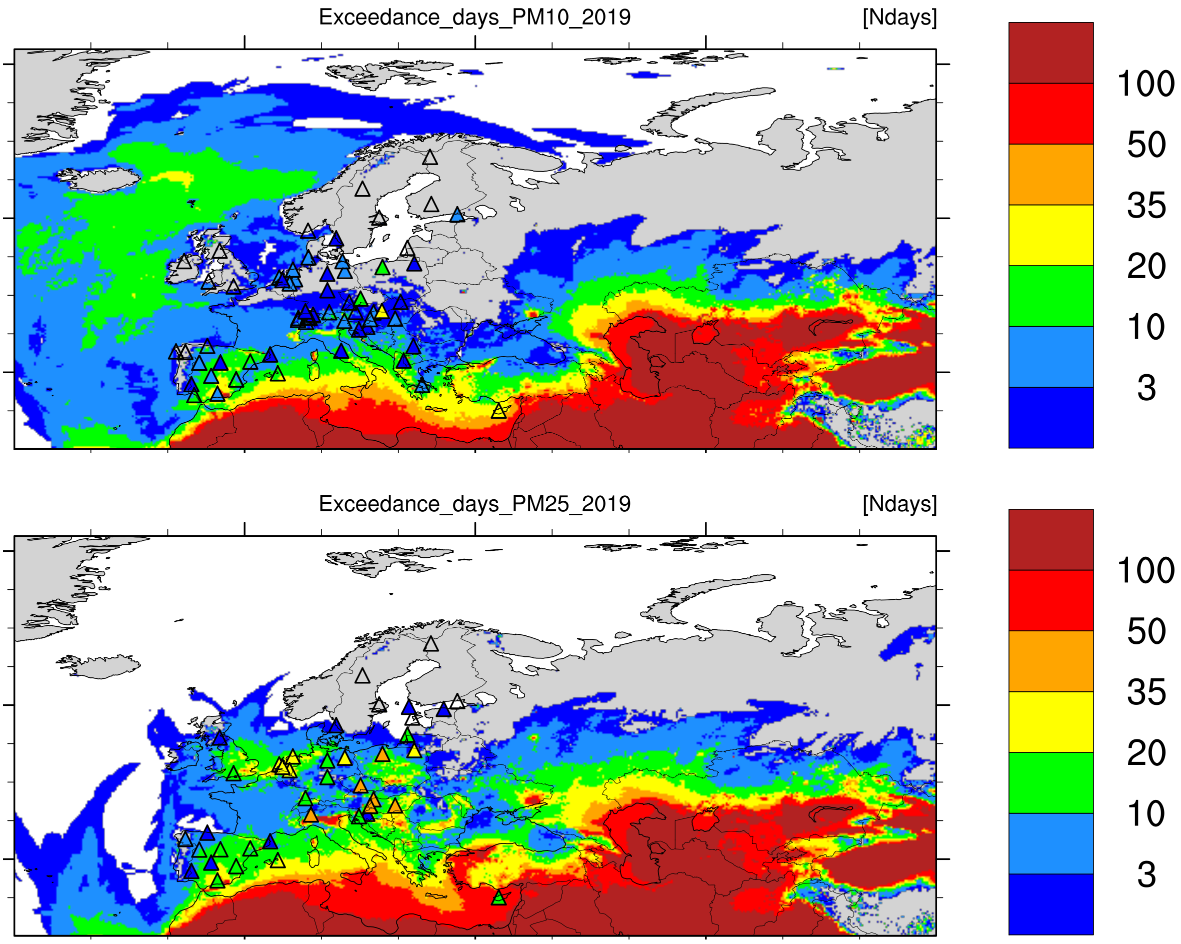


Figure 2.12: Calculated (with 0.1°resolution) and observed (triangles) number of days with exceedances in 2019: PM_{10} exceeding 50 $\mu g\ m^{-3}$ (upper) and $PM_{2.5}$ exceeding 25 $\mu g\ m^{-3}$ (lower panel). *Note: The EU Directive requires no more than 35 days with exceedances for* PM_{10}*, whereas WHO recommends no more than 3 days with exceedances for* PM_{10} *and* $PM_{2.5}$ *per calendar year.*

The maps in Figure 2.12 show the number of days with exceedances of 50 $\mu g\ m^{-3}$ for

PM_{10} and 25 μg m^{-3} for $PM_{2.5}$ in 2019: modelled values as colour contours and observed values as triangles.

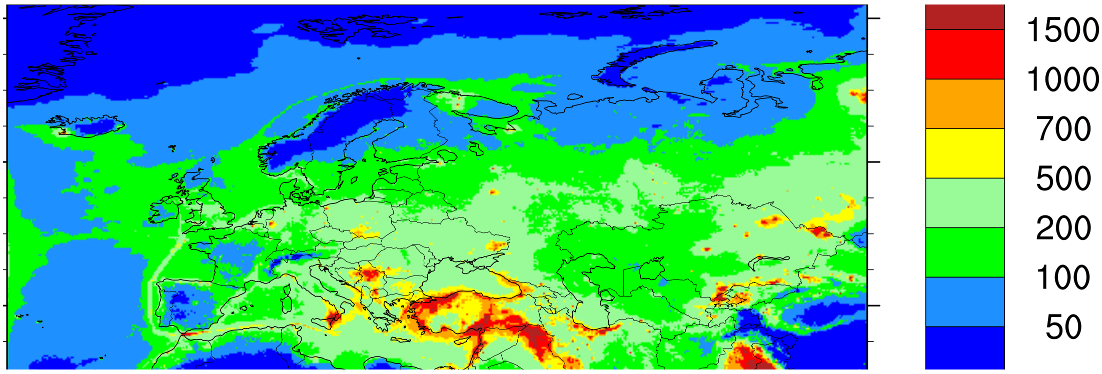
Overall, the number of days with PM exceedances, observed and modelled for EMEP sites for 2019, was the smallest in the last decade. Out of the 67 sites with daily or hourly PM_{10} measurements with data coverage above 75%, exceedance days were observed at 31 sites. No exceedances of the PM_{10} EU limit value (more than 35 exceedance days) were observed. Still, 12 sites had more than 3 exceedance days, as recommended by the WHO AQG. The highest numbers of days with observed exceedances of PM_{10} were 7 at DE0001 and 6 at LV0010 and RS0005.

$PM_{2.5}$ concentrations exceeded the WHO AQG recommended limit of 25 μg m^{-3} at 37 out of 51 stations in 2019. Among those, at 21 sites the number of exceedance days were more than 3 (the recommended limit according to WHO AQG). The highest number of exceedance days was 40, observed at HU0002 and IT0004, followed by 30, 26 and 24 exceedance days at DE0044, PL0005 and AT0002, respectively.

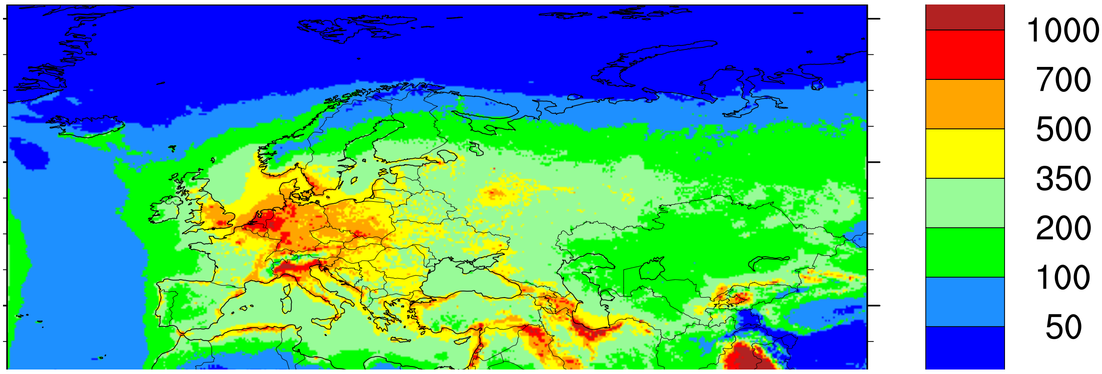
The modelled number of exceedance days for 2019 shows in general a good correspondence with the observations, with somewhat better agreement for PM_{10} than for $PM_{2.5}$. For PM_{10}, the model happens to underestimate the occurrence of exceedances of the EU limit value of 50 μg m^{-3} for some central European sites, for instance for AT0002 and the Dutch sites NL0009 and NL0010 (no modelled exceedance days versus 5 observed), and in the Baltic for LV0010 (0 exceedance day vs. 6 observed). On the other hand, the model tends to overestimate the number of exceedance days at some Mediterranean sites, influenced by Saharan dust, e.g. at the Cypriot site CY0002 (21 vs. 4 observed) and several Spanish sites (in particular ES0007 with 21 vs. 2 observed). Most of the exceedances registered at the Central European sites occurred during the winter (mainly caused by residential combustion) and in the spring (often due to agricultural emissions), while rather few exceedances occurred in the autumn 2019, which was rather wet. By contrast, at the Mediterranean sites the exceedances were more frequent during summer.

For $PM_{2.5}$, the model reproduces number of exceedance days at IT0004 (40), with most of then (61 %) coinciding with the observed ones. However, it calculates 12 exceedance days versus 40 observed at HU0002, only 3 versus 30 observed at DE0044, and no exceedance days versus 26 observed at PL0005. At the Dutch sites, the model slightly underestimates observed $PM_{2.5}$ exceedance days at NL0009 and NL0010, but overestimates those at NL0091 and NL0644 (same as for 2018 reported last year). Similar to PM_{10}, the model calculates a larger number of exceedance days for $PM_{2.5}$ compared with observations at CY0002 (47 vs 3 observed) and several Spanish sites, which is related to the uncertainties in windblown dust modelling. The seasonality of $PM_{2.5}$ exceedances is similar to that of PM_{10}, with most exceedance days at the Mediterranean sites in summer and at the other sites in winter, spring and autumn. The only difference is that the largest number of $PM_{2.5}$ exceedances at three of four German sites occurred in spring, while much fewer occurred during the cold seasons. As discussed above, much rain in November-December combined with the mild winter temperatures resulted in the absence of major PM episodes in 2019 typical for Europe in winters.

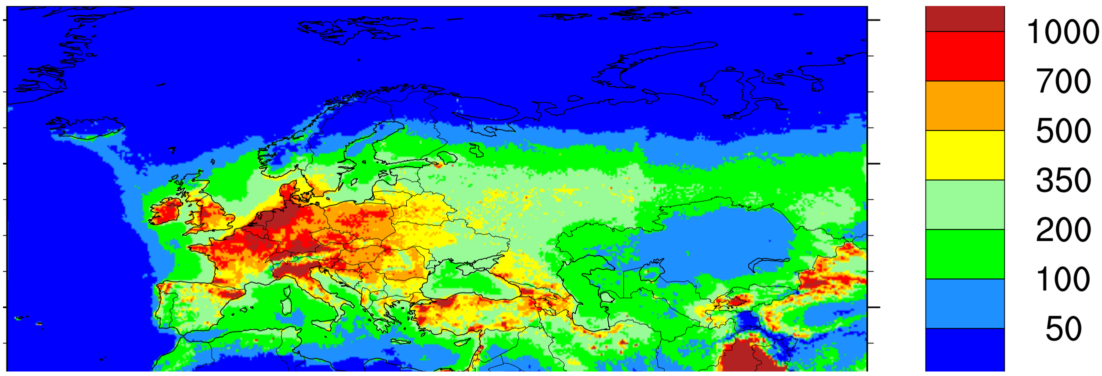
2.4.3 Deposition of sulfur and nitrogen



(a) oxidized S



(b) oxidized N



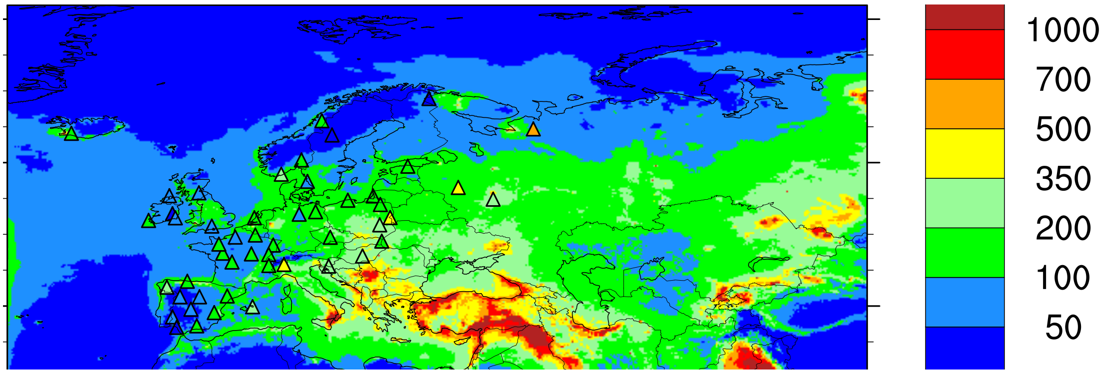
(c) Reduced N

Figure 2.13: Deposition of sulfur and nitrogen [mg(S)m^{-2}, mg(N)m^{-2}] in 2019.

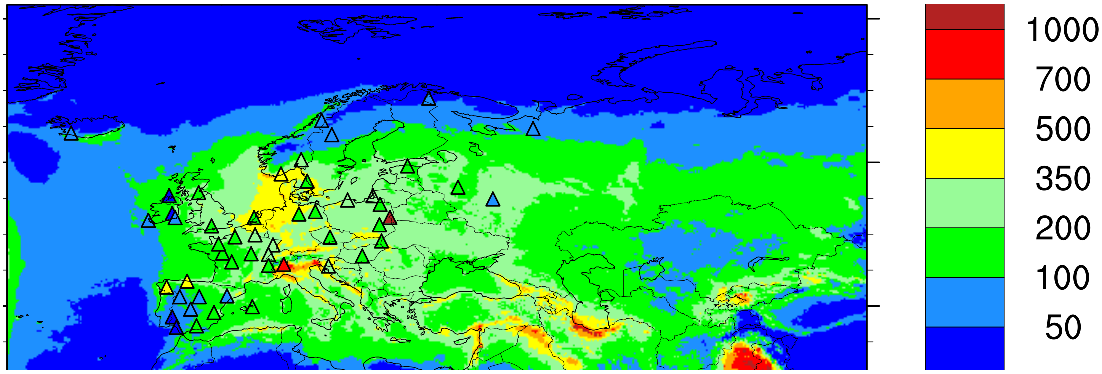
Modelled total depositions of sulfur and oxidised and reduced nitrogen are presented in Figure 2.13. For sulfur, many hot spots are found in the south-eastern part of the domain. In addition, volcanic emissions of SO_2 lead to high depositions in and around Sicily.

Oxidised nitrogen depositions are highest in northern Germany, the Netherlands, Belgium, Poland and northern Italy. These countries also have high depositions of reduced nitrogen, as do parts of the United Kingdom, France and Belgium in western Europe, and Turkey, Georgia, Armenia, Azerbaijan, Kyrgyzstan, Uzbekistan and Tajikistan in the east.

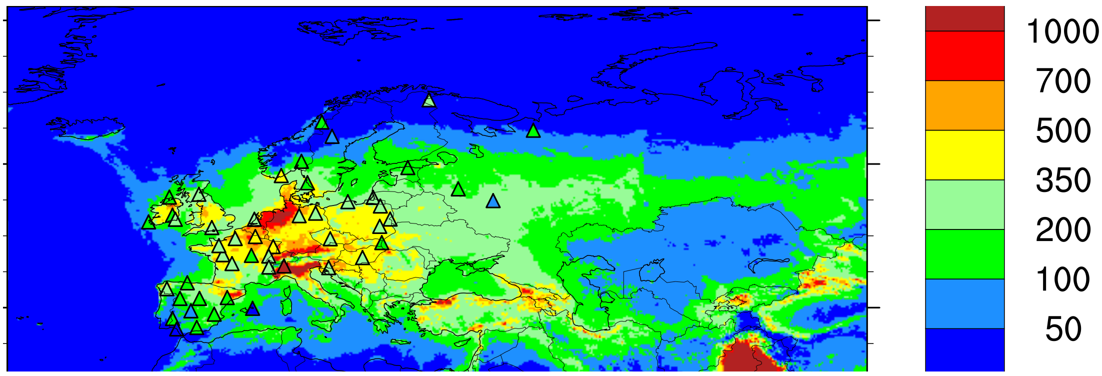
In Figure 2.14 wet depositions of nitrogen and sulfur compounds are compared to measurements at EMEP sites for 2019. Overall, the bias of the model with respect to measurements is around -32% to +19% (Appendix F), but higher for individual sites. A more detailed comparison between model and measurements for the year 2019 can be found at `https://aeroval.met.no/evaluation.php?project=emep&exp_name=2021-reporting`.



(a) oxidized S



(b) oxidized N



(c) Reduced N

Figure 2.14: Modelled wet deposition of sulfur and nitrogen [mg(S)m^{-2}, mg(N)m^{-2}] in 2019, with EMEP observations on top (marked by triangles).

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CHAPTER 3

Emissions for 2019

Bradley Matthews, Katarina Mareckova, Sabine Schindlbacher, Bernhard Ullrich, Robert Wankmüller and all CEIP/Umweltbundesamt Austria, Jeroen Kuenen (TNO)

In addition to meteorological variability, changes in the emissions affect the inter-annual variability and trends of air pollution, deposition and transboundary transport. The main changes in emissions in 2019 with respect to previous years are documented in the following sections.

The EMEP Reporting guidelines (UNECE 2014) requests all Parties to the LRTAP Convention to report annually emissions of air pollutants (SO_x[1], NO_2[2], CO, NMVOCs[3], NH_3, HMs, POPs, PM[4] and voluntary BC) and associated activity data. Projection data, gridded data and information on large point sources (LPS) have to be reported to the EMEP Centre on Emission Inventories and Projections (CEIP) every four years.

3.1 Reporting of emission inventories in 2021

Completeness and consistency of submitted data have improved significantly since EMEP started collecting information on emissions. Data of at least 47 Parties each year were submitted to CEIP since 2017 (see Figure 3.1). In 2021 (as of 1 June 2021), 48 Parties (94%)

[1]"sulfur oxides (SO_x)" means all sulfur compounds, expressed as sulfur dioxide (SO_2), including sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), and reduced sulfur compounds, such as hydrogen sulfide (H_2S), mercaptans and dimethyl sulfides, etc.

[2]"Nitrogen oxides (NO_x)" means nitric oxide and nitrogen dioxide, expressed as nitrogen dioxide (NO_2).

[3]"Non-methane volatile organic compounds" (NMVOCs) means all organic compounds of an anthropogenic nature, other than methane, that are capable of producing photochemical oxidants by reaction with nitrogen oxides in the presence of sunlight.

[4]"Particulate matter" (PM) is an air pollutant consisting of a mixture of particles suspended in the air. These particles differ in their physical properties (such as size and shape) and chemical composition. Particulate matter refers to:
(i) "$PM_{2.5}$", or particles with an aerodynamic diameter equal to or less than 2.5 micrometers (μm);
(ii) "PM_{10}", or particles with an aerodynamic diameter equal to or less than 10 μm.

submitted inventories[5], three Parties[6] did not submit any data and 42 Parties reported black carbon (BC) emissions (see Ch 3.2). As 2021 is a reporting year for large point sources (LPS) and gridded emissions, 32 Parties reported information on LPS, 26 Parties reported gridded data (Pinterits et al. 2021).

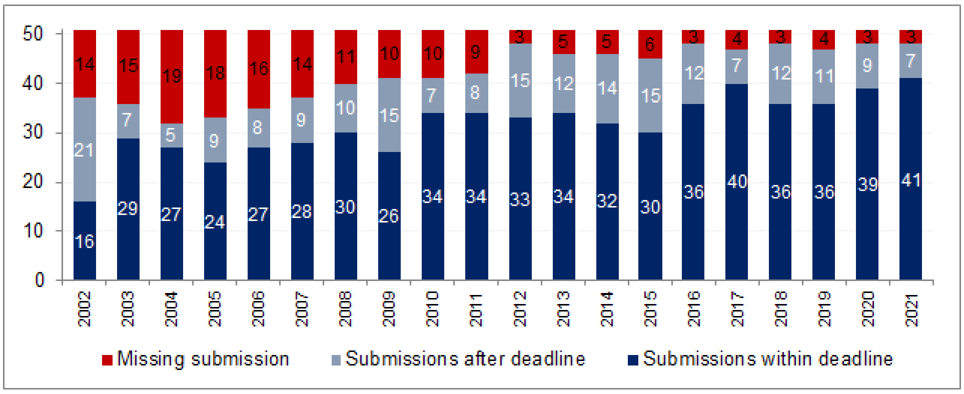


Figure 3.1: Parties reporting emission data to EMEP since 2002, as of 1 June 2021.

The quality of the submitted data across countries differs quite significantly. By compiling the inventories, countries have to use the newest available version of the *EMEP/EEA air pollutant emission inventory guidebook*, which is the version of 2019 (EMEP/EEA 2019). However, many countries still use the 2016 Guidebook (EMEP/EEA 2016) or older versions (e.g. EMEP/EEA (2013)). As analysed in a technical report (Schindlbacher et al. 2021), uncertainty of the reported data (national totals, sectoral data) is relatively high, e.g. the reported uncertainty estimates ranged from 6.9% to 56% for NO_x emissions reported in 2020. Further, the completeness of reported data has not turned out satisfactory for all pollutants and sectors either.

More detailed information on recalculations, completeness and key categories, plus additional review findings can be found in the annual CEIP technical country reports[7].

Indeed, the issue of recalculations is highly relevant to users of EMEP emissions datasets. The aforementioned CEIP report on uncertainties in reported emissions highlighted how time series of reported emissions can vary significantly over subsequent rounds of submissions due to inter alia revisions in activity data, updates of methods and emissions factors and/or inclusion of previously overlooked sources of emissions (Schindlbacher et al. 2021). The following subchapters summarise the inventory submissions in terms of three topics that are currently of high interest within the Convention:

- Reporting of black carbon emissions (Ch 3.2)
- Inclusion of the condensable component in particulate matter emissions (Ch 3.3)
- Comparison of reported Party emissions to respective reduction targets set out in the Gothenburg Protocol (Ch 3.4)

[5]The original submissions from the Parties can be accessed via the CEIP homepage on `https://www.ceip.at/status-of-reporting-and-review-results/2021-submissions`.
[6]Azerbaijan, Bosnia and Herzegovina and Kyrgyzstan
[7]`https://www.ceip.at/review-of-emission-inventories/technical-review-reports`

3.2 Black Carbon (BC) emissions

Over the last decade, black carbon (BC) has emerged as an important air pollutant in terms of both climate change and air quality.

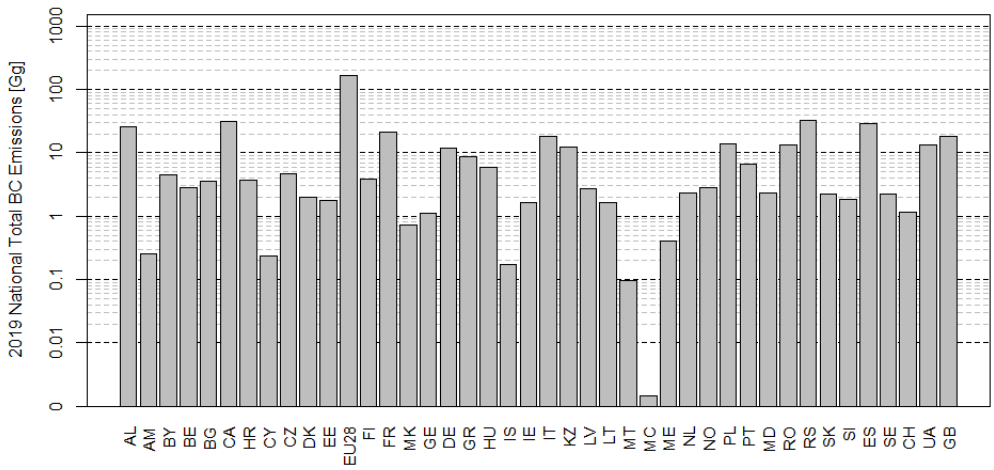


Figure 3.2: Black carbon emissions of the year 2019 as reported by CLRTAP Parties.

The emerging significance of BC is mirrored in developments in the international policy arena with respect to emissions reporting. Since the Executive Body Decision 2013/04, Parties to the LRTAP Convention have been formally encouraged to submit inventory estimates of their national BC emissions, and in 2015 the reporting templates were updated to include BC data emissions.

While BC is not a mandatory pollutant to be reported under the Convention, CEIP continues to monitor and review the level of BC reporting by the Convention's Parties. A brief overview of BC emissions estimates submitted by Parties in 2021 is given below.

Since enabling the reporting of BC, a total of 45 CLRTAP Parties have reported BC emissions estimates[8]. In this round of reporting, 30 CLRTAP Parties submitted a complete time series of national total BC emissions (1990-2019), while 38 CLRTAP Parties submitted a complete time series from 2000 onwards. Furthermore, 42 EMEP Parties have provided national total BC emissions estimates for the year 2019 (see Figure 3.2).

For more detailed information on BC consult the annual CEIP technical inventory review report (Pinterits et al. 2020).

3.3 Inclusion of the condensable component in reported PM emissions

The condensable component of particulate matter is a class of organic compounds of low volatility that may exist in equilibrium between the gas and particle phase. It is probably the biggest single source of uncertainty in PM emissions. For more background see Simpson et al. (2020). Currently the condensable component is not included or excluded consistently in PM

[8] As of 1 June 2021 Austria, Bosnia and Herzegovina, Liechtenstein, Luxembourg, Russia, and Turkey have yet to report estimates of national BC emissions.

emissions reported by Parties of the LRTAP Convention. Also in the EMEP/EEA Guidebook (EMEP/EEA 2019) the condensable fraction is not consistently included or excluded in the emission factors. Various EMEP centres and task forces and other stakeholders jointly discuss the topic and work on progress in this area. An important activity in 2020 was the workshop organised by MSC-W that resulted in a workshop report (Simpson et al. 2020). However, at the moment PM emissions reported by Parties to the LRTAP Convention are not directly comparable, which has implications on the modeling of overall exposure to PM.

Small scale combustion sources make a notable contribution to total PM emissions. For all Parties that reported $PM_{2.5}$ emissions for "1A4bi Residential: Stationary" for the year 2019 the average contribution to the national total $PM_{2.5}$ emissions from this source category was 46%. Small-scale combustion is one of the sources where the inclusion of the condensable component has the largest impact on the emission factor. For example, for conventional woodstoves, one of the most important categories in Europe, the emission factors excluding and including the condensable fractions may differ by up to a factor of five (Denier van der Gon et al. 2015). To improve the quality of the input data for air quality models, and following a decision of UNECE (2020), the group of experts that met at the workshop organised by MSC-W agreed on the following approach (for more details see Simpson et al. (2020)):

- In year one (2020) the so-called REF2 emission data provided by TNO, which include condensable organics, is used in an initial estimate for residential combustion emissions. The REF2 data and their usage in the EMEP modeling work in 2020 are described in Denier van der Gon et al. (2020) and Fagerli et al. (2020).

- In subsequent years these top-down estimates should be increasingly replaced by national estimates once procedures for quantifying condensables in a more harmonized way are agreed on and implemented.

CEIP in co-operation with TNO prepared a list of Parties where it could be assumed with a good degree of certainty that the condensable component is mostly included in PM emissions for GNFR sector C. The analysis focused on small scale combustion. This analysis was based on (a) the calculation of Implied Emission Factors (emission divided by the reported activity data), (b) the fuel mix of the Party, (c) the information provided in the Informative Inventory Report and (d) in a few cases direct information from Parties (received via e-mail).

The analysis resulted in a list of Parties where the conclusion was that the PM emission data reported by the Party should be used as the condensable component seemed to be included. For other Parties the TNO REF2.1 data are used. The REF2.1 dataset is described below in Ch 3.3.1. In a few cases data that had been gap-filled by CEIP was used for the respective Party where no REF2.1 estimate was available (see Table 3.1). In this report, the emission dataset which combines REF2.1 estimates for $PM_{2.5}$ from GNFR C with EMEP estimates are referred to as EMEPwREF2.1C dataset (see Appendix A).

Parties were asked to include a table with information on the inclusion of the condensable component in PM_{10} and $PM_{2.5}$ emission factors for reporting under the CLRTAP Convention in 2021. This table has been added to the revised recommended structure for IIRs[9]. Twenty-three Parties provided information on the inclusion of the condensable component in PM_{10} and $PM_{2.5}$ emission factors[10]. This reporting is a first step towards a better understanding of

[9] `https://www.ceip.at/reporting-instructions`

[10] Status as of 15 May 2021

Table 3.1: Data source for PM emissions in GNFR C used in the EMEP staus runs and source-receptor calculations in 2021 (EMEPwREF2.1C dataset).

Party	Data source for PM emission in GNFR C	Party	Data source for PM emission in GNFR C
Albania	REF2.1	**Italy**	CEIP, reported
Armenia	CEIP, gap-filled	**Kyrgyzstan**	CEIP, gap-filled
Austria	REF2.1	**Kazakhstan**	CEIP, gap-filled
Azerbaijan	CEIP, gap-filled	**Liechtenstein**	CEIP, reported
Belgium	CEIP, reported	**Lithuania**	REF2.1
Bosnia & Herzegovina	REF2.1	**Luxembourg**	CEIP, reported
Bulgaria	CEIP, reported	**Latvia**	CEIP, reported
Belarus	REF2.1	**Monaco**	CEIP, reported
Switzerland	REF2.1	**Republic of Moldova**	CEIP, reported
Cyprus	REF2.1	**Montenegro**	REF2.1
Czechia	CEIP, reported	**North Macedonia**	CEIP, reported
Germany	REF2.1	**Malta**	CEIP, reported
Denmark	CEIP, reported	**Netherlands**	CEIP, reported
Estonia	REF2.1	**Norway**	CEIP, reported
Spain	CEIP, reported	**Poland**	REF2.1
Finland	CEIP, reported	**Portugal**	CEIP, reported
France	REF2.1	**Romania**	CEIP, reported
United Kingdom	CEIP, reported	**Serbia**	CEIP, reported
Georgia	CEIP, gap-filled	**Russian Federation**	REF2.1 + CEIP (gap-filled)
Greece	CEIP, reported	**Sweden**	CEIP, reported
Croatia	CEIP, reported	**Slovenia**	CEIP, reported
Hungary	CEIP, reported	**Slovakia**	REF2.1
Ireland	REF2.1	**Turkey**	REF2.1
Iceland	CEIP, reported	**Ukraine**	REF2.1

reported PM data. The information that Parties provided on whether the condensable component is included in PM emissions was quite heterogeneous. The status of inclusion or exclusion is best known for emissions from the energy sector and road transport, for which many Parties submitted information.

3.3.1 REF2.1 emissions and improvements compared to last year's REF2 emissions

The REF2 emission inventory provides a bottom-up database of PM emissions (both PM_{10} and $PM_{2.5}$) from small combustion activities (GNFR category C), taking into account activity data and consistent emission factors that include condensables, for both wood and solid fuel combustion. It was originally developed for the year 2010 (Denier van der Gon et al. 2015). Residential emissions vary from year to year, because of technological developments in the sector (replacement of stoves and boilers) but also because of the heating demand due to fluctuating temperatures. To take this into account, an alternative REF2 was developed for

2015 which was also used as an input to EMEP modelling in 2020. These REF2 emission data and their usage in the EMEP modelling work in 2020 are described in Denier van der Gon et al. (2020) and Fagerli et al. (2020). This version was developed by scaling the original REF2 for 2010 to the year 2015 by using the trend in the official reported data for $PM_{2.5}$ from GNFR C for that particular year. The idea behind this approach was that by scaling in this way both the technological changes within each country as well as the annual fluctuation in heating demand are included. It is desirable but difficult to separate these effects because the detailed underlying country data are not available. Countries report emissions only by source sector and for the sum of all fuels; activity data or emissions by appliance type are not available.

This scaled REF2 for the year 2015 has been used both in EMEP and other modelling activities, and presented in various international expert group meetings such as CAMS, EMEP and UNECE Task Forces (in particular TFEIP and TFMM). This triggered several discussions with experts (including some specific countries), which resulted in the provision of additional information of the national circumstances on the types of stoves installed, etc. (see also Simpson et al. (2020)).

With this information, as well as additional information made available by IIASA (Z. Klimont), for 5 specific countries (Austria, Germany, Finland, France, the Netherlands) the REF2 emission estimates were revised. This revised emission inventory is referred to as REF2.1 in this report. The main reason to change the emission estimates is the new information that became available on the appliance types, especially regarding the split between different types of heating stoves (traditional vs. modern). For modern stoves, the PM emission factors are significantly lower compared to traditional stoves, and for the condensable component of PM this effect is even larger. The 5 selected countries were chosen because of feedback received or discussions with national experts which suggested that REF2 emissions may be overestimated. It is planned to also revisit the REF2.1 emission estimates for the other countries, but this is ongoing work.

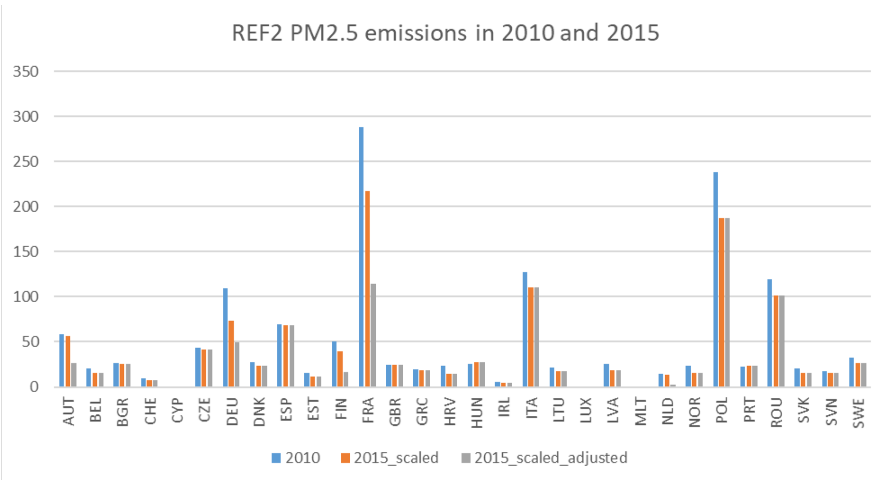


Figure 3.3: Results for REF2 for 2010 (original), 2015 (after scaling, used in EMEP 2020) and REF2.1 for 2015 (after scaling + adjustment for 5 countries, used in EMEP 2021). Unit: Gg.

Figure 3.3 shows the different REF2 emission estimates for $PM_{2.5}$ from GNFR C. The year 2010 is the original REF2 estimate, while 2015_scaled represents the scaled REF2 to the year 2015 using the official reported data (used in the 2020 EMEP modelling). The estimate 2015_scaled_adjusted is the updated version described here, where for 5 selected countries in the original REF2 data have been revised based on new information (REF2.1). From the figure, it can be seen that the 2015 emissions are lower than 2010 for almost all countries. This is partly the result of technological advancements in countries (replacement of older stoves with new ones), but also largely related to the fact that 2010 was a relatively cold year in Europe, hence with higher emissions from the residential sector compared to other years. The figure also shows that for the five countries that have been adjusted in the latest update, in each case the REF2.1 emissions including condensables is corrected downward. This adjusted REF2.1 is, however, still considerably higher than reported emission for each of these countries.

3.4 Gothenburg Protocol targets

The 1999 Gothenburg Protocol (GP) lists emission reduction commitments of NO_x, SO_x, NMVOCs and NH_3 for most of the Parties to the LRTAP Convention for the year 2010 (UNECE (1999)). These commitments should not be exceeded in 2010 and in subsequent years either.

In 2012, the Executive Body of the LRTAP Convention decided that adjustments to inventories may be applied in some circumstances (UNECE (2012)). From 2014 to 2021, adjustment applications of ten countries (Belgium, Czechia, Denmark, Finland, France, Hungary, Germany, the Netherlands, Luxembourg, Spain and the United Kingdom) have been accepted by expert review team and therefore these approved adjustments have to be subtracted for the respective countries when compared with the targets. In April 2021, Czechia and France submitted new adjustment applications; the NH_3 adjustment application of Czechia was rejected by the review team and application from France has been accepted.

Further, the reporting guidelines (UNECE (2014)) specify that some Parties within the EMEP region (i.e. Austria, Belgium, Ireland, Lithuania, Luxembourg, the Netherlands, Switzerland, the United Kingdom of Great Britain and Northern Ireland) *may choose to use the national emission total calculated on the basis of fuels used* in the geographic area of the Party as a basis for compliance with their respective emission ceilings.

However, when considering only reported data, approved adjustments and fuel used data of the respective countries, Figure 3.4 indicates that in the year 2019 North Macedonia could not reduce their SO_x emissions below their respective Gothenburg Protocol requirements, and that Croatia and Spain are above their 1999 Gothenburg Protocol ceilings concerning NH_3. For NO_x and NMVOC all countries were below their individual ceilings in year 2019.

3.5 Datasets for modellers 2021

Under the Convention, CEIP is responsible for synthesizing the reported emissions data of the EMEP countries into complete gridded emissions datasets for the EMEP domain (covering the geographic area between 30°N-82°N latitude and 30°W-90°E longitude. These data are mainly used for modelling of air pollutant concentrations and depositions.

To compile these datasets each year, CEIP synthesizes and evaluates the most recent national sectoral emissions estimates and national gridded emissions data reported by the EMEP countries. CEIP strives to include, to the largest possible extent, the reported emissions data it receives from EMEP countries. However, due to cases of non-reporting or identified quality issues in the reported data, emissions need to be gap-filled or replaced. Furthermore, it

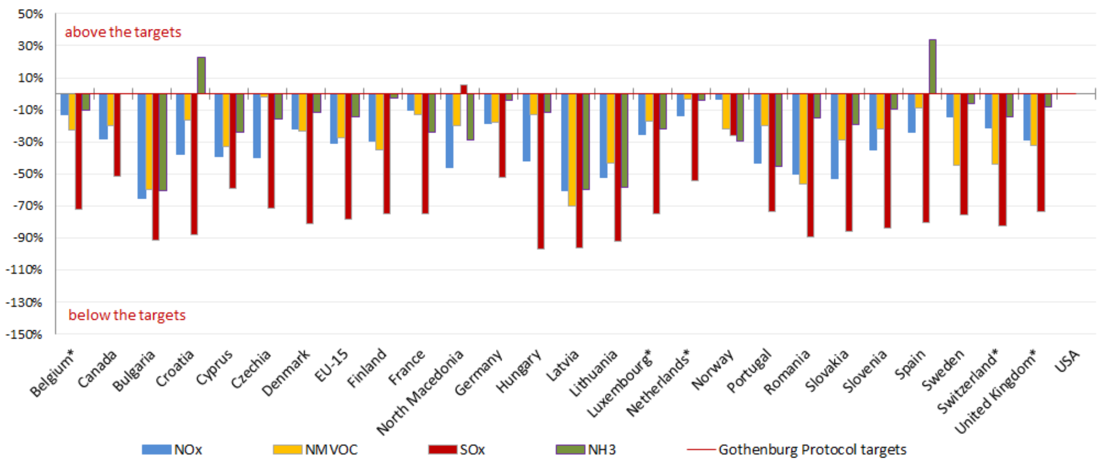


Figure 3.4: Distance to Gothenburg Protocol targets in 2019 (based on reported data in 2021). Only Parties that ratified the Gothenburg Protocol are included. * Emission data based on fuels used for road transport. Approved adjustments are considered for Denmark (NMVOCs, NH_3), Finland (NH_3), Germany (NO_x, NMVOCs, NH_3), Luxembourg (NO_x, NMVOCs), the Netherlands (NH_3, NMVOCs).

should be noted how gridded and sectoral emissions totals are combined in compiling these datasets. National gridded emissions data, even if reported annually, are not directly utilized but are rather used to map out relative emissions, with which national sector emission totals are spatially distributed. If for a given year both national sector emissions totals and gridded estimates reported by a given country pass through the CEIP QA/QC checks, the generated gridded emissions will be identical to the gridded emissions reported by the country. The following subchapters describe important aspects of the 2021 EMEP datasets, summarising:

- The status of reporting of national gridded emissions data and the extent to which these are used to distribute emissions spatially (Ch 3.5.1)
- The extent to which sectoral emissions were gap-filled or replaced (Ch 3.5.2)
- The sectoral contributions (Ch 3.5.3) and temporal trends (Ch 3.5.4) in the emissions of carbon monoxide, nitrogen oxides, sulfur oxides, ammonia, non-methane volatile organic carbons, and particulate matter including black carbon. Trends in shipping emissions are discussed separately (Ch 3.5.5).

3.5.1 Reporting of gridded data

After the first round of submissions in 2017, 2021 was the second year for which EMEP countries were obliged to report gridded emissions in the grid resolution of $0.1^\circ \times 0.1^\circ$ longitude/latitude. As of June 2021, 34 of the 48 countries which are considered to be part of the EMEP area reported sectoral gridded emissions in this resolution.

The majority of gridded sectoral emissions in $0.1^\circ \times 0.1^\circ$ longitude/latitude resolution have been reported for the year 2015 (32 countries). For 2019 gridded sectoral emissions have been reported by 29 countries, for 2016 and 2017 by five countries and for 2018 by four countries. In comparison to reporting in 2017, reported gridded data are available for 11 more countries in 2021.

Table 3.2: Gridded emissions in $0.1° \times 0.1°$ longitude/latitude resolution reported until 2017, 2020 and 2021.

Country	2017 Gridded data available for the years…	2020 Gridded data available for the years…	2021 Gridded data available for the years…	Comments
Austria	2015	2015	2000, 2005, 2010, 2015, 2019	
Belgium	2015	2015	2015, 2019	
Bulgaria	2015	2015	2015, 2019	
Croatia	1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015, 2019	
Cyprus			1990, 1995, 2000, 2005, 2010, 2015, 2019	
Czechia	2015	2015	2015, 2019	
Denmark	2015	2015	2015, 2019	
Estonia		1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015, 2019	
Finland	2014, 2015	2014, 2015, 2016, 2017, 2018[(a)]	1990, 1995, 2000, 2005, 2010, 2015, 2016, 2017, 2019	(a) Gridded data for 2014, 2015 and 2018 could not be used for the preparation of spatial distributed emission data.
France		2015	2015, 2019	
North Macedonia		2015	2015, 2019[(b)]	(b) The submission of gridded emissions was too late to be considered for the preparation of gridded data for modelers in 2021
Georgia		2015	2015	
Germany	1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015, 2017	1990, 1995, 2000, 2005, 2010, 2015, 2017, 2019	
Greece		2015	2015, 2019	
Hungary	2015[(c)]	2015	2015	(c) The submission of gridded emissions was too late to be considered for the preparation of gridded data for modelers in 2017
Ireland	2015	2015	2015, 2019[(d)]	(d) The submission of gridded emissions was too late to be considered for the preparation of gridded data for modelers in 2021
Italy		2015[(e)]	2015[(e)]	(e) Reported gridded data was replaced by CAMS and EDGAR proxies
Latvia	2015	2015	2015, 2019	
Lithuania	2015[(f)]	2015	2015, 2019[(g)]	(f) Reported gridded emissions only on national total level, which could not be used for the gridding, which is done on sectoral level g) The submission of gridded emissions was too late to be considered for the preparation of gridded data for modelers in 2021
Luxembourg	2005, 2010, 2015	2005, 2010, 2015	2015, 2019	
Malta		2016	2016	Grid reporting not in the defined 0.1°x0.1° coordinates
Monaco	2014, 2015	2014, 2015, 2016	2014-2019	
Netherlands		1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015, 2019	
Norway	1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015	1990, 1995, 2000, 2005, 2010, 2015, 2019	
Poland	2014, 2015	2014, 2015, 2018	2014, 2015, 2018, 2019	
Portugal	2015	2015	2015, 2019	The spatial disaggregation of sector 'F – Road Transport' was replaced by CAMS proxies
Romania	2005	2005, 2015	2005, 2015	
Slovakia	2015	2015	2015, 2019	
Slovenia	2015	2015	2015, 2019	
Spain	1990-2015	1990-2018	1990-2019	The spatial disaggregation of sector 'F – Road Transport' was replaced by CAMS proxies
Sweden		1990, 2000, 2005, 2010, 2015	1990, 2000, 2005, 2010, 2015, 2019	
Switzerland	1980-2015	1980-2018	1980-2019	
United Kingdom	2010, 2015	2010, 2015	2010, 2015, 2019	
Russian Federation			2019	The submission of gridded emissions was too late to be considered for the preparation of gridded data for modelers in 2021

Fifteen countries reported gridded emissions additionally for previous years (one country for the whole time series from 1980 to 2019; one country for the whole time series from 1990 to 2019; seven countries for the years 1990, 1995, 2000, 2005 and 2010; one country for the years 1990, 2000, 2005 and 2010; one country for the years 2000, 2005 and 2010; one country for the year 2005; one country for the year 2010; and two countries for the year 2014).

Reported gridded sectoral data in 0.1°×0.1° longitude/latitude resolution, which can be used for the preparation of gridded emissions for modelers, covers less than 25% of the cells within the geographic EMEP area. For the remaining areas (or for EMEP countries that have no reported gridded data) missing emissions are gap-filled and spatially distributed by expert estimates. Reported grid data can be downloaded from the CEIP website[11]. The gap-filled gridded emissions are also available there[12].

An overview of gridded data in 0.1°×0.1° longitude/latitude resolution reported in 2017, 2020 and 2021 is provided in Table 3.2.

For compiling the 2021 EMEP emisisons dataset, reported gridded data in 0.1°×0.1° longitude-latitude resolution was used from Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Ireland, Latvia, Luxembourg, Malta, Monaco, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

3.5.2 Gap-filling of reported data in 2021

As described above, sectoral emissions reported by the EMEP countries are used, to the largest extent possible, to compile the gridded EMEP datasets. Each year the reported source-sector level data (NFR level) are aggregated into the 13 GNFR sectors and are then evaluated to identify countries for which emissions have not been reported or appear to exhibit implausible emission levels and/or trends. Based on this assessment, a procedure is then implemented to gap-fill missing emissions data and to replace data that have been identified as implausible. The sectoral emissions are then distributed spatially using, where available (and appropriate), the reported national gridded emissions as relative spatial proxies, or other independent datasets of spatial proxies.

Given the end of May deadline for compiling EMEP datasets, a cut-off date for incorporating reported emissions has to be set to allow necessary time for evaluating the reported emissions and implementing the gap-filling procedure. This year, the sectoral emissions data reported by 14 April 2021 were evaluated and considered for use in the compilation of the 2021 EMEP datasets of gridded emissions.

The Parties, where data were (partly) replaced, corrected or gap-filled in 2021 are Albania, Armenia, Austria, Azerbaijan, Belarus, Bosnia and Herzegovina, Cyprus, Denmark, Georgia, Kazakhstan, Kyrgyzstan, Liechtenstein, Lithuania, Luxembourg, Montenegro, the Republic of Moldova, the Russian Federation, Serbia, Turkey and the Ukraine. The results of the quality control and gap-filling procedures are described in detail in CEIP gap-filling report (Matthews and Wankmüller 2021).

Finally, it should be noted that the gap-filling and replacement procedure has been updated since 2020. The gap-filling/replacement of EMEP country emissions remains based on the

[11] https://www.ceip.at/status-of-reporting-and-review-results

[12] https://www.ceip.at/webdab-emission-database/emissions-as-used-in-emep-models

independent estimates from the ECLIPSE v6b[13] dataset that has been compiled by IIASA using their GAINS model (Amann et al. 2011). However, the emissions for areas North Africa, remaining Asian areas, the Aral Lake and the part of Russia within the EMEP domain for which Russia does not report emissions (referred to as 'Russian Federation Asian part' further in this chapter), are now based on the updated EDGAR v5.0[14] dataset (Crippa et al. 2019) that was generated by the European Commission's Joint Research Centre (JRC). Previously, the emissions for these areas were based on a previous version (EDGAR v4.3.2) of the dataset (Crippa et al. 2018).

3.5.3 Contribution of GNFR sectors to total EMEP emissions

Figure 3.5 shows the contribution of each GNFR sector to the total emissions of individual air pollutants (SO_x, NO_x, CO, NMVOC, NH_3, $PM_{2.5}$, PM_{10}, PM_{coarse} and BC). To clarify, the reader is reminded that these analyses are based on the emission data in the EMEP datasets for modellers i.e. data based largely on reported emissions, but also compiled with independent emissions estimates for countries and regions where data are not reported or the reported data have been omitted due to quality issues. The sea regions were excluded for this sectoral analysis.

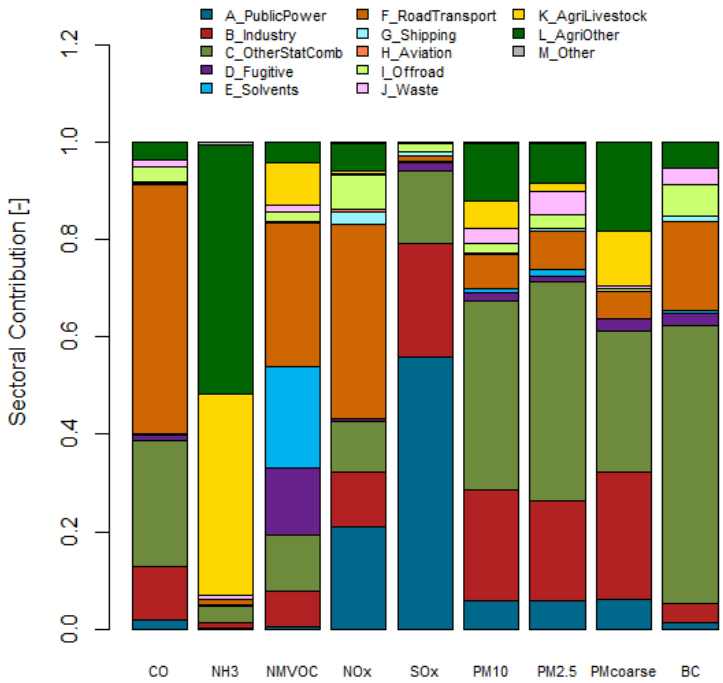


Figure 3.5: GNFR sector contribution to national total emissions in 2019 for the EMEP domain apart from the sea regions.

It is evident that the combustion of fossil fuels is responsible for a significant part of all

[13]https://iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv6.html

[14]https://edgar.jrc.ec.europa.eu/dataset_ap50

emissions. For NO_x emissions, the largest contributions come from transport (sector F, 40%) and from large power plants (sector A, 21%).

NMVOC sources are distributed more evenly among the different sectors, such as 'E - Emissions from solvents' (21%), 'F - Road transport' (30%), 'D - Fugitive Emissions' (14%), 'B - Industry combustion' (7%), 'K - Manure management' (9%) and 'C - Other stationary combustion' (12%).

The main source of SO_x emissions are large point sources from combustion in energy and transformation industries (sector A, 56% and sector B, 23%).

Ammonia arises mainly from agricultural activities; about 92% combined contribution from sectors K and L. Emissions of CO originate primarily from 'F - Road transport' (51%) and 'C - Other stationary combustion' (26%).

The main sources of primary PM_{10} and $PM_{2.5}$ emissions are industry (23% and 20%) and other stationary combustion processes (39% and 55%). Due to the higher agricultural emissions of PM_{10} versus $PM_{2.5}$, sectors K and L make a much larger relative contribution to PM_{coarse} emissions (29% combined) together with significant contributions from 'B - industry combustion' (26%) and 'C - Other stationary combustion' (29%).

Finally, the most important contributors to BC emissions are 'F - Road transport' (18%) and 'C - Other stationary combustion' (57%).

Figure 3.6 illustrates the sector contributions to the sum of total emissions in the EMEP West region and the EMEP East region. The split between the EMEP West and EMEP East regions is according to `https://www.ceip.at/countries` (sea regions, North Africa and the remaining Asian areas are excluded, with the Aral Lake area assigned to EMEP East). The comparison of both graphs highlights some significant differences between West and East.

For NO_x in both the EMEP West and EMEP East regions the most important sector is 'F - Road transport emissions' (38% and 34%, respectively), although it is worth noting the higher contribution from 'A - Public electricity and heat production' in the East region (23%).

For NMVOC in the EMEP West region the most relevant sector is 'E - Emissions from solvents' with a share of 35%. In the EMEP East region the same sector has a considerable lower share (14%), whilst the sector 'F - Road transport' is of high importance (32%).

The main source of SO_x are 'A - Public electricity and heat production' and and 'B - Industry combustion'. These two sectors together contribute to 78% and 86% of the SO_x emissions within the EMEP West and EMEP East areas, respectively.

The main sources of NH_3 emissions for both EMEP West and EMEP East are the agricultural sectors (K and L) with 93% and 94%, respectively.

CO emissions arise mainly from 'F - Road transport emissions' (60%) in EMEP East. In the EMEP West region the main sector is 'C - Other stationary combustion' (40%).

For $PM_{2.5}$ and PM_{10} 'C - Other stationary combustion' holds a significant share of the total emissions in the EMEP West area (54% and 37%), compared to the EMEP East area (18% and 14%). For the EMEP East area sector 'B - Industry combustion' is of higher importance. For PM_{coarse} it is worth mentioning the higher contributions from agriculture in the EMEP East area (44%). Finally, it is interesting to note the significant contribution to BC emissions in the EMEP East area from fugitive emissions (13% in EMEP East versus 1% in EMEP West).

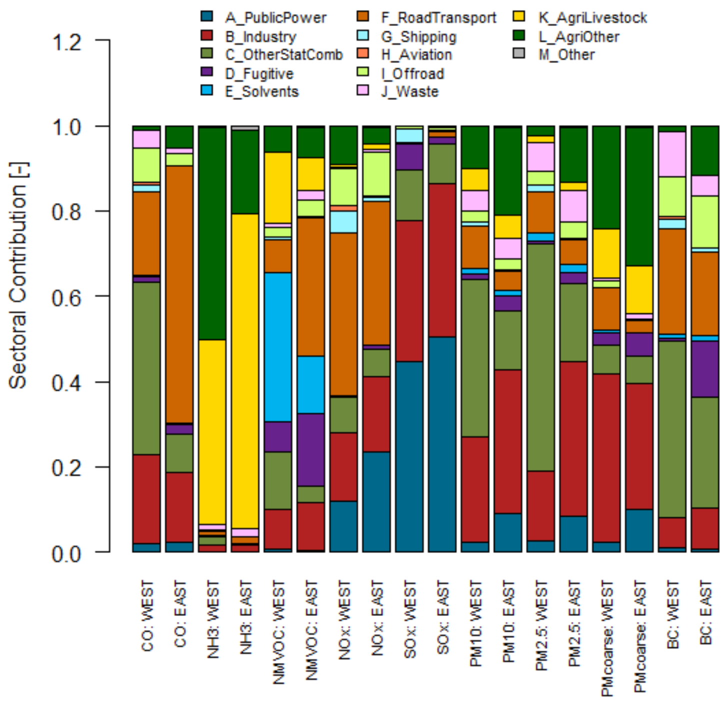


Figure 3.6: GNFR sector contribution to national total emissions in 2019 for the EMEP West and EMEP East areas. Asian areas, North Africa and the sea regions are not included.

3.5.4 Trends in emissions in the geographic EMEP domain

The following trend analyses are based on the emissions data in the EMEP datasets for modellers, i.e. data based largely on reported emissions, but also compiled with independent

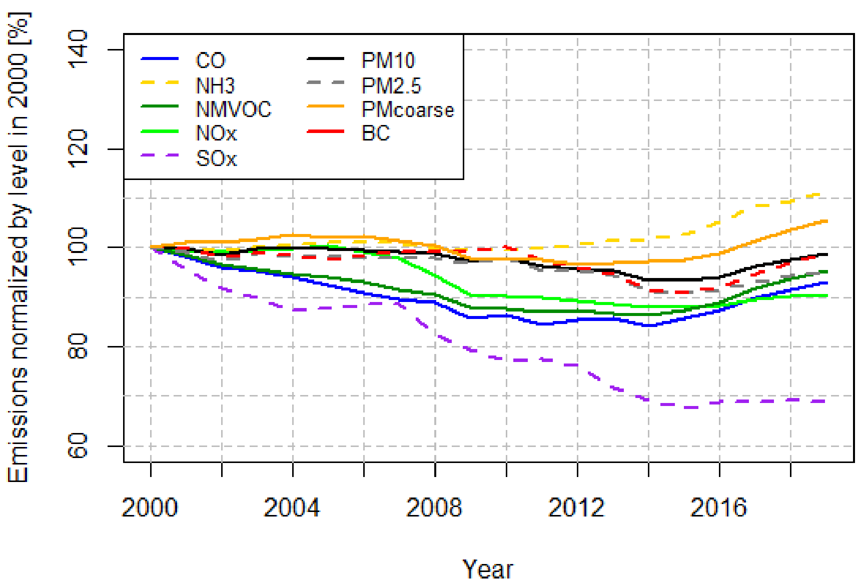
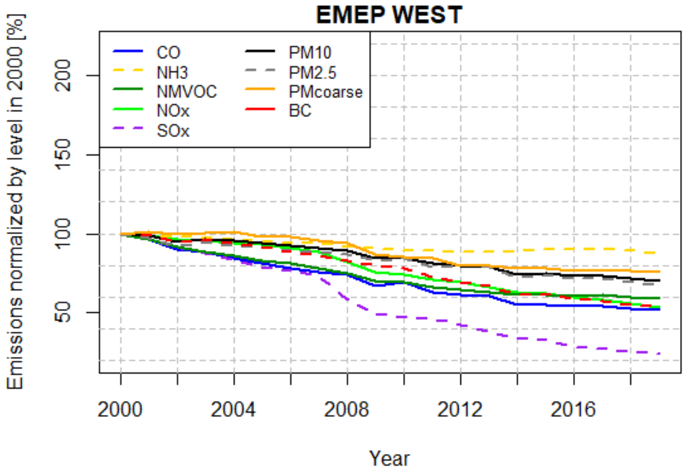
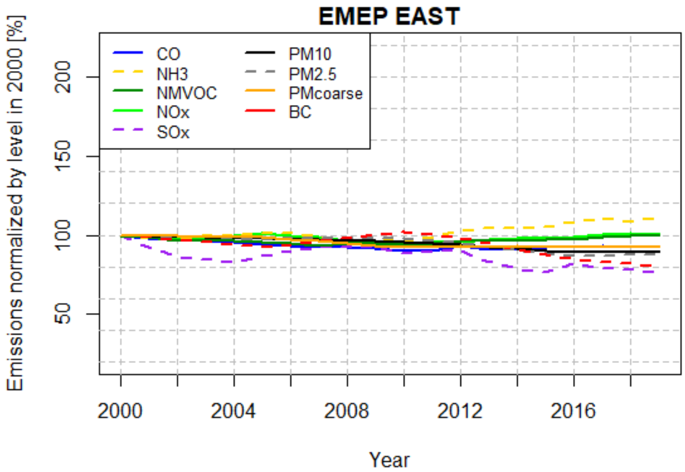


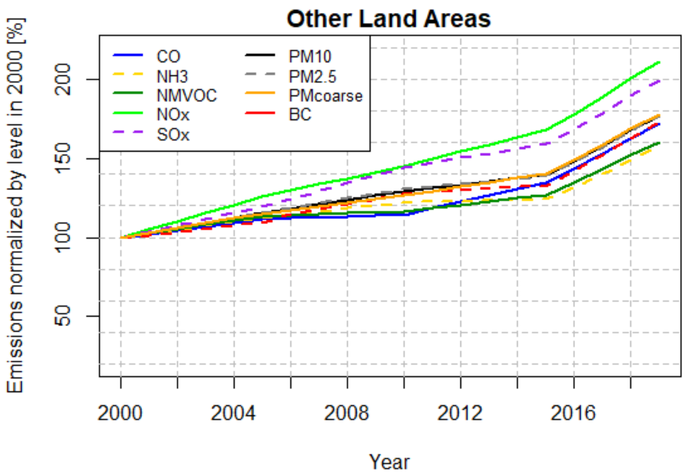
Figure 3.7: Emission trends 2000–2019 in the geographic EMEP area (emissions from international shipping in the sea regions are excluded).



(a) EMEP West



(b) EMEP East



(c) Other Land Areas

Figure 3.8: Emission trends 2000-2019 in the geographic EMEP domain (emissions from international shipping in the sea regions are excluded) divided into three areas: 'EMEP West' (top), 'EMEP East' (middle) and 'Other Land Areas' (bottom), that include the emissions from North Africa and the remaining Asian areas.

emissions estimates for countries and regions where data are not reported or the reported data have been omitted due to quality issues.

Excluding shipping emissions in the sea regions (these are summarised in the following subchapter), the trend analyses of total emissions from the non-sea areas in the EMEP domain[15] in Figure 3.7 show that emissions of seven of the nine pollutants have decreased overall since 2000. Only the 2019 PM_{coarse} and NH_3 emissions have increased (by 6 and 12%, respectively) since 2000. The 2019 emissions of SO_x are 69% of the respective 2000 emissions. While the 2019 emissions of CO, NMVOC, NO_x, $PM_{2.5}$, PM_{10} and BC are all lower than respective emissions in 2000 (1-10% lower), it is interesting to note that emissions of these pollutants have been increasing since ca. 2014.

Despite these overall trends, assessment shows that regional emission developments seem to follow strongly different patterns (Figure 3.8). While emissions of all the pollutants in the EMEP West countries are clearly decreasing, emissions of all pollutants in the EMEP East countries of the EMEP domain have been somewhat stable (albeit gradually decreasing for most pollutants) over the 2000-2019 period. For the Other Land Areas (North Africa and the remaining Asian areas, emissions are clearly on the rise.

Of course it is not just the emission trends that separate the three land regions. Whereas the emission trends of the EMEP West countries are based to a very large extent on the official national inventories reported to CEIP, the countries of the Other Land Areas within the EMEP domain (North Africa, remaining Asian areas) are not Parties to the Convention and thus are not obliged to report their emissions. For these regions, emissions are based completely on the independent gridded emission estimates of the EDGAR v5.0 dataset (Crippa et al. 2019). For the EMEP East region, again not all countries are Parties to the Convention (Turkmenistan, Tajikistan and Uzbekistan) and reported Russian emissions do not cover the region of Russia within the EMEP domain that is ca. east of the Urals. Emissions for the area of the Aral Lake are also not reported by any Convention country. Note that the emissions for the eastern part of Russia and the Aral Lake have also been gap-filled using the independent gridded emission estimates of the EDGAR v5.0 dataset. Finally, it should be noted that many of the emissions time series for the EMEP East countries that are Parties have been partially or fully replaced with independent estimates from the ECLIPSE v6b[16] dataset that has been compiled by IIASA using their GAINS model (Amann et al. 2011).

Non-sea emission levels in the geographic EMEP domain for 2019 of the individual countries and areas are compared to 2000 emission levels for each pollutant (see Tables 3.3-3.3 cont.). Again, the reader is reminded that the following trend analyses are based on the emissions data in the EMEP datasets for modellers i.e. data based largely on reported emissions, but also compiled with independent emissions estimates for countries and regions where data are not reported or the reported data have been omitted due to quality issues. Overview tables with reported emission trends for individual countries have been published on the CEIP website[17]. Detailed information on the sectoral level can also be accessed in WebDab[18].

The assessment of emission levels in individual countries and areas show an increase of

[15]The EMEP domain covers the geographic area between 30° N-82° N latitude and 30° W-90° E longitude.

[16]`https://iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv6.html`

[17]`https://www.ceip.at/webdab-emission-database/reported-emissiondata`

[18]`https://www.ceip.at/webdab-emission-database/emissions-as-used-in-emep-models` and/or `https://www.ceip.at/webdab-emission-database/reported-emissiondata`

Table 3.3: Differences between emissions for 2000 and 2019 (based on gap–filled data as used in EMEP models). Negative values mean that 2019 emissions were lower than 2000 emissions. Red/blue coloured data indicates that 2019 emissions were higher/lower than 2000 emissions. Furthermore, the symbol in parentheses indicate whether the emissions times series are completely based on reported data (R), are partially based on reported data (r), or have been completely replaced/gap-filled (-).

Country	CO	NH_3	NMVOC	NO_x	SO_x	PM_{10}	$PM_{2.5}$	PM_{coarse}	BC
Albania	-3.3 (-)	13 (-)	2.3 (-)	47.6 (-)	-30.7 (-)	35.5 (-)	34.8 (-)	39 (-)	-0.3 (-)
Armenia	-27.9 (-)	60.7 (-)	10.7 (-)	152.5 (-)	503.8 (-)	90 (-)	99.9 (-)	60.5 (-)	310.7 (-)
Asian Areas	76.7 (-)	60 (-)	66.5 (-)	122.6 (-)	108.9 (-)	82.1 (-)	82 (-)	82.3 (-)	72.9 (-)
Austria	-31.3 (R)	4.9 (R)	-40.1 (R)	-31.9 (R)	-65.4 (R)	-30.2 (R)	-41.5 (R)	-10.6 (-)	-47.5 (-)
Azerbaijan	101.4 (-)	58.9 (r)	222.9 (-)	196.8 (-)	-63.2 (-)	130.8 (-)	140.5 (-)	99.3 (-)	229.5 (-)
Belarus	-41.3 (r)	-5.7 (r)	-24.7 (r)	-5 (r)	-79.2 (r)	-12.8 (-)	-8.7 (-)	-23.7 (-)	-10.4 (-)
Belgium	-62.4 (R)	-28.9 (R)	-51.4 (R)	-55.5 (R)	-82.7 (R)	-50.2 (R)	-54 (R)	-39.9 (-)	-68.2 (R)
Bosnia and Herzegovina	48.9 (-)	53.7 (-)	73.9 (-)	37.4 (-)	-51.4 (-)	63.7 (-)	141 (-)	-31.9 (-)	184.6 (-)
Bulgaria	-31.3 (R)	-13.4 (R)	-33.7 (R)	-33 (R)	-89.8 (R)	0.1 (R)	17 (R)	-20.2 (-)	25.7 (R)
Croatia	-53.2 (R)	-16.6 (R)	-26.8 (R)	-40.7 (R)	-86.5 (R)	-8.3 (R)	-19 (R)	32.9 (-)	-29.1 (R)
Cyprus	-63.8 (R)	-31.3 (R)	-29.7 (R)	-37.4 (R)	-66.8 (R)	-55.6 (R)	-58 (R)	-53 (-)	-63.4 (r)
Czech Republic	-23.5 (R)	-19.8 (R)	-31.5 (R)	-42.1 (R)	-65.7 (R)	-29.6 (R)	-28.1 (R)	-34 (-)	-28.5 (R)
Denmark	-56.3 (R)	-22.7 (R)	-44.5 (R)	-56.5 (R)	-67.9 (R)	-29.9 (R)	-38.5 (R)	-14.6 (-)	-54.3 (r)
Estonia	-34.3 (R)	23.2 (R)	-38 (R)	-44.9 (R)	-80.6 (R)	-71.3 (R)	-61.8 (R)	-80 (-)	-49.3 (R)
Finland	-42.6 (R)	-9.3 (R)	-52.5 (R)	-50.3 (R)	-64.6 (R)	-30 (R)	-36.9 (R)	-19.2 (-)	-40.8 (R)
France	-63.1 (R)	-10.5 (R)	-53.3 (R)	-54.7 (R)	-83.8 (R)	-51.8 (R)	-61.7 (R)	-21.8 (-)	-70 (R)
Georgia	-18 (R)	-26.2 (r)	-22.4 (R)	64.9 (r)	90.1 (-)	-18.1 (-)	-23.3 (-)	28 (-)	57.5 (-)
Germany	-43.9 (R)	-6.4 (R)	-37.8 (R)	-40.3 (R)	-59.5 (R)	-32.7 (R)	-45.6 (R)	-16.5 (-)	-70 (R)
Greece	-54 (R)	-15.1 (R)	-53.3 (R)	-42 (R)	-85.5 (R)	-52.6 (R)	-44.6 (R)	-61.3 (-)	-21.6 (R)
Hungary	-58.6 (R)	-6.7 (R)	-37.4 (R)	-39.4 (R)	-96 (R)	-16.9 (R)	-20.7 (R)	-9.2 (-)	-27.8 (R)
Iceland	41.5 (R)	-3 (R)	-40.5 (R)	-36.7 (R)	50.5 (R)	-14 (R)	-17.9 (R)	-9 (-)	-50 (R)
Ireland	-72.4 (R)	4.6 (R)	-7.1 (R)	-44.6 (R)	-92.5 (R)	-27.8 (R)	-40.9 (R)	-13.5 (-)	-57.5 (R)
Italy	-56.6 (R)	-21.8 (R)	-45.1 (R)	-58.3 (R)	-86.1 (R)	-30.7 (R)	-28.4 (R)	-38.9 (-)	-57.5 (R)
Kazakhstan	10.7 (-)	42.6 (-)	61.7 (-)	95.7 (r)	47.4 (-)	17.6 (-)	18 (-)	17 (-)	4.9 (-)
Kyrgyzstan	102.2 (-)	34.3 (-)	94.9 (-)	121.9 (-)	57 (-)	67.5 (-)	77.9 (-)	44 (-)	61.8 (-)
Latvia	-54.3 (R)	30.4 (R)	-24.8 (R)	-20.8 (R)	-79.2 (R)	-7.2 (R)	-26.4 (R)	106.4 (-)	-19.8 (R)
Liechtenstein	-34 (R)	-1.9 (R)	-48.2 (R)	-52.8 (R)	-85.2 (R)	-30.9 (R)	-36.8 (R)	-18 (-)	-61.8 (-)
Lithuania	-36.7 (R)	3.2 (R)	-14.5 (R)	-14.4 (R)	-70.1 (R)	-15.3 (r)	-28.7 (r)	1.3 (-)	5.3 (-)
Luxembourg	-54.4 (R)	-8.4 (R)	-29.5 (R)	-52.9 (R)	-72.2 (R)	-39.3 (R)	-51.2 (R)	9.6 (-)	-71.5 (-)
Malta	-52 (R)	-35.1 (R)	-29.8 (R)	-43.8 (R)	-98.2 (R)	-0.7 (R)	-48.2 (R)	125.7 (-)	-47.7 (R)
Monaco	-44 (R)	-78.8 (R)	-41.5 (R)	-72.4 (R)	-87.1 (R)	-40.3 (R)	-63.1 (R)	12.3 (-)	-79.7 (R)
Montenegro	-18 (R)	-46.2 (R)	-5.8 (R)	40.5 (R)	14 (R)	254.9 (-)	301.7 (-)	119.6 (-)	448.7 (-)
Netherlands	-17.8 (R)	-29.1 (R)	-29.3 (R)	-49.5 (R)	-70.7 (R)	-44 (R)	-55.8 (R)	-15.8 (-)	-76.9 (R)
North Africa	35.4 (-)	41.1 (-)	32.3 (-)	68.3 (-)	68.2 (-)	48.2 (-)	43.6 (-)	54.4 (-)	72.9 (-)
North Macedonia	-62.1 (R)	-37 (R)	-48.2 (R)	-52.3 (R)	8.9 (R)	-69.9 (R)	-72.2 (R)	-65 (-)	-72.9 (R)
Norway	-32.3 (R)	-0.1 (R)	-63.3 (R)	-32.2 (R)	-39.8 (R)	-37.3 (R)	-44.2 (R)	-4.8 (-)	-42.8 (R)
Poland	-37.6 (R)	-12.3 (R)	-17.5 (R)	-23 (R)	-68.2 (R)	-24.2 (R)	-25.8 (R)	-22 (-)	-17.6 (R)
Portugal	-57.1 (R)	-23.1 (R)	-32.2 (R)	-49.5 (R)	-85 (R)	-36 (R)	-32.2 (R)	-43.8 (-)	-42 (R)
Republic of Moldova	203.2 (R)	-16.5 (R)	137.4 (R)	99.8 (R)	35.9 (r)	329.7 (R)	444.9 (R)	93.8 (-)	454 (r)
Romania	0.6 (R)	-9.5 (R)	-20.8 (R)	-26 (R)	-79.9 (R)	10.5 (R)	6.1 (R)	24.4 (-)	10.5 (R)
Russian Federation (European part)	-2 (r)	-0.2 (r)	-0.7 (r)	-12.6 (r)	-50.2 (r)	-27.6 (r)	-38.2 (r)	-18.6 (-)	-32.4 (-)
Russian Federation (Asian part)	-22.3 (-)	17.7 (-)	1.7 (-)	-16.6 (-)	-40.2 (-)	-16.6 (-)	-30.3 (-)	12.1 (-)	-50.5 (-)

Table 3.3 cont. Differences between emissions for 2000 and 2019 (based on gap–filled data as used in EMEP models).

Serbia	-27 (R)	-30 (R)	-18.8 (R)	-13.2 (R)	-14.7 (R)	4.8 (R)	3.1 (R)	10.1 (-)	-1 (-)
Slovakia	-48.9 (R)	-5.8 (R)	-34.9 (R)	-43.8 (R)	-86.6 (R)	-56 (R)	-58.9 (R)	-42.8 (-)	-30.5 (R)
Slovenia	-53 (R)	-17 (R)	-43.2 (R)	-50.3 (R)	-95.4 (R)	-24.9 (R)	-24.9 (R)	-24.7 (-)	-26.6 (R)
Spain	-36.3 (R)	-10 (R)	-34.9 (R)	-52.2 (R)	-89.2 (R)	-21.8 (R)	-17.7 (R)	-29.6 (-)	-25.7 (R)
Sweden	-50.2 (R)	-10.6 (R)	-39.9 (R)	-41 (R)	-63.2 (R)	-29.7 (R)	-47.2 (R)	1 (-)	-58.6 (R)
Switzerland	-59.7 (R)	-12 (R)	-47.3 (R)	-40 (R)	-73 (R)	-25.7 (R)	-47 (R)	7.6 (-)	-70.2 (R)
Tajikistan	644.4 (-)	61 (-)	290.2 (-)	482.5 (-)	369.7 (-)	446.3 (-)	461.3 (-)	402 (-)	425.4 (-)
Turkey	-48.9 (r)	19.5 (R)	-30.3 (R)	13.2 (r)	9.5 (R)	7 (-)	-2.3 (-)	36.6 (-)	-41.6 (-)
Turkmenistan	120 (-)	82.4 (-)	123.7 (-)	87.5 (-)	183.5 (-)	38.5 (-)	42.3 (-)	27.3 (-)	33.2 (-)
Ukraine	-21.9 (-)	-9.3 (-)	-37.1 (-)	-38.6 (-)	-78 (r)	-29.6 (-)	-29.2 (-)	-30.4 (-)	-28.6 (-)
United Kingdom	-65 (R)	-10.4 (R)	-50.6 (R)	-58.9 (R)	-87.4 (R)	-29.5 (R)	-28.9 (R)	-30.5 (-)	-57.8 (R)
Uzbekistan	9.4 (-)	60.1 (-)	40.1 (-)	-13.7 (-)	1 (-)	4.3 (-)	7.2 (-)	-4.2 (-)	0.3 (-)
Increase (no. countries)	**12**	**18**	**13**	**14**	**14**	**17**	**16**	**24**	**16**
Decrease (no. countries)	**42**	**36**	**41**	**40**	**40**	**37**	**38**	**30**	**38**

emissions in 2019 compared to 2000 emission levels in several countries or areas.

In case of PM emissions, 24 countries/areas have higher PM_{coarse} emissions in 2019 than in 2000, while PM_{10} and $PM_{2.5}$ emissions increased in 17 and 16 countries/areas, respectively. In case of NO_x and SO_x there are 14 countries/areas, NMVOC 13, NH_3 18 and CO 12 countries/areas with higher emissions in 2019 than in year 2000. Detailed explanatory information on emission trends for the reporting countries should be provided in the respective informative inventory reports (IIRs). Tables 3.3-3.3 cont. indicates whether the emissions were based completely (R) or partially (r) on reported data.

3.5.5 Trends in emissions from international shipping

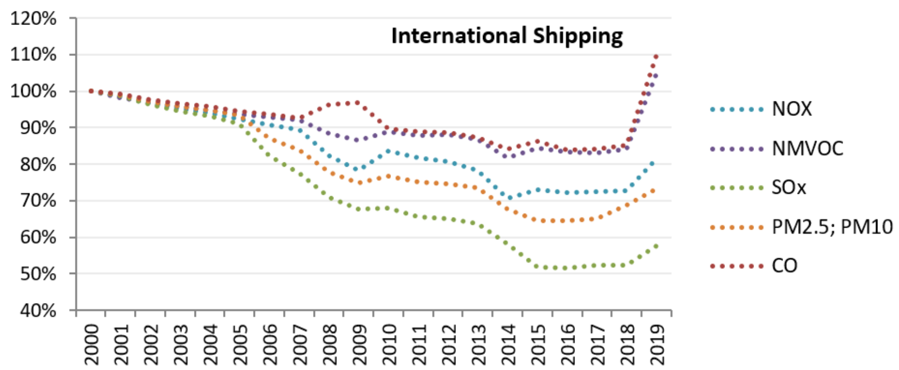


Figure 3.9: International shipping emission trends in the EMEP area, extracted from the CAMS global shipping emission dataset developed by FMI, and provided via ECCAD (*CAMS_GLOB_SHIP*) in April 2019 (for the years 2000 to 2017) and in November 2019 (for the year 2018). These are the emissions which have been used for the most recent trend calculations with the EMEP model.

International shipping emissions are not reported by Parties. Gridded emissions for the sea regions (European part of the North Atlantic, Baltic Sea, Black Sea, Mediterranean Sea and North Sea) were calculated using the CAMS global shipping dataset (Granier et al. 2019) for the years 2000 to 2019 (Figure 3.9), developed by the Finnish Meteorological Institute (FMI), and provided via ECCAD[19] the dataset *CAMS_GLOB_SHIP* (ECCAD 2019).

According to FMI the high increase in shipping emissions from 2018 to 2019 is because much more small vessels are using AIS than in previous years, which means that emissions from this small vessels are included in the shipping emissions for 2019, but not in previous years. Due to the selective implementation of the Sulfur Emission Control Areas (SECAs) on the North Sea and Baltic Sea only, the emission trends differ between those seas and the other seas.

3.6 Summary

This chapter summarises the status of emissions reported by LRTAP Convention Parties and the extent to which these data have been incorporated into the 2021 EMEP emissions datasets for modellers. The chapter documents the historical improvement in reporting over time, noting the increasing extent of reporting emissions inventories for the mandatory pollutants and black carbon, as well as increased reporting of gridded emissions in 2021 compared to 2017. Despite these positive trends in terms of reporting, reporting is not yet complete. For some parties, emissions inventories and gridded data are not reported (or are reported late and/or incomplete). There is further room for improvement on the reporting of particulate matter emissions with respect to whether the condensable component has been included in the reported estimates.

The 2021 EMEP emissions datasets for modellers therefore need to be complied carefully and this chapter documents for which countries and pollutants the time series have been based fully or partially on reported inventories and gridded data, and for which countries and regions the datasets have been built using independent emissions data products.

Based on the complied datasets in 2021, it is worth noting that the 2000 to 2019 trends in emissions from the land areas have decreased for most pollutants except for PM_{coarse} and NH_3. This trend appears to be driven by the trends of the EMEP West countries, for which the time series are based almost completely on reported data. In contrast, EMEP East as whole shows a rather stable trend in terms of emissions (emissions based partially on reported data), with notable emissions increases shown for the 'Other areas' (based completely on independent estimates). International shipping emissions had been shown to be decreasing up to 2018; however, a notable jump in 2018 to 2019 emissions of all pollutants likely stems from a methodological artefact, whereby the number of smaller vessels using AIS systems (on which the CAMS global shipping dataset is based) seems to have increased.

[19] https://eccad.aeris-data.fr

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Part II

Trends in air pollution

CHAPTER 4

Trends in observations and EMEP MSC-W model calculations 2000-2019

Wenche Aas, Hilde Fagerli, Karl Espen Yttri, Svetlana Tsyro, Sverre Solberg, David Simpson, Jonas Gliß, Augustin Mortier, Eivind Grøtting Wærsted, Hans Brenna, Anne Hjellbrekke, Jan Griesfeller, Agnes Nyíri, Michael Gauss, Thomas Scheuschner

4.1 Introduction and background

At its thirty-ninth session (Geneva, 9–13 December 2019), the Executive Body launched the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (the Gothenburg Protocol) as amended in 2012. In order to assess the progress made towards achieving the environmental and health objectives of the Protocol, a list of questions was given to the subsidiary bodies of the Air Convention. Several of these questions were related to the trends of air pollution in Europe.

In this chapter we present an assessment of the trends in air pollution in Europe for the period 2000–2019 based on long term observational data from the EMEP network as well as EMEP MSC-W model calculations. We analyze trends in air quality for ozone, sulfur dioxide, particulate matter (and their species; sulfate, nitrate, ammonium, elemental carbon and organic carbon), oxidized and reduced nitrogen as well as wet deposition of sulfur and nitrogen species. In addition, we present trends in some indicators of health and vegetation risk (SOMO35, exceedances of WHO Air Quality Guidelines (AQG) values for $PM_{2.5}$ and PM_{10}, AOT40 for forests and crops, exceedances of critical loads for acidification and eutrophication for every 5th year since 2000).

Comparison of trends in measured and modelled VOCs is not included in this report. The main reasons are the lack of established procedures for doing such a comparison as well as the lack of proper monitoring sites with sufficient data capture and sufficient homogeneity in the monitoring during the 2000-2019 period. The topic of VOC trends will be investigated in more detail in the near future.

Unfortunately, the EMEP observational network is dominated by sites in the western parts of the EMEP domain and has hardly any coverage in the EECCA (Eastern Europe, Caucasus and Central Asia) countries. Therefore, the assessment discussed in this chapter is only valid for a part of the EMEP domain. As discussed in Ch 3, the development of emissions in the western and eastern part of the EMEP domain follows different patterns, with clear decreases of all pollutants in the western countries but more stable (albeit gradually decreasing for most pollutants) in the eastern part of the domain over the 2000–2019 period. Thus, the trends in the eastern part of the EMEP domain are expected to be different than those presented here for the western part. Note, however, that the uncertainties related to emissions and their trends in the eastern countries are large (see Ch 3). It should also be pointed out that for the different components analyzed, the number of observational sites available and the geographical coverage differ. Thus the trends for the different components are not fully consistent.

4.2 Setup for EMEP MSC-W model calculations

The EMEP MSC-W model version rv4.42 has been used to perform model runs for years from 2000 through 2019. The horizontal resolution is $0.1° \times 0.1°$, with 20 vertical layers (the lowest with a height of approximately 50 meters). Meteorology, emissions, boundary conditions and forest fires for the respective years have been used as input. Meteorological data have been derived from ECMWF-IFS(cy40r1) simulations for the years 2000 to 2018 and from a ECMWF-IFS(cy46r1) simulation for 2019 (see Ch 2.1). The boundary conditions for the main gaseous and aerosol species were based on climatological observed values with prescribed trends in trans-Atlantic fluxes, while ozone levels have been corrected based on measurements at Mace Head in Ireland (c.f. Simpson et al. 2012). The boundary conditions for natural particles of sea salt and mineral dust were the same as in the status run, namely 5-year monthly average concentrations, derived from EMEP MSC-W global runs, kept invariable over the calculation period. Daily emissions from forest fires were from the Fire INventory from NCAR (FINN, Wiedinmyer et al. 2011) for 2002-2019, whereas for 2000 and 2001 (unavailable from FINN), monthly averages over the 2005-2015 period were used.

Volcanic SO_x emissions from passive degassing of Italian volcanoes (Etna, Stromboli and Vulcano) are those reported by Italy. SO_x and PM emissions from volcanic eruptions of Icelandic volcanoes in the period 2000–2019 (Eyjafjallajökull in 2010, Grímsvötn in 2011 and Barðarbunga in 2014–2015) are reported by Iceland.

The speciation of PM emissions into emissions of elemental carbon (EC), primary organic aerosol (POA), and 'remPPM' (remaining PPM) components was based on ECLIPSE v6b emission data [1]. These ECLIPSE emissions are given in 5-year intervals (2000, 2005, etc.); intermediate years were derived by linear interpolation. However, all years after 2015 used the 2016 speciation of PM emissions. The VOC speciation was based upon data from various CAMS datasets as described in Simpson et al. (2020a). NOx speciations (into NO, NO_2 and 'shipNOx') were as used in previous reports. For NOx and VOC the same (sector-based) speciations were used for all years. Soil NO_x emissions were based on the new CAMS-GLOB-SOIL v2.2 NO_x inventory Simpson and Darras (2021). Soil-NO_x emissions which are related to the use of fertilizer were not taken from the CAMS-GLOB-SOIL inventory, as these are already included in the EMEP (CEIP) emissions. A revised set of anthropogenic

[1] https://iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv6.html

emissions for all the years 2000–2019 has been used in the model calculations (including all the reported and re-reported data by June 2021), see Ch 3.

4.2.1 Issues with inventories used in modelling

The problems with condensable organics in EMEP emission inventories have been highlighted in a number of studies (Denier van der Gon et al. 2015, Simpson and Denier van der Gon 2015, TFEIP/TFMM (2018), Simpson et al. 2019, Denier van der Gon et al. 2020, Fagerli et al. 2020), with an expert meeting convened on this subject in 2020 by MSC-W (Simpson et al. 2020b), and have resulted in the REF2 and REF2.1 emissions discussed in Ch 3.3. Using the notation of Simpson et al. (2020b), we can write:

$$\text{POA} = \text{FPOA} + \text{CPOA} \tag{4.1}$$

where POA is the total primary (particulate) organic aerosol emission, FPOA is the solid (filterable) component of POA, and CPOA is the condensable component of POA.

It has clearly shown that some countries include, and some countries exclude the CPOA component from their reporting of $PM_{2.5}$ emissions. Further, even for the same country, CPOA might be included or excluded differently for different sectors. In many cases, countries did not have the technical information needed to know the extent of inclusion for specific sectors. Inclusion or exclusion, or the extent of inclusion of CPOA, has also changed over the years, which directly complicates trend analyses of emissions.

Thus, PM emissions from countries which include CPOA might appear larger than from countries which exclude CPOA, even if both countries emit identical amounts of pollutants. Given that POA emissions make up a substantial fraction of $PM_{2.5}$ emissions in Europe, these uncertainties also make it difficult to interpret the emission trends. Countries that tend to exclude CPOA (such as Germany) will have their $PM_{2.5}$ emission trends more dominated by trends in S- and N- components, whereas countries which include CPOA (e.g. Norway) will have their trends more controlled by POA emissions.

It should also be mentioned that these uncertainties regarding CPOA emissions also impact the EC emissions (and their trends) in the modelling work. Following the usual MSC-W procedures, reported emissions of $PM_{2.5}$ are split into EC, POA, and remPPM, and this splitting procedure typically relies upon assumed POA/EC (or often OC/EC) ratios for the different emission sectors. If POA is defined differently from country to country, and as POA/EC ratios do not typically account for these differences, then the assumed EC emission will also be similarly ill-defined. For this report, the splits used are derived from the ECLIPSE v6b time-series for 2000–2016 (see Ch 5.2.6). As this inventory makes heavy use of EMEP reported data for the European region, then the emissions of both POA and EC used in the trend analysis will be affected, as will modelled trends in these components and $PM_{2.5}$.

4.3 Observations

The observations used have all been reported to EMEP and are openly available from the EBAS database (`http://ebas.nilu.no`). The time series have been selected based on statistical criteria as described in Ch 4.4. Sites which are situated higher than 1200 m.a.s.l. have been excluded (except Schauinsland at 1205 m.a.s.l.) in addition to NO0042G at 474 m.a.s.l (which is situated close to the boundaries of the model domain). These sites are often measuring above the boundary layer, which is not well represented by a model with a resolution of $0.1° \times 0.1°$. For EC and OC, only observations using the reference method EUSAAR-2 (Cavalli et al. 2010) have been selected and, due to the lack of a long consistent time series, statistics are only done for the last decade for these compounds. Further, visual inspection of the time series revealed some data sets with very high annual variability and inconsistent development. This can be due to contamination of the samples, change in methods or in the surroundings. Some of these time series have been excluded. Some sites which have moved a very short distance during the time period has been combined into one times series, i.e.: FI0017R and FI0018R, NO0001R and NO0002R, SE0002R and SE0014R, SE0011R and SE0020R. An overview of all the sites that has been used for the different components and periods are found in Table C:1 in Appendix C.

4.4 Method for calculation of trends

Both observed and modelled trends were processed with the pyaerocom software (`https://github.com/metno/pyaerocom`) for the following periods: 2000–2019, 2005–2019, 2000–2010, and 2010–2019. The periods were chosen in order to represent the last 2 decades and to indicate individual changes in each of the 2 decades, particularly also because more observations became available in the recent years. The 2005–2019 period was chosen as 2005 is the base year of the Gothenburg Protocol. All observations were provided via the EBAS database.

Since the provided temporal resolution can change over time for a given site, the lowest common resolution was identified and higher resolution data were down-sampled to that resolution during the merging process. For temporal re-sampling, we required ca. 75% coverage in a hierarchical manner; that is, at least 18 hourly measurement values to retrieve a daily mean, and at least 21 daily values to retrieve a monthly mean. Trends are computed based on yearly averages, as described in more detail below. To retrieve the yearly averages, at least one monthly value is required per season. In addition to trends based on yearly averages, seasonal trends are computed as well for all variables except for O_3 which is focused on the annual percentiles of the the daily maximum concentrations (details below).

A second analysis was done using a 25% coverage constraint instead of 75% coverage. Finally, a data capture requirement of ca. 75% was also applied for yearly averages (requiring at least 14 yearly values for the period 2000–2019, 10 years for 2005–2019 and 7 yearly values for the two 10 year periods).

For O_3, a different approach for the re-sampling was applied. Firstly, daily maximum concentrations were computed based on hourly measurements, requiring at least 18 hourly measurements per day corresponding to a 75% data capture as for the other variables. Then, annual percentiles of these daily maximum values were computed requiring at least 90% valid daily data corresponding to 330 daily values. The reason for this strict criterion is that the high ozone episodes typically cover a short period of the year. Besides, the data completeness of the O_3 monitoring is normally very high at most stations. Trends were then calculated for six such annual percentiles, the 10th, 50th, 75th, 95th, 98th and 99th percentiles, the latter corresponding to the 4th highest daily maximum concentration each year.

Model output in daily resolution was used for the trend analysis, including the daily maximum of O_3 (calculated based on hourly values). To compute the model trends, the daily model output for each variable was co-located in space and time with the observations. Co-location in space was done by picking the nearest model grid to each station. Co-location in time was done by first re-sampling both model and observation data to the lowest common temporal resolution, then invalidating the model output at times when observations are missing, and finally calculating the monthly mean of both. Precipitation (reported in units of mm) was co-located in time based on monthly aggregates, which were calculated independently for model and observations.

The monthly time series of the co-located model and observation data were output as csv files for each individual site. The scripts used for processing the data and calculating trends are available from a GitHub repository (`https://github.com/metno/emep_trends_2021`). The processed data itself, including relevant station metadata and trends results, are available in a separate location (link in description of the repository). The time series plots comparing the modelled and observed trends at the individual sites are available at the TFMM web page: `https://projects.nilu.no/ccc/tfmm/timeseries_GPrev/`

In order to compute the trends for the model and observation time series at the individual sites, the same methodology as described by Aas et al. (2019) and Mortier et al. (2020) has been used. The significance of the trends is tested with the Mann-Kendall test (Hamed and Rao 1998). The related p-value is used to determine if the trend is significant or not. A p-value less than 0.05 is defined as statistically significant (corresponding to 2σ confidence). The slope is calculated with the Theil-Sen estimator which is less sensitive to outliers than standard least-squares methods (Sen 1968).

An uncertainty is provided for each trend by combining the error of the slope calculation itself to the error of the residuals:

$$Uncertainty = \sqrt{\left(\frac{\Delta m}{y(start)}\right)^2 + \left(\frac{m \cdot \Delta r}{y(start)^2}\right)^2} \tag{4.2}$$

where Δm is the Theil-Sen estimator 68% confidence interval, $y(start)$ is the value of the regression line at the first year of the period, m is the value of the Theil-Sen slope and Δr is the uncertainty of $y(start)$ which is estimated based on the average magnitude of the fit residual.

In order to allow for consistent comparisons, the trend is provided as a relative trend (%/yr) with respect to the first year of the time period, i.e. the intercept of the time series.

Some of the trend calculations have not been done using the pyaerocom software. The trends in EC and OC have been calculated using the python pyMannKendall package (Hussain and Mahmud 2019), the gridded modelled trends using an NCL package (`https://www.ncl.ucar.edu/Document/Functions/Built-in/trend_manken.shtml`), while SOMO35 and AOT40 trends used the R packages 'Kendall' (McLeod 2011) for the Mann-Kendall calculations and 'zyp' (Bronaugh and Werner 2019) for the calculation of Sen's slopes. The confidence intervals for the mean values (of SOMO35 and AOT40) were calculated by the R package 'boot' (Canty and Ripley 2021).

The trends and their uncertainties for all the individual sites are available from the mentioned GitHub repository. In the following sections aggregated trend values are presented. These values were calculated by taking the averages of the Sen slopes or the relative trends for all the sites, including those with non-significant trends. In addition, confidence intervals for these mean values were calculated. It should be noted that these 95% confidence intervals for the average trends will be less accurate when the number of sites with significant trends is low.

4.5 Trends in sulfur

Emissions of SO_x have declined by more than 80% (-4.3 %/yr) within part of the EMEP domain (EU27+UK+EFTA countries) over the last two decades, and both the observed and modelled trends for all the atmospheric sulfur components show substantial decreases (Fig. 4.1 and Tables 4.1–4.3), in line with several studies on trends published lately (Aas et al. 2019, Colette et al. 2016, Vivanco et al. 2018, Theobald et al. 2019, Colette et al. 2021, Banzhaf et al. 2015, Tørseth et al. 2012, Crippa et al. 2016). A majority of the time series show significant trends for the 20 year period for all the compounds (Tables 4.1–4.3).

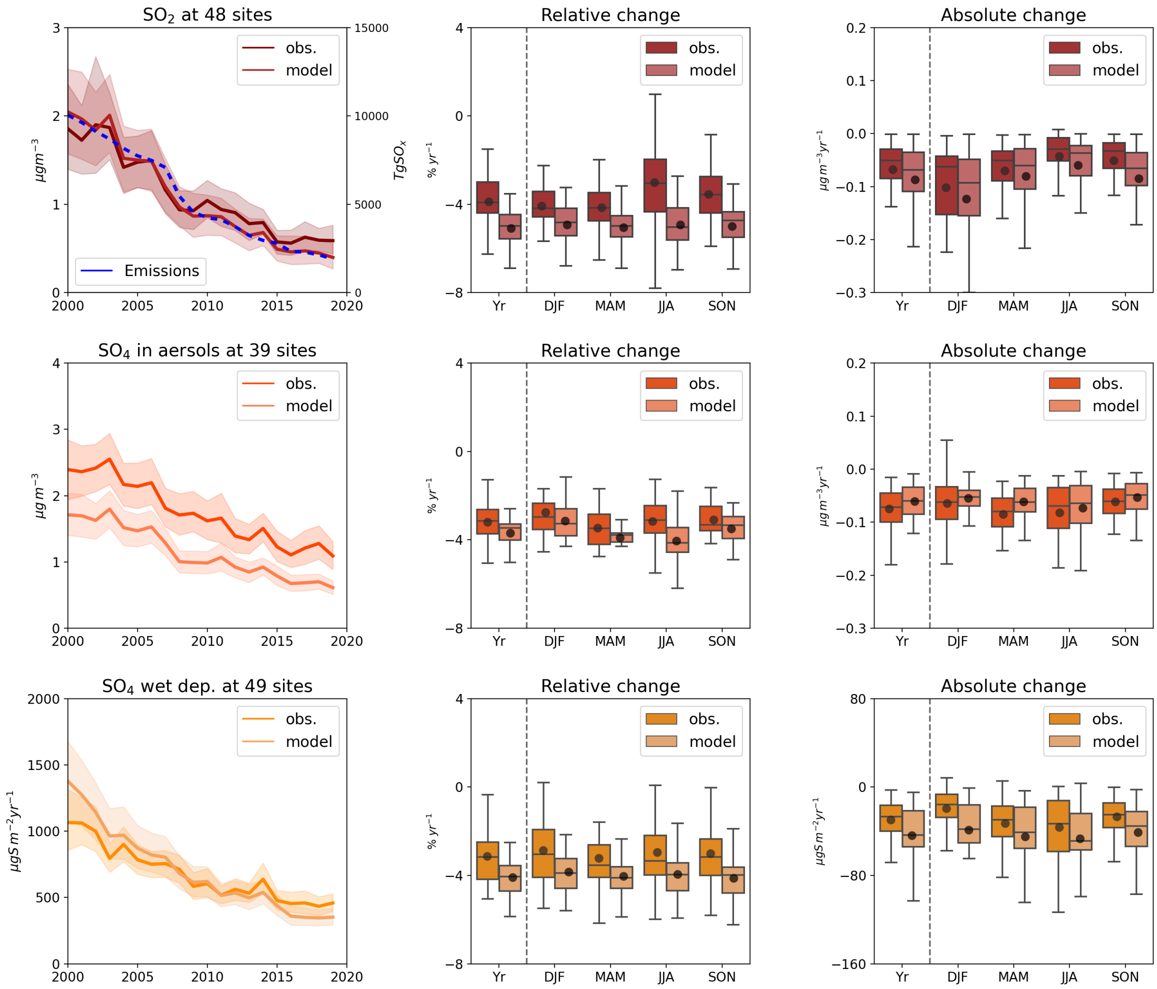

Figure 4.1: Trends in sulfur components from 2010–2019 for EMEP observations and model. The solid line in the trend plots indicate the average annual mean concentrations for all the sites and the shaded area the 95% confidence interval. The box plot represent the 50th, 25th, and 75th percentiles and the whiskers lie within the 1.5 inter-quartile ranges for the trends of all the sites, including those with not significant trends. In addition, the mean trends are indicated with black circles and the trend in SOx emission is indicated in the plot of SO_2 with secondary y-axes.

Table 4.1: Absolute and relative change and corresponding 95% confidence intervals in observed and modelled annual and seasonal aggregated SO_2 concentrations for the different time periods. The number of sites with a significant outcome is provided.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	48	46	48	-0.068	(-0.085, -0.051)	-0.088	(-0.109, -0.067)	-3.88	(-4.23, -3.53)	-5.10	(-5.39, -4.81)
	winter	50	45	49	-0.102	(-0.127, -0.076)	-0.124	(-0.153, -0.095)	-4.08	(-4.36, -3.8)	-4.94	(-5.22, -4.65)
	spring	48	45	48	-0.070	(-0.086, -0.053)	-0.081	(-0.101, -0.061)	-4.15	(-4.45, -3.85)	-5.09	(-5.35, -4.84)
	summer	48	33	48	-0.043	(-0.057, -0.029)	-0.060	(-0.078, -0.041)	-3.01	(-3.59, -2.43)	-4.94	(-5.3, -4.58)
	autumn	48	36	47	-0.051	(-0.066, -0.035)	-0.086	(-0.107, -0.064)	-3.55	(-3.94, -3.15)	-5.02	(-5.3, -4.75)
2005-2019	all	57	41	54	-0.055	(-0.068, -0.041)	-0.067	(-0.084, -0.05)	-4.27	(-4.72, -3.83)	-5.26	(-5.6, -4.93)
2010-2019	all	60	36	42	-0.050	(-0.062, -0.037)	-0.056	(-0.072, -0.041)	-4.81	(-5.94, -3.69)	-6.39	(-7.15, -5.63)
2000-2010	all	66	30	58	-0.079	(-0.103, -0.054)	-0.117	(-0.142, -0.091)	-3.52	(-4.31, -2.73)	-5.39	(-5.93, -4.84)

Table 4.2: As Tab 4.1, but for SO_4^{2-} concentrations in aerosols.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	39	38	39	-0.074	(-0.087, -0.062)	-0.065	(-0.076, -0.053)	-3.20	(-3.46, -2.93)	-3.81	(-4.04, -3.58)
	winter	40	29	34	-0.064	(-0.08, -0.049)	-0.056	(-0.066, -0.046)	-2.75	(-3.22, -2.28)	-3.21	(-3.44, -2.97)
	spring	38	36	38	-0.085	(-0.098, -0.072)	-0.065	(-0.075, -0.055)	-3.46	(-3.72, -3.19)	-4.03	(-4.21, -3.84)
	summer	38	36	38	-0.082	(-0.102, -0.063)	-0.078	(-0.097, -0.059)	-3.15	(-3.46, -2.85)	-4.20	(-4.5, -3.91)
	autumn	37	34	37	-0.062	(-0.073, -0.05)	-0.057	(-0.067, -0.046)	-3.08	(-3.4, -2.76)	-3.59	(-3.81, -3.38)
2005-2019	all	43	35	42	-0.067	(-0.079, -0.055)	-0.054	(-0.063, -0.046)	-3.48	(-3.88, -3.09)	-4.01	(-4.25, -3.77)
2010-2019	all	46	20	32	-0.053	(-0.068, -0.038)	-0.044	(-0.055, -0.034)	-3.43	(-4.11, -2.75)	-4.26	(-4.91, -3.62)
2000-2010	all	54	15	43	-0.068	(-0.085, -0.051)	-0.094	(-0.109, -0.079)	-2.51	(-2.95, -2.07)	-4.19	(-4.52, -3.86)

Table 4.3: As Tab 4.1, but for wet deposition of SO_4^{2-}.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} m^2 yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	49	40	49	-29.5	(-34.8, -24.2)	-48.1	(-56.9, -39.4)	-3.14	(-3.46, -2.82)	-4.27	(-4.5, -4.04)
	winter	47	25	44	-19.5	(-24.5, -14.5)	-41.4	(-49.5, -33.3)	-2.87	(-3.34, -2.4)	-3.97	(-4.21, -3.73)
	spring	45	30	45	-32.7	(-39.1, -26.2)	-49.2	(-59.7, -38.6)	-3.23	(-3.6, -2.86)	-4.19	(-4.41, -3.98)
	summer	47	31	45	-36.5	(-44.5, -28.5)	-52.6	(-63.0, -42.2)	-2.95	(-3.35, -2.54)	-4.20	(-4.46, -3.94)
	autumn	46	27	42	-26.7	(-32.3, -21.1)	-45.0	(-54.6, -35.5)	-3.00	(-3.49, -2.51)	-4.25	(-4.52, -3.99)
2005-2019	all	53	30	50	-22.9	(-27.9, -17.9)	-36.3	(-42.4, -30.2)	-2.87	(-3.51, -2.22)	-4.53	(-4.79, -4.27)
2010-2019	all	60	15	40	-20.9	(-27.1, -14.6)	-34.0	(-40.6, -27.3)	-2.86	(-3.78, -1.93)	-5.08	(-5.56, -4.59)
2000-2010	all	54	28	44	-46.9	(-56.6, -37.1)	-68.5	(-81.4, -55.7)	-4.44	(-5.15, -3.74)	-5.29	(-5.68, -4.9)

The spatial distribution of the relative trends (Fig. 4.2) shows that the decreases in sulfur air concentrations and wet deposition have been quite homogeneous across Europe west of Russia, though somewhat higher in Spain and France and lower in Poland. There have been higher reductions in the primary component SO_2 compared to secondary SO_4^{2-}. The greater decrease in SO_2 compared to secondary sulfate is likely due to a combined effect of higher oxidation rate (hence more SO_2 converted to SO_4^{2-}) and increased dry deposition rate of SO_2. One possible explanation is that the oxidation capacity of the atmosphere may have increased as the emissions have decreased (Dalsøren et al. 2016). This would give less acidic clouds due to less SO_2 and only slight decreases in NH_3, which has increased the oxidation rate of SO_2 to SO_4^{2-} via the ozone pathway (Banzhaf et al. 2015, Redington et al. 2009). In addition, less acidity in the environment probably leads to more efficient dry deposition of SO_2 (Fowler et al. 2009).

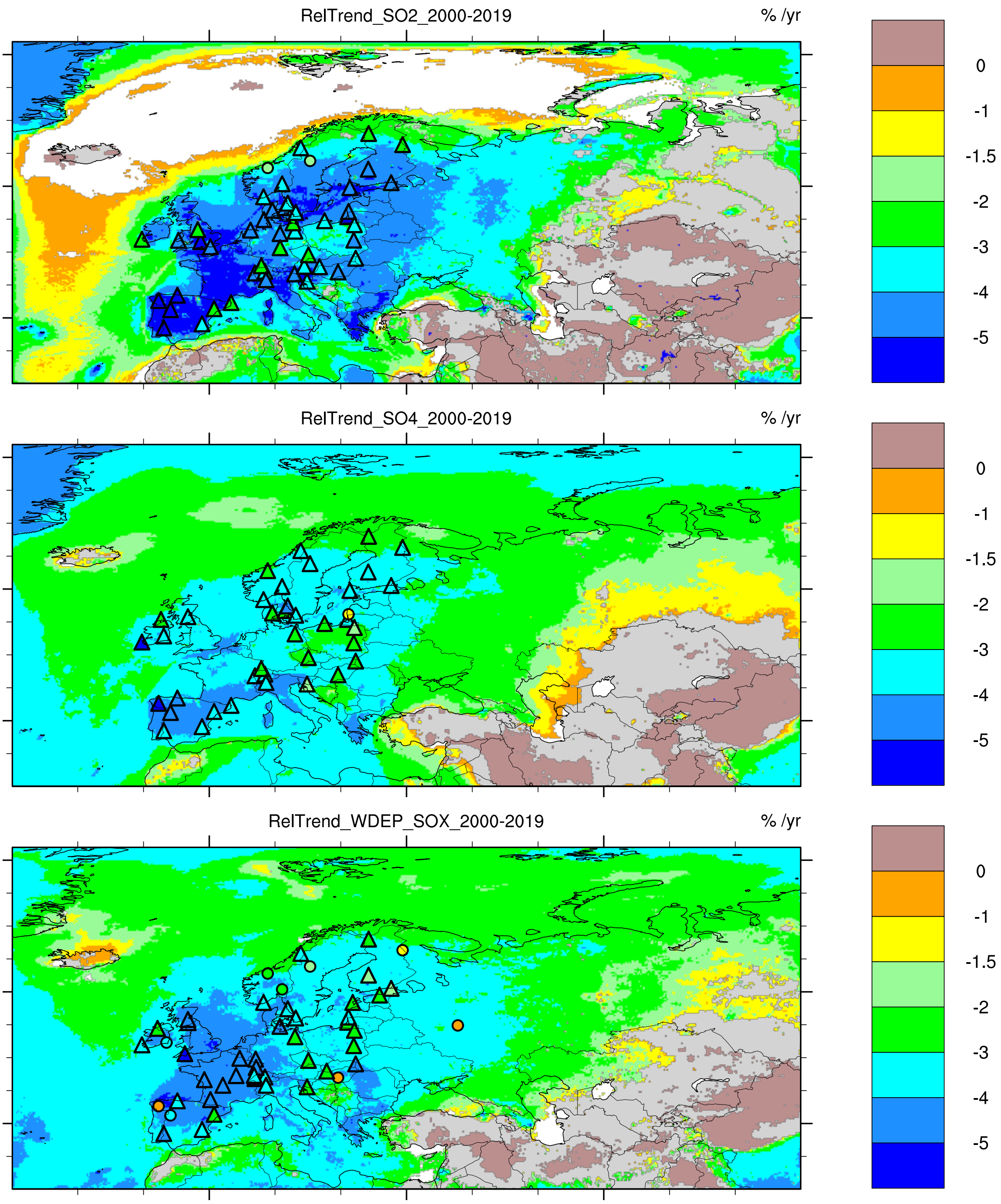

Figure 4.2: Relative trends for SO_2, SO_4^{2-} in aerosols and wet deposition of SO_4^{2-} in the period of 2000–2019: EMEP modelled are shown as coloured contours (grey/white means non-significant trends) and observed by coloured triangles (significant) and circles (non-significant).

The average observed trends for the last 20 years (2000–2019) are -3.9, -3.2 and -3.1 %/yr for SO_2, SO_4^{2-} in aerosols and SO_4^{2-} in wet deposition, respectively, while the trends in model calculations are somewhat greater: -5.1, -3.8 and -4.3 %/yr, respectively. The overestimation in sulfur trends by the model is seen both for relative and absolute trends for SO_2, and wet deposition of SO_4^{2-} while for SO_4^{2-} in aerosols the absolute trend is higher in observations, but within the 95% confidence interval of the modelled trends.

It is not clear why the trends calculated by the model are larger than the trends in observations. However, it is worth noting that also the trends in reported emissions are larger than the trends in the different sulfur components in observations. The mismatch between the calculated trends and the observed trends are particularly large for eastern Spain and parts of eastern Europe. These differences between the modelled trends, the trends in emissions and the trends in observations might potentially indicate that the emission reductions reported by the countries are somewhat optimistic for some countries. However, firm conclusions are difficult to draw as we do not monitor the full sulfur budget (e.g. dry deposition of sulfur is lacking). Furthermore, changes in emissions distribution that are not correctly accounted for or missing processes in the model could also play a role.

The relative difference between the two decades are small. The reductions in SO_x emissions are 58% for 2000–2010 and 55% for 2010–2019, and in observations the total changes in these two periods are between 26–43% for the different compounds in 2010–2019 and 25–44% for 2000–2010. For the model the reductions are between 38–50% and 42–54%, respectively. In the observations, it seems like the decrease in wet deposition was larger in the first period than in the second period, while slightly opposite for the air components. However less than half the sites show significant trends for the 10 year periods and quantification of the reductions are therefor quite uncertain. The relative trends across the different seasons are similar. However, there are larger absolute changes in SO_2 for both observations and model calculations during the winter (Fig. 4.1).

For the period of 2005–2019 (starting with the reference year of the Gothenburg Protocol), the reported emission reductions in the EU27+UK+EFTA countries are 75%, which is reflected in the modelled results with reductions of 74% in SO_2, 56% in SO_4^{2-} in aerosols and 63% in wet deposition of SO_4^{2-}. The observations show smaller reductions than the emissions (and the model), with 60% in SO_2, 49% in SO_4^{2-} in aerosol and 40% for wet deposition of SO_4^{2-}.

4.6 Trends in oxidised nitrogen

During the last decades, the total emissions of NO_x have declined significantly in Europe, leading to reductions in NO_2 concentrations, total nitrate (nitric acid plus particulate nitrate) in air and oxidized nitrogen wet deposition at EMEP background sites. This is found both for the EMEP MSC-W model calculations and for observations. Similar results have been presented in Theobald et al. (2019) for wet deposition of oxidized nitrogen for the 1990–2010 period and in Banzhaf et al. (2015) for total nitrate for 1990–2009. Tørseth et al. (2012) also find decreasing trends in nitrogen dioxide, total nitrate and nitrate in precipitations 1990–2009 in EMEP observations. A more recent study, analyzing the period 2000–2017 (Colette et al. 2021) and including Airbase and most EMEP observations, also finds decreasing trends in NO_2.

Figure 4.3 shows an overview of the annual and seasonal trends in oxidised nitrogen compounds from 2000 to 2019. Tables 4.4 to 4.8 show absolute and relative changes in the different oxidized nitrogen compounds.

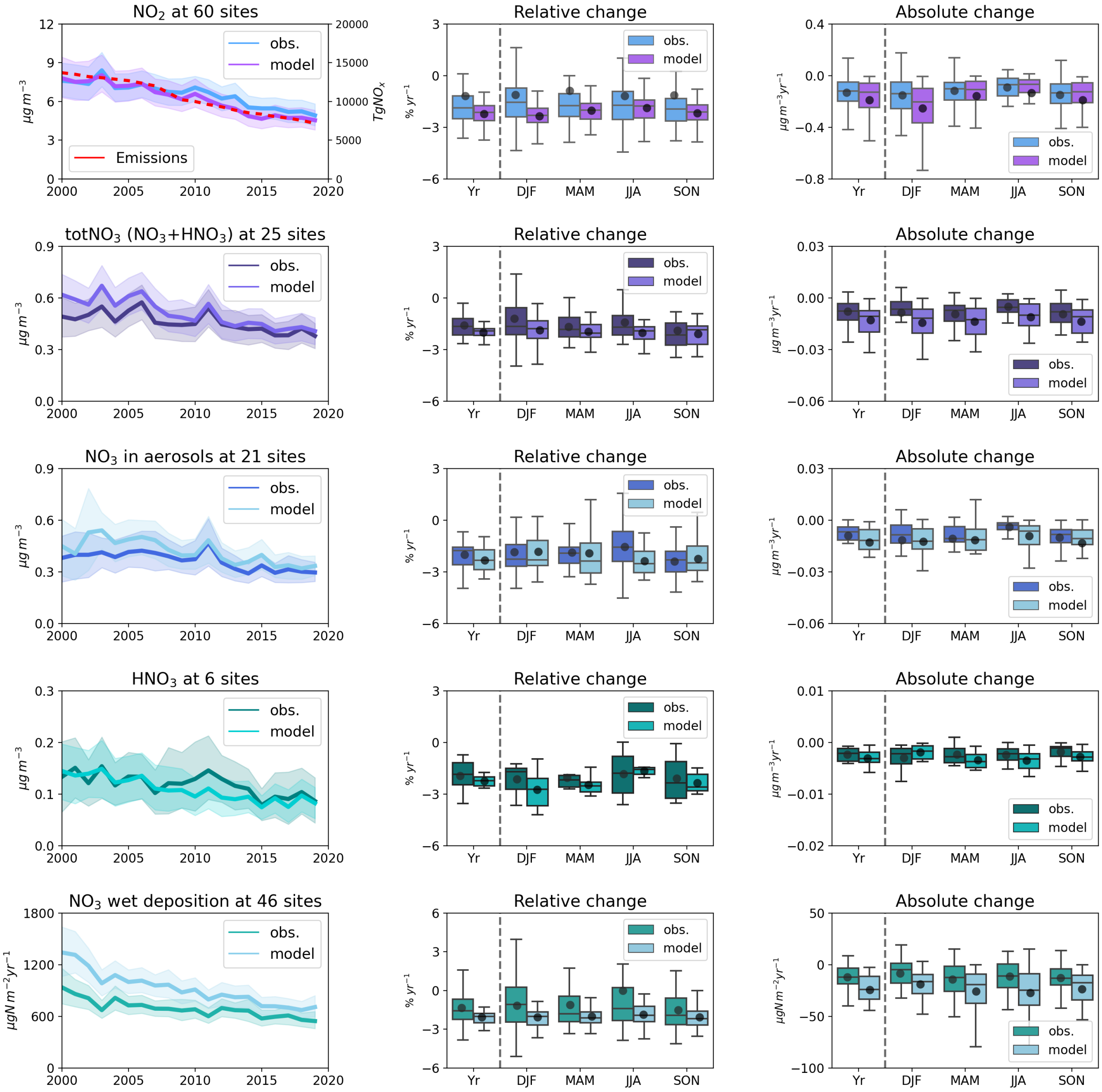

Figure 4.3: As Fig. 4.1, but for oxidized nitrogen components.

From 2000–2019, the reductions have been on average -1.2 %/yr for NO_2 concentrations at EMEP background sites (total -24%). As NO_2 has a short lifetime, the trend in NO_2 is expected to reflect the trend in (local) emissions of NOx. During the 2000–2019 period, NO_x emissions within the western EMEP domain (EU27+UK+EFTA countries), where the dominant part of the long term EMEP observations are situated, decreased by -48%. EMEP MSC-W model calculations follow the reported emission reductions closely (average reductions of -2.2 %/yr, or in total -42%). The trends calculated from observations and from the model (and emissions) agree well for the last period (2010–2019), with trends around -2.6% yr^{-1}, whilst the trend in the first period is substantially lower in the observations than in the model calculations (and emissions). From Figure 4.3 it can be seen that the agreement between observations and model calculations is excellent until around 2008, but that in the year 2009 and onwards the model (and emissions) is shifted down relative to the observations. Similar results have been found in (Colette et al. 2021).

Table 4.4: As Tab 4.1, but for NO_2 concentrations.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Average change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	60	45	59	-0.131	(-0.162, -0.1)	-0.191	(-0.235, -0.147)	-1.18	(-2.21, -0.15)	-2.25	(-2.42, -2.07)
	winter	61	30	58	-0.151	(-0.192, -0.111)	-0.256	(-0.303, -0.209)	-1.13	(-2.03, -0.22)	-2.36	(-2.54, -2.19)
	spring	59	37	55	-0.119	(-0.15, -0.088)	-0.158	(-0.201, -0.116)	-0.88	(-2.09, 0.32)	-2.07	(-2.26, -1.88)
	summer	59	39	55	-0.092	(-0.118, -0.067)	-0.132	(-0.174, -0.09)	-1.18	(-2.07, -0.29)	-1.88	(-2.12, -1.64)
	autumn	59	41	58	-0.149	(-0.186, -0.112)	-0.189	(-0.236, -0.141)	-1.13	(-2.41, 0.15)	-2.19	(-2.37, -2.01)
2005-2019	all	64	49	63	-0.160	(-0.195, -0.125)	-0.194	(-0.237, -0.152)	-1.86	(-2.56, -1.16)	-2.58	(-2.8, -2.36)
2010-2019	all	66	36	52	-0.184	(-0.226, -0.142)	-0.174	(-0.212, -0.135)	-2.65	(-3.39, -1.92)	-2.62	(-2.89, -2.35)
2000-2010	all	64	11	42	-0.093	(-0.141, -0.044)	-0.181	(-0.231, -0.13)	-1.00	(-1.74, -0.27)	-1.98	(-2.36, -1.61)

Table 4.5: As Tab 4.1, but for total nitrate (HNO_3 + $NO_3{}^-$) in air.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	25	17	25	-0.008	(-0.011, -0.005)	-0.013	(-0.016, -0.01)	-1.60	(-2.0, -1.2)	-2.13	(-2.33, -1.94)
	winter	27	7	16	-0.009	(-0.014, -0.003)	-0.014	(-0.018, -0.01)	-1.21	(-1.75, -0.66)	-1.93	(-2.26, -1.6)
	spring	25	13	21	-0.010	(-0.013, -0.007)	-0.015	(-0.018, -0.011)	-1.69	(-2.08, -1.29)	-2.24	(-2.46, -2.02)
	summer	25	17	23	-0.005	(-0.007, -0.003)	-0.012	(-0.015, -0.009)	-1.43	(-1.86, -1.0)	-2.27	(-2.43, -2.1)
	autumn	24	16	16	-0.009	(-0.013, -0.006)	-0.014	(-0.019, -0.01)	-1.89	(-2.43, -1.35)	-2.20	(-2.48, -1.93)
2005-2019	all	31	18	26	-0.011	(-0.014, -0.008)	-0.014	(-0.017, -0.011)	-2.29	(-2.74, -1.84)	-2.51	(-2.8, -2.22)
2010-2019	all	29	16	9	-0.015	(-0.019, -0.01)	-0.010	(-0.014, -0.007)	-3.38	(-4.26, -2.5)	-2.16	(-2.58, -1.75)
2000-2010	all	33	7	11	-0.006	(-0.011, -0.001)	-0.017	(-0.022, -0.012)	-0.54	(-1.55, 0.47)	-2.12	(-2.66, -1.57)

Table 4.6: As Tab. 4.1, but for $NO_3{}^-$ concentrations in aerosols.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	21	13	15	-0.009	(-0.012, -0.006)	-0.014	(-0.018, -0.009)	-2.01	(-2.49, -1.53)	-2.53	(-2.86, -2.2)
	winter	20	8	5	-0.012	(-0.018, -0.005)	-0.012	(-0.016, -0.008)	-1.85	(-2.77, -0.93)	-2.01	(-2.55, -1.47)
	spring	20	12	15	-0.011	(-0.017, -0.005)	-0.012	(-0.018, -0.007)	-1.89	(-2.69, -1.09)	-2.21	(-2.97, -1.45)
	summer	20	8	13	-0.004	(-0.006, -0.002)	-0.010	(-0.014, -0.006)	-1.55	(-2.17, -0.94)	-2.70	(-2.98, -2.43)
	autumn	20	11	9	-0.010	(-0.013, -0.007)	-0.014	(-0.021, -0.007)	-2.41	(-2.8, -2.01)	-2.42	(-2.83, -2.01)
2005-2019	all	26	11	16	-0.011	(-0.015, -0.006)	-0.014	(-0.018, -0.009)	-2.32	(-2.84, -1.81)	-2.77	(-3.21, -2.33)
2010-2019	all	32	3	6	-0.010	(-0.015, -0.004)	-0.009	(-0.013, -0.005)	-1.98	(-2.85, -1.11)	-1.46	(-2.23, -0.68)
2000-2010	all	20	3	9	-0.006	(-0.013, 0.001)	-0.020	(-0.028, -0.012)	-1.54	(-2.8, -0.27)	-3.01	(-3.99, -2.03)

Table 4.7: As Tab. 4.1, but for concentrations of HNO_3.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	6	4	6	-0.002	(-0.004, -0.001)	-0.003	(-0.005, -0.002)	-1.94	(-2.77, -1.11)	-2.35	(-2.64, -2.07)
	winter	6	3	4	-0.003	(-0.005, -0.001)	-0.002	(-0.003, -0.001)	-2.15	(-2.92, -1.37)	-2.80	(-3.71, -1.89)
	spring	6	4	6	-0.002	(-0.004, -0.001)	-0.003	(-0.005, -0.002)	-2.05	(-3.15, -0.95)	-2.68	(-3.17, -2.19)
	summer	6	3	6	-0.002	(-0.004, -0.001)	-0.004	(-0.006, -0.002)	-1.83	(-2.97, -0.7)	-1.85	(-2.06, -1.63)
	autumn	6	3	6	-0.002	(-0.003, -0.0)	-0.003	(-0.004, -0.001)	-2.09	(-3.22, -0.97)	-2.49	(-2.99, -1.99)
2005-2019	all	12	7	9	-0.004	(-0.005, -0.003)	-0.003	(-0.004, -0.001)	-2.48	(-3.16, -1.8)	-2.26	(-2.85, -1.67)
2010-2019	all	16	4	3	-0.005	(-0.007, -0.003)	-0.002	(-0.003, -0.0)	-4.25	(-5.65, -2.86)	-0.67	(-2.31, 0.97)
2000-2010	all	10	3	4	-0.006	(-0.012, 0.0)	-0.005	(-0.007, -0.003)	-1.63	(-3.86, 0.61)	-3.33	(-4.17, -2.5)

Table 4.8: As Tab. 4.1, but for wet deposition of nitrate.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg(N) m$^{-3}m^2$ yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	46	21	44	-12.1	(-15.7, -8.5)	-26.4	(-31.3, -21.4)	-1.36	(-1.74, -0.98)	-2.35	(-2.49, -2.21)
	winter	45	6	25	-8.3	(-12.4, -4.3)	-19.9	(-23.5, -16.4)	-1.16	(-1.69, -0.63)	-2.23	(-2.46, -2.0)
	spring	43	17	33	-14.2	(-20.5, -7.9)	-27.8	(-35.2, -20.3)	-1.11	(-1.74, -0.48)	-2.33	(-2.54, -2.12)
	summer	45	10	33	-11.3	(-16.3, -6.2)	-30.4	(-37.4, -23.3)	-0.02	(-1.83, 1.78)	-2.17	(-2.44, -1.9)
	autumn	45	12	28	-12.8	(-16.6, -9.0)	-25.6	(-31.6, -19.7)	-1.53	(-2.01, -1.05)	-2.36	(-2.59, -2.13)
2005-2019	all	50	15	40	-10.0	(-14.8, -5.2)	-24.0	(-27.7, -20.3)	-0.53	(-2.04, 0.98)	-2.62	(-2.8, -2.44)
2010-2019	all	58	7	19	-13.3	(-17.6, -8.9)	-23.6	(-28.3, -18.9)	-1.54	(-2.23, -0.86)	-2.60	(-2.98, -2.22)
2000-2010	all	45	8	15	-13.2	(-20.8, -5.5)	-26.4	(-34.3, -18.5)	-1.12	(-2.22, -0.03)	-2.24	(-2.65, -1.83)

The trends in wet deposition of oxidized nitrogen reflect changes in long range transported oxidized nitrogen (e.g. NO_x has been converted to nitric acid and particulate nitrate and then washed out by rain) and are less sensitive to local changes. Also the trends for wet deposition of nitrate are lower in the observations than in the model calculations (and emissions of NO_x) for the 2000–2019 period. Whilst the average trend in observations is -1.4 %/yr (total of -26%), the model calculates the trend at the same sites to be -2.3 %/yr (total of -45%), close to the trends in emissions from the western EMEP domain (-48%). However, the model overestimates nitrate wet deposition somewhat until around 2010, and is then shifted downward and in good agreement with observations for the years after. Note that the number of sites with significant trends for the shorter periods is small, and thus the results encumbered with more uncertainty.

For particulate nitrate, nitric acid and their sum, the results are more complex. The number of sites are few (especially for nitric acid, with only 6 sites), the coverage of Europe more scattered, and the gas/aerosol partitioning to nitrate and nitric acid is methodologically biased(EMEP 2014).

The modelled trends for 2000 to 2019 are all around -2 to -2.5 %/yr for particulate nitrate, nitric acid and their sum - aligned with the results of NO_2, wet deposition of oxidized nitrogen and the emissions. The observations show a somewhat smaller negative trend of around -1.6 %/yr for the sum and around -2 %/yr both for particulate nitrate and nitric acid. For the shorter periods, the number of sites with significant trends are very small, both in the model calculations and the observations, and thus the results are more uncertain. However, for all the three observations, the trend in the first period (2000–2010) is smaller than the trend in the second period, whilst the model shows a rather similar trend for the sum, and larger trends in the first period for the separate components.

In Fig. 4.4, the trends for the individual sites are visualized on top of model calculations. For NO_2 and wet deposition of oxidized nitrogen, the trends in observations on the eastern EMEP domain are smaller and to a larger extent non significant, whilst the trends in model calculations are in general larger and more often significant. The reasons for these discrepancies are not clear, but could be related to problems/inaccuracies in emission reporting and their trends, processes are not (well enough) taken into account, or in the observations themselves.

In summary we find that oxidized nitrogen in air and precipitation has been decreasing since 2000. However, the decrease in the observations (-24% for NO_2 and -26% for wet deposition of oxidized nitrogen) is smaller than in model calculations (-42% for NO_2 and -45% for wet deposition of oxidized nitrogen) and emissions (-48% for EU27+UK+EFTA).

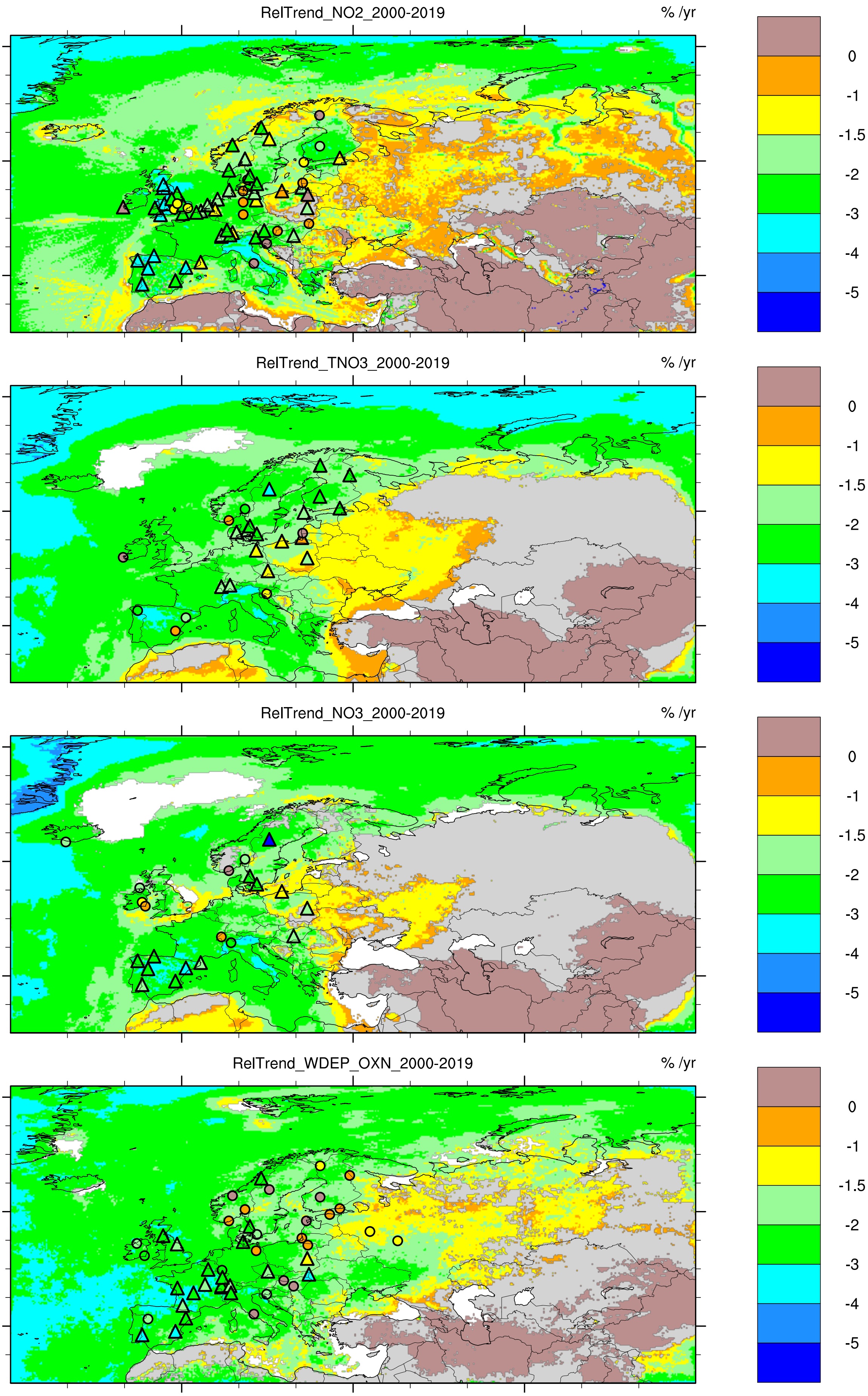

Figure 4.4: As Fig. 4.2, but for NO_2, total nitrate, nitrate aerosol and wet deposition of oxidized nitrogen.

4.7 Trends in reduced nitrogen

Ammonia emissions from agricultural activities have only been slightly reduced for the western EMEP domain since 2000 (-12% in EU27+UK+EFTA countries). In the EMEP domain as a whole, ammonia emissions have increased by 12% since 2000 (see Ch 3).

With such small changes in emissions it is very difficult to detect any trends in the observations – considering also that the meteorological variability introduces year to year changes of the same magnitude as the expected trends. Note that previous studies (e.g. Tørseth et al. 2012, Theobald et al. 2019) have found decreasing trends for reduced nitrogen. However, those studies analyzed earlier periods (e.g. 1980–2009 or 1990–2009), where the reported ammonia emissions decreased more.

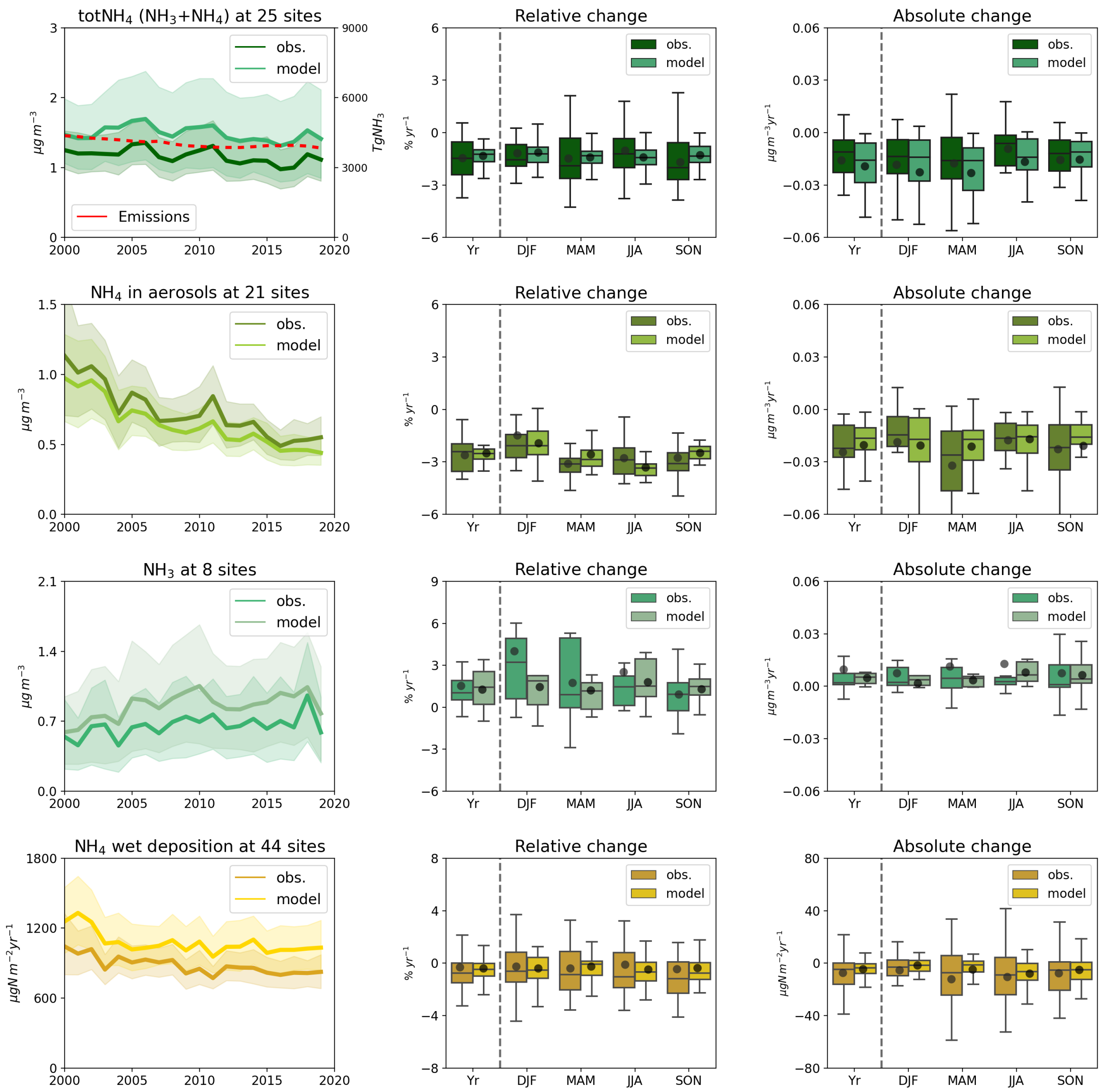

Figure 4.5: As Fig. 4.1, but for reduced nitrogen components.

Figure 4.5 shows an overview of the annual and seasonal trends in reduced nitrogen compounds from 2000 to 2019. Figure 4.6 visualizes the trends in different reduced nitrogen compounds from observations on top of modelled trends on a European map. Tables 4.9 to 4.12 show absolute and relative changes in the different reduced nitrogen compounds.

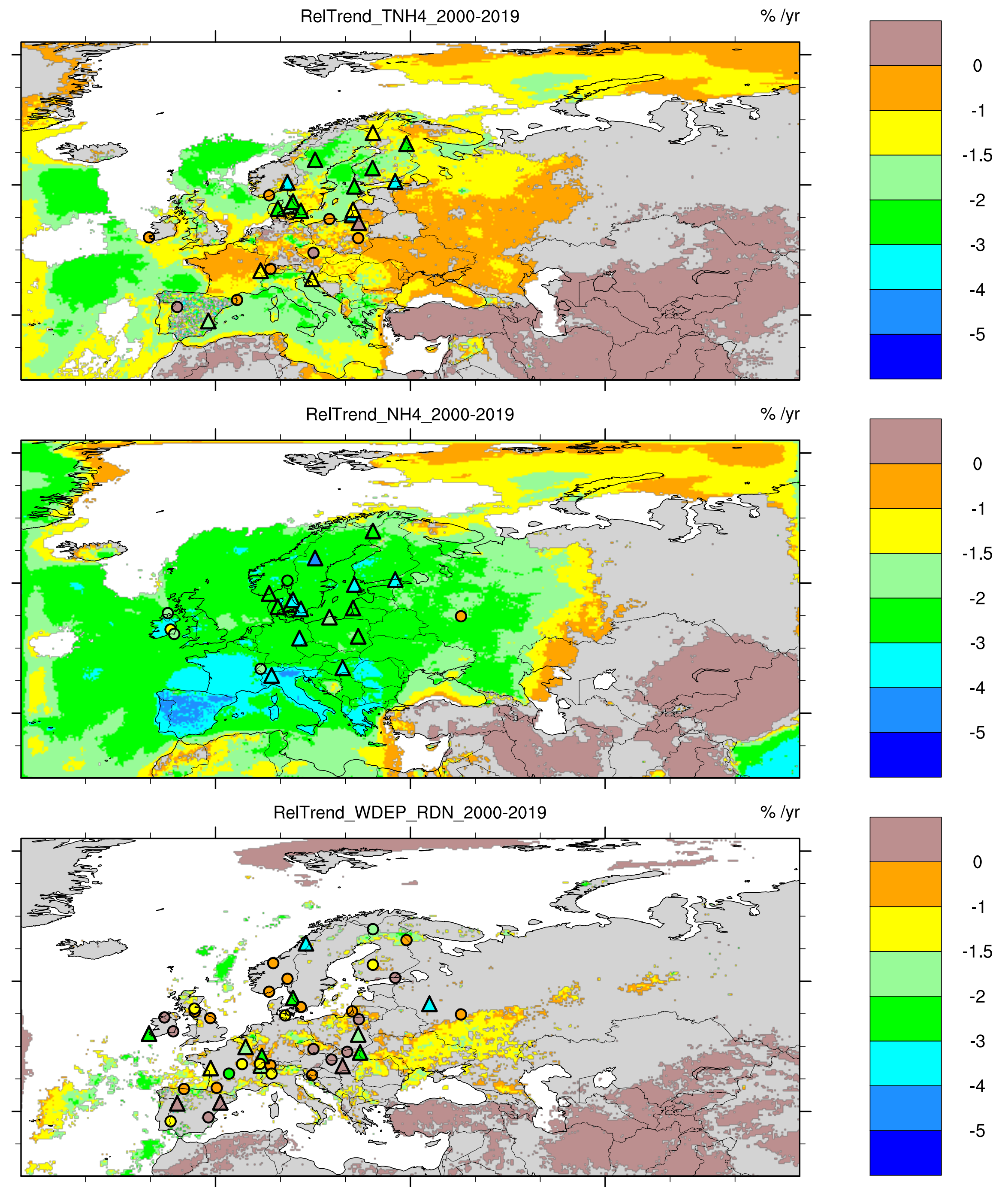

Figure 4.6: As Fig. 4.2, but for total ammonium (sum of ammonia and aerosol ammonium), aerosol ammonium and wet deposition of reduced nitrogen.

Indeed, both observations and model calculations find very few significant trends in wet deposition of reduced nitrogen. Out of 44 sites with long term measurements at EMEP background sites, only 13 are significant for the observations and 9 for the model. The average change in the observations for 2000 to 2019 is -0.31 %/yr, with a confidence interval from -0.99 %/yr to +0.37 %/yr, while the model shows an average trend of -0.4 %/yr and a confi-

Table 4.9: As Tab. 4.1, but for concentrations of total ammonium (NH_3 +NH_4^+) in air.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	25	17	18	-0.016	(-0.024, -0.007)	-0.019	(-0.027, -0.012)	-1.45	(-1.99, -0.91)	-1.36	(-1.58, -1.14)
	winter	28	9	10	-0.018	(-0.029, -0.008)	-0.023	(-0.033, -0.013)	-1.18	(-1.72, -0.64)	-1.14	(-1.47, -0.81)
	spring	25	10	16	-0.017	(-0.029, -0.006)	-0.023	(-0.032, -0.015)	-1.48	(-2.21, -0.75)	-1.46	(-1.71, -1.2)
	summer	25	10	20	-0.009	(-0.018, -0.001)	-0.017	(-0.025, -0.009)	-1.02	(-1.61, -0.44)	-1.44	(-1.71, -1.18)
	autumn	24	11	7	-0.015	(-0.025, -0.006)	-0.016	(-0.023, -0.009)	-1.67	(-2.27, -1.08)	-1.32	(-1.61, -1.03)
2005-2019	all	27	12	12	-0.019	(-0.029, -0.009)	-0.020	(-0.029, -0.011)	-1.90	(-2.55, -1.24)	-1.53	(-1.88, -1.18)
2010-2019	all	27	6	7	-0.017	(-0.026, -0.008)	-0.012	(-0.021, -0.004)	-2.31	(-3.25, -1.36)	-1.12	(-1.75, -0.5)
2000-2010	all	37	6	13	-0.022	(-0.034, -0.01)	-0.024	(-0.033, -0.016)	-1.36	(-2.11, -0.62)	-1.20	(-1.82, -0.58)

Table 4.10: As Tab. 4.1, but for concentrations of NH_4^+ in aerosols.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	21	15	20	-0.024	(-0.033, -0.016)	-0.021	(-0.028, -0.014)	-2.61	(-3.01, -2.22)	-2.61	(-2.79, -2.43)
	winter	22	10	9	-0.019	(-0.035, -0.002)	-0.020	(-0.028, -0.013)	-1.47	(-2.49, -0.45)	-1.94	(-2.43, -1.45)
	spring	20	17	16	-0.032	(-0.043, -0.021)	-0.022	(-0.03, -0.015)	-3.09	(-3.64, -2.55)	-2.74	(-3.17, -2.31)
	summer	20	14	20	-0.017	(-0.023, -0.012)	-0.018	(-0.023, -0.013)	-2.78	(-3.22, -2.35)	-3.39	(-3.62, -3.16)
	autumn	19	11	11	-0.023	(-0.031, -0.014)	-0.022	(-0.032, -0.012)	-2.75	(-3.65, -1.85)	-2.58	(-2.8, -2.35)
2005-2019	all	27	16	23	-0.025	(-0.033, -0.017)	-0.022	(-0.028, -0.016)	-2.90	(-3.41, -2.38)	-3.01	(-3.2, -2.83)
2010-2019	all	31	16	17	-0.029	(-0.041, -0.017)	-0.019	(-0.027, -0.012)	-3.48	(-4.7, -2.26)	-3.22	(-3.9, -2.54)
2000-2010	all	23	9	12	-0.034	(-0.048, -0.02)	-0.036	(-0.047, -0.024)	-3.43	(-4.6, -2.27)	-3.18	(-3.63, -2.73)

dence interval of -0.7 %/yr to -0.1 %/yr. For the shorter time periods (2000–2010 and 2010–2019) there are even fewer sites with significant trends (see Table 4.12).

Total ammonium (NH_3 + NH_4) in air shows larger negative changes in observations of about -1.45 %/yr, and for the model -1.36 %/yr, and with a larger fraction of the sites having significant trends. This trend is larger than the reduction in ammonia emissions for EU27+UK+EFTA countries (-12%), in total 27% in observations and 26% in model calculations for 2000–2019.

The trend for ammonium aerosols is even more negative, -2.61 %/yr, both in observations and model calculations.

Very few sites have long term time series of ammonia in air (8 sites), and very few of the trends calculated are significant. However, on average, the changes observed and calculated are positive: +1.55 and +1.54 %/yr in observations and model calculations, respectively, with all values within the confidence interval being positive.

This large difference between the trends of the different reduced nitrogen components can be explained by the interaction of ammonia with the sulfur and nitrogen components. When ammonia is released into the air, it reacts with secondary sulfate originating from the SO_x emissions and forms particulate ammonium sulfate. If more ammonia is available, it reacts with nitric acid in an equilibrium reaction to form particulate ammonium nitrate. During the years from 2000 onwards, large reductions in SO_x and NO_x emissions have taken place, and thus less sulfate and nitric acid is available for forming ammonium particles. Therefore, a smaller fraction of NH_3 is converted to aerosol ammonium, and the decrease in particulate ammonium is strongly linked to the decrease in sulfate and nitrate. It is therefore to be ex-

Table 4.11: As Tab. 4.1, but for concentrations of NH_3 in air.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3} yr^{-1}) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	8	2	6	0.010	(-0.005, 0.024)	0.006	(-0.006, 0.017)	1.55	(0.22, 2.88)	1.54	(0.42, 2.66)
	winter	8	1	3	0.007	(-0.001, 0.016)	0.002	(-0.007, 0.011)	4.03	(0.61, 7.44)	1.47	(0.1, 2.84)
	spring	8	3	3	0.011	(-0.007, 0.03)	0.003	(-0.005, 0.011)	1.76	(-0.32, 3.83)	1.46	(0.09, 2.84)
	summer	8	1	6	0.013	(-0.009, 0.035)	0.009	(-0.002, 0.02)	2.53	(-0.3, 5.36)	2.27	(0.88, 3.65)
	autumn	8	1	4	0.008	(-0.005, 0.02)	0.007	(-0.001, 0.015)	0.94	(-0.36, 2.24)	1.49	(0.65, 2.33)
2005-2019	all	18	3	7	0.005	(-0.002, 0.012)	0.000	(-0.009, 0.01)	0.57	(-0.26, 1.39)	0.84	(0.1, 1.59)
2010-2019	all	22	4	5	0.012	(-0.009, 0.032)	0.001	(-0.017, 0.019)	2.80	(-1.35, 6.95)	2.58	(0.67, 4.49)
2000-2010	all	12	3	4	0.003	(-0.021, 0.028)	0.012	(0.0, 0.025)	3.14	(0.5, 5.78)	1.99	(0.4, 3.57)

Table 4.12: As Tab. 4.1, but for wet deposition of ammonium.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Average change (μg(N) m$^{-3}m^2yr^{-1}$) obs.	conf.interval	mod.	conf.interval	Relative change (% yr^{-1}) obs.	conf.interval	mod.	conf.interval
2000-2019	all	44	13	9	-7.4	(-11.8, -3.0)	-4.8	(-8.1, -1.5)	-0.31	(-0.99, 0.37)	-0.40	(-0.71, -0.09)
	winter	44	5	3	-5.3	(-9.4, -1.3)	-1.7	(-3.8, 0.4)	-0.25	(-0.94, 0.43)	-0.39	(-0.72, -0.06)
	spring	42	5	4	-12.2	(-19.4, -4.9)	-4.7	(-11.5, 2.1)	-0.39	(-1.1, 0.31)	-0.27	(-0.64, 0.11)
	summer	43	9	6	-10.4	(-16.7, -4.1)	-8.0	(-11.6, -4.4)	-0.12	(-1.17, 0.93)	-0.48	(-0.84, -0.12)
	autumn	43	10	4	-7.5	(-12.8, -2.3)	-5.2	(-9.3, -1.0)	-0.45	(-1.37, 0.47)	-0.35	(-0.8, 0.11)
2005-2019	all	52	8	4	-4.8	(-10.7, 1.0)	-3.4	(-6.4, -0.3)	-0.12	(-0.95, 0.71)	-0.43	(-0.78, -0.08)
2010-2019	all	62	3	4	-2.7	(-8.6, 3.1)	-5.8	(-11.1, -0.4)	0.90	(-0.95, 2.75)	-0.47	(-1.04, 0.11)
2000-2010	all	44	4	3	-9.3	(-17.8, -0.8)	-4.0	(-12.2, 4.2)	-0.36	(-1.24, 0.52)	-0.09	(-0.91, 0.73)

pected that the trend in ammonium aerosol (-2.6 %/yr, observations) lies somewhere between the trend in particulate sulfate (-3.2 %/yr, observations) and nitrate (-2.0 %/yr, observations).

When less ammonia is converted to ammonium, the (very small) decrease in ammonia emissions is compensated by a larger part of ammonia residing in the gas phase, and no decreases in ammonia (very few significant trends) are detected.

For the sum of ammonia and ammonium, the two opposite trends of ammonia (no trend or slightly positive) and ammonium (negative) results in a negative trend that is smaller than the trend for ammonium alone.

The analysis done for the shorter time periods (2000–2010 and 2010–2019) confirms the findings discussed above. It is worth noting that the agreement between the trends calculated from model calculations and the observation is excellent for the different reduced nitrogen components, which indicates that the EMEP MSC-W model does a very good job in reproducing the non-linear interactions between sulfur, oxidized nitrogen and reduced nitrogen and how this has evolved during the past 20 years.

In summary, the observations and the model calculations confirm that very small reductions of ammonia emissions have been achieved during the 2000–2019 period. However, the contribution of ammonia emission to aerosols have been largely reduced during this period, due to the impact of SO_x and NO_x emission reductions.

4.8 Trends in Elemental and Organic Carbon

4.8.1 Elemental Carbon, EC

Table 4.13: As Tab 4.1, but for EC in $PM_{2.5}$, and period 2010–2019.

Number of sites				Absolute change (μg(C) m^{-3} yr^{-1})				Relative change (% yr^{-1})			
Season	Tot.	Sign. Obs.	Sign. Mod.	obs.	Conf.interval	Mod.	Conf.interval	Obs.	Conf.interval	Mod.	Conf.interval
All	15	11	12	-0.019	(-0.031, -0.008)	-0.014	(-0.021, -0.007)	-4.49	(-5.25, -3.73)	-3.81	(-4.59, -3.03)
Winter	15	6	4	-0.029	(-0.053, -0.006)	-0.019	(-0.032, -0.006)	-4.27	(-5.49, -3.06)	-3.10	(-4.21, -1.98)
Spring	15	5	8	-0.012	(-0.018, -0.006)	-0.013	(-0.018, -0.009)	-3.88	(-4.67, -3.09)	-3.86	(-4.92, -2.8)
Summer	15	8	10	-0.011	(-0.015, -0.007)	-0.008	(-0.013, -0.004)	-4.73	(-5.71, -3.74)	-3.71	(-4.59, -2.82)
Autumn	15	8	11	-0.023	(-0.036, -0.01)	-0.018	(-0.027, -0.009)	-4.96	(-6.03, -3.9)	-4.25	(-5.15, -3.35)

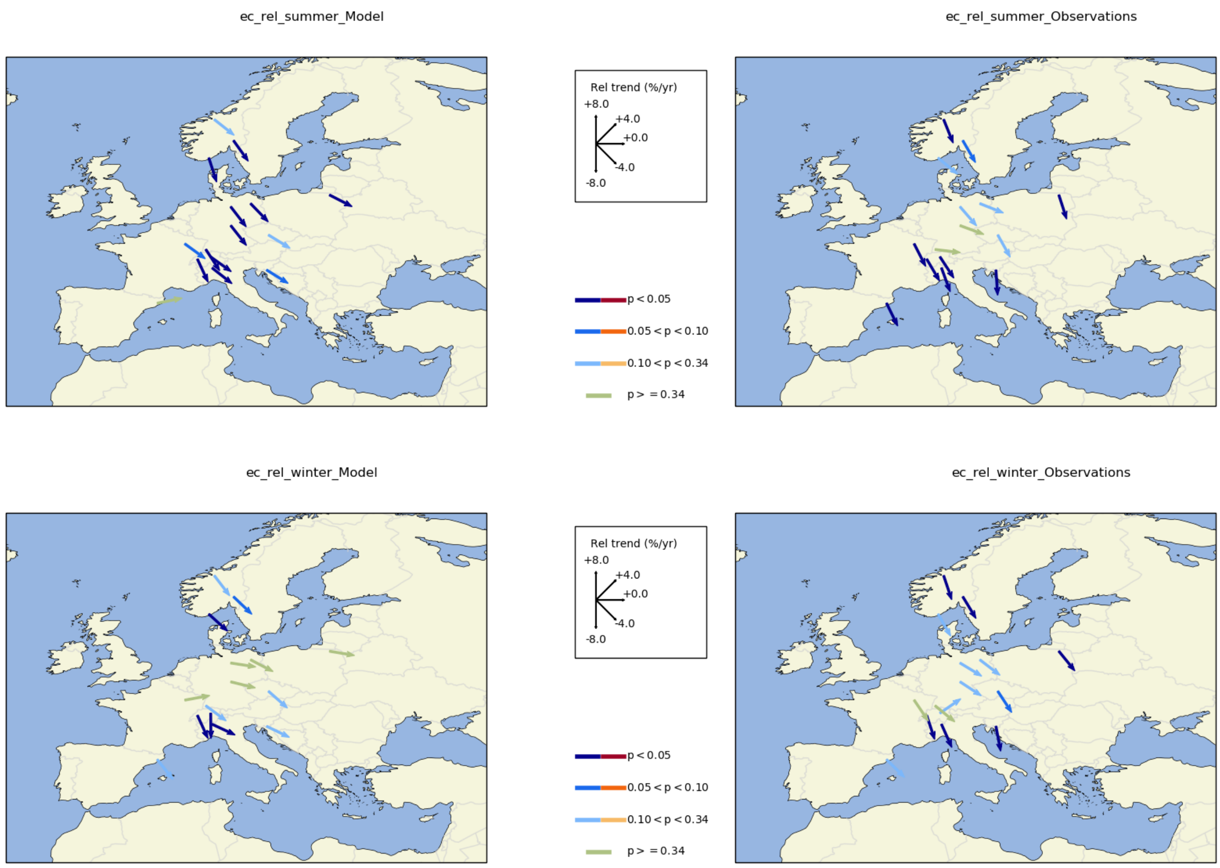

Figure 4.7: Relative trends for EC in $PM_{2.5}$ over the period of 2010–2019, from both model (left) and observations (right), and for summer (top) and winter (bottom). The magnitude of the trends is indicated by the angle made (see key), which also indicates the trend values associated with 45°and 90°angles. The colour indicates the p-values associated with the trends. (The style of these plots is based upon those used in the TOAR project, e.g. Chang et al. 2017, Mills et al. 2018.)

Table 4.13 presents the absolute and relative changes over 2010–2019 from 15 EMEP sites, as annual values, and with confidence intervals, from both observed and modelled values. The spatial variation of these trends for summer and winter can be seen as 'arrow' plots in

Fig. 4.7, and Fig.4.8 shows again the annual trends, but superimposed upon the field of modelled EC. Fig. 4.9 illustrates the statistics of the reductions in EC over the period 2010–2019, and for different seasons.

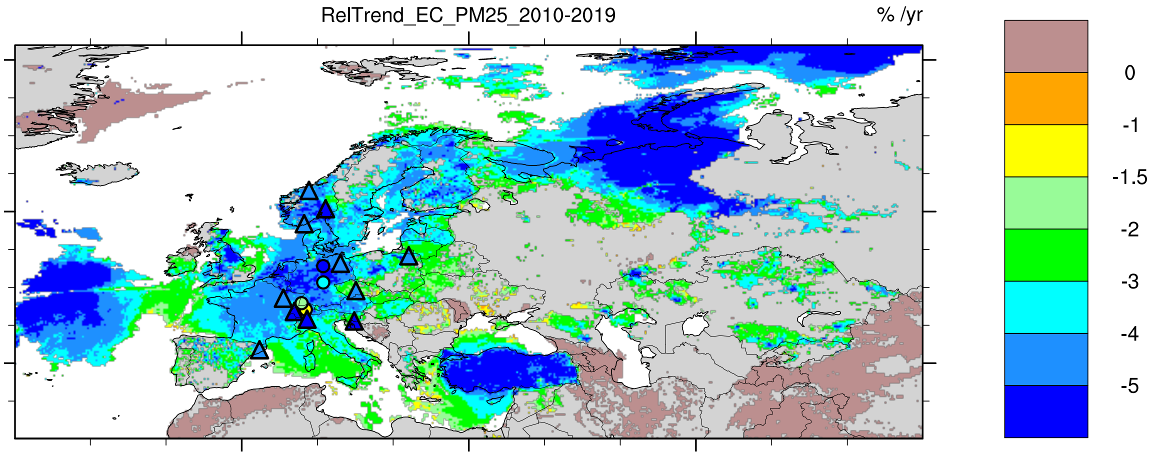

Figure 4.8: As Fig. 4.2, but for EC in $PM_{2.5}$, and the period 2010–2019.

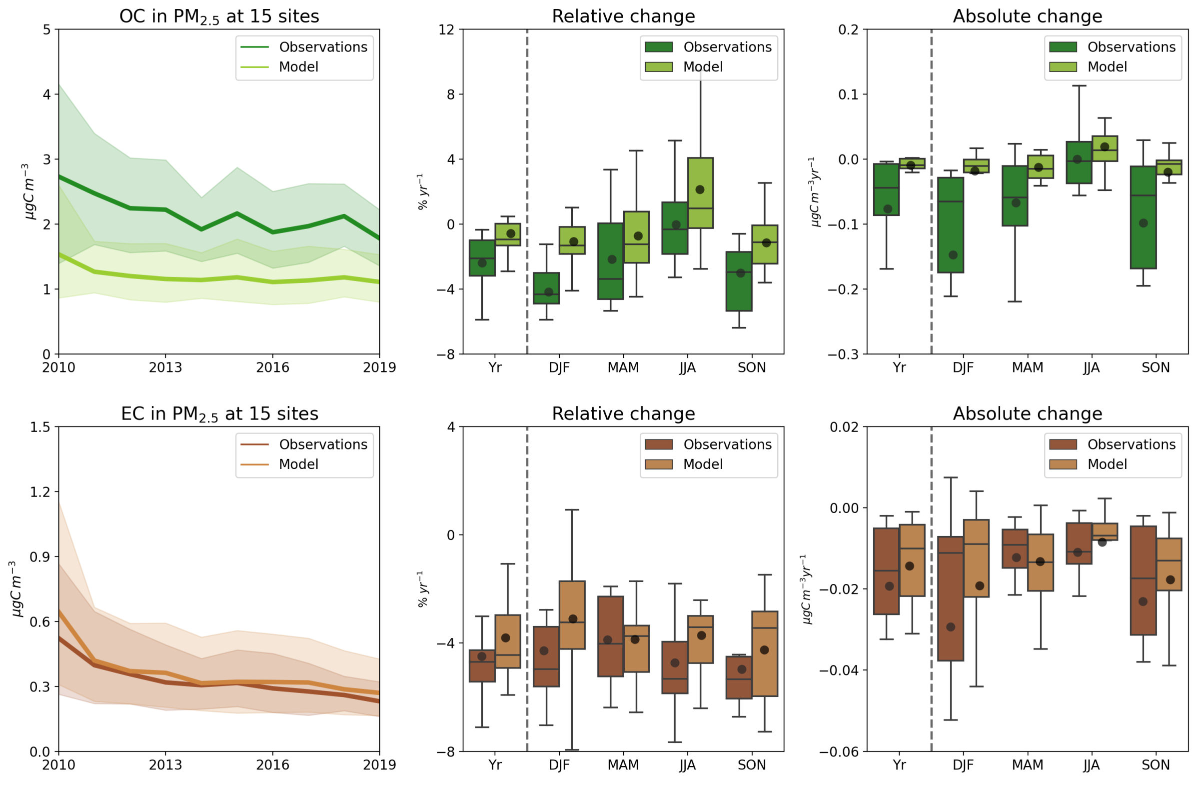

Figure 4.9: As Fig. 4.1, but for OC in $PM_{2.5}$ (top) and EC in $PM_{2.5}$ (bottom), for 15 EMEP sites for the period 2010–2019.

Considering first the observed trends in elemental carbon (EC) for 2010–2019, a reduction (-4.5±1.5 %/yr, Tab. 4.13) was calculated for the 15 sites assessed, which is quite comparable to the reduction (-5.0±0.9 %/yr) calculated for the eleven sites where the reduction was statistically significant. The reduction was rather similar considering these eleven sites, ranging from -4.2 %/yr to -5.8 %/yr for ten out of eleven sites. The largest reduction was seen amongst the sites with the highest EC levels, i.e. at Iskrba (-7 %/yr) in Slovenia and at Ispra (-5.8 %/yr) in the Po Valley region in Northern Italy (Fig. 4.8). Notably, these were the only sites where a statistically significant reduction was observed for all seasons, being most pronounced in summer, although by a small margin. When considering all sites, the reduction was most pronounced in summer and autumn (Tab. 4.13, Fig. 4.9), but the general picture is that there is a minor seasonal variability in the reduction of EC. It can be noted though that there are more sites with significant trends (p-values < 0.05) in summer than in winter (Fig.4.7).

Fig. 4.9 illustrates the statistics of the reductions in EC in both observed and model results over the period 2010–2019, and for different seasons. For EC, the model is seen to capture the year to year changes very well over the ten years, and captures well the relative changes which are ca. -4 %/yr in all seasons. Larger differences are seen in the absolute changes (which may reflect the difficulties with the EC emissions mentioned in Ch 4.2.1). These points about model-measurement comparison for EC are discussed further in Ch 4.8.3.

4.8.2 Organic Carbon, OC

Table 4.14 presents the absolute and relative changes in OC over 2010–2019 from 15 EMEP sites, as annual values and with confidence intervals, and from both observed and modelled values. The spatial variation of these trends for summer and winter can be seen as 'arrow' plots in Fig. 4.10, and Fig.4.11 shows again the annual trends, but superimposed upon the modelled field of modelled OC. Fig. 4.9 illustrates the statistics of the reductions in OC over the period 2010–2019, and for different seasons. A 2.4±1.6 %/yr reduction in organic carbon (OC) for 2010–2019 was calculated for the 15 sites assessed (Tab. 4.14), but the downward trend was statistically significant only for Iskrba (Slovenia) and Ispra (Italy), which are amongst the sites with the highest OC loading. At these two sites, the reduction was noticeably higher (-3.1 %/yr at Iskrba, -5.9 %/yr at Ispra) than for the mean of all sites. The reduction in OC appears somewhat lower at the westernmost and northernmost sites (Fig.4.11).

Table 4.14: As Tab 4.1, but for OC in $PM_{2.5}$, and period 2010–2019.

Number of sites				Absolute change (μg(C) m^{-3} yr^{-1})				Relative change (% yr^{-1})			
Seasons	Tot.	sign. obs.	sign. mod.	obs.	conf.interval	mod.	conf.interval	obs.	conf.interval	mod.	conf.interval
all	15	2	1	-0.077	(-0.132, -0.022)	-0.009	(-0.019, 0.0)	-2.40	(-3.23, -1.57)	-0.59	(-1.21, 0.03)
winter	15	6	1	-0.148	(-0.249, -0.047)	-0.018	(-0.032, -0.004)	-4.19	(-5.16, -3.22)	-1.09	(-2.03, -0.15)
spring	15	1	0	-0.067	(-0.104, -0.03)	-0.013	(-0.023, -0.003)	-2.18	(-3.68, -0.67)	-0.74	(-1.94, 0.47)
summer	15	0	1	-0.000	(-0.024, 0.023)	0.019	(-0.003, 0.041)	-0.03	(-1.19, 1.12)	2.13	(0.44, 3.83)
autumn	15	1	0	-0.098	(-0.16, -0.037)	-0.020	(-0.041, 0.0)	-3.03	(-4.43, -1.62)	-1.16	(-2.47, 0.15)

There was a pronounced seasonal variability in the reduction observed for OC (Tab. 4.14, Figs. 4.9,4.10). In winter, the reduction (-4.2 %/yr) was equal to that for EC (-4.3 %/yr, but only statistically significant for six of the sites, whereas no reduction (0 %/yr) was seen in summer. Spring (-2.2 %/yr, Tab. 4.14) and autumn (-3.0 %/yr) are transition seasons with reductions in between that of winter and summer and statistically significant reductions were observed only for Ispra. Figure 4.10 makes it clear that there were large differences in both sign and magnitude of the summertime trends in OC at individual sites, in both modelled and observed results. For the winter trends, Fig. 4.10 shows that essentially all observed wintertime trends were reductions, whereas the modelled trends were more variable and less

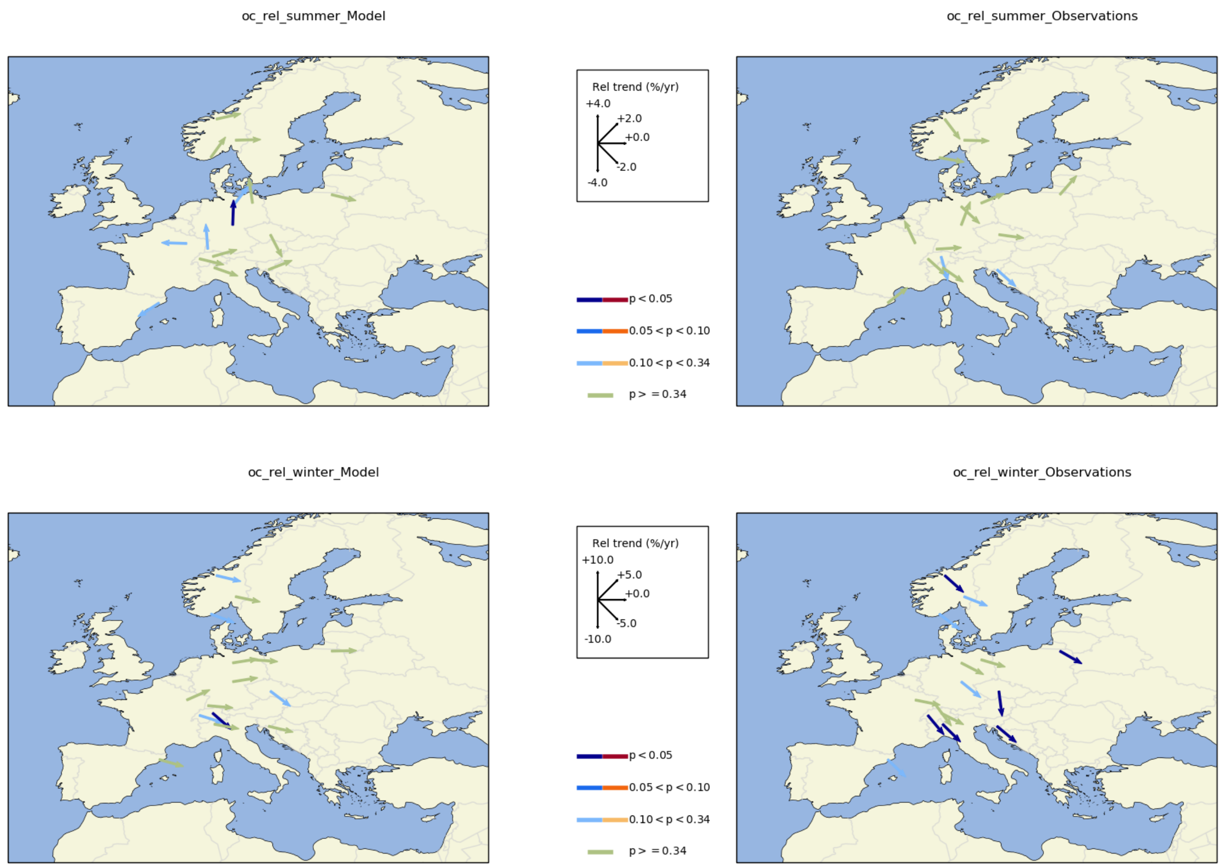

Figure 4.10: As Fig. 4.7, but for OC in $PM_{2.5}$.

significant. In summertime the trends can be positive or negative, and are generally not significant.

Fig. 4.9 illustrates the statistics of the reductions in OC over the period 2010–2019, and for different seasons. For OC the model substantially underpredicts the yearly concentrations over the whole period (see also Tab. 4.14), and also underpredicts the trends. There is substantial

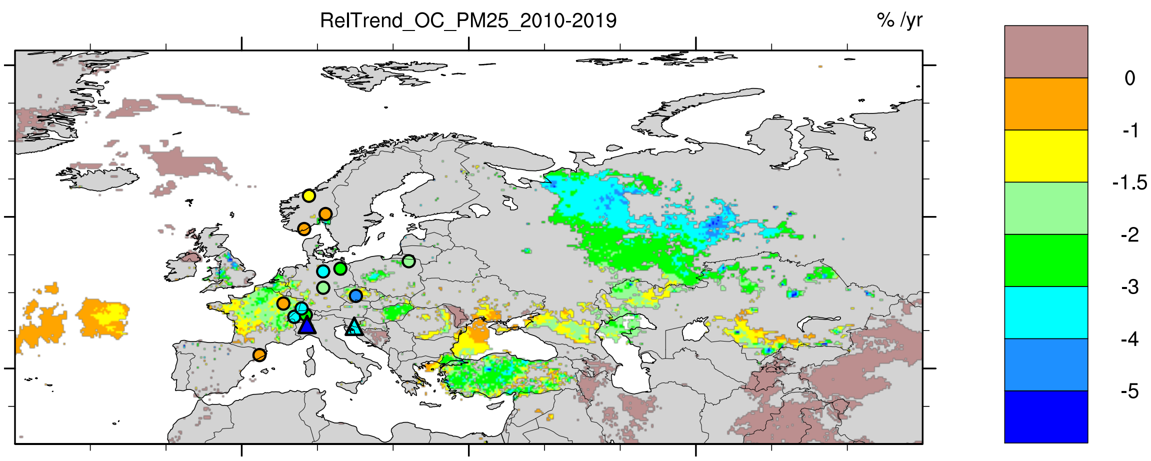

Figure 4.11: As Fig. 4.8, but for OC in $PM_{2.5}$.

seasonal variation though. Observed reductions in winter (DJF) of -4.2 %/yr (Tab. 4.14) are not reproduced by the model at all (-1.1 %/yr), though even in winter the observed trends were only significant for six of the 15 sites. In summer the observed trends are very small but negative (-0.03 %/yr), whereas the model suggests positive trends of 2.1 %/yr. As noted above (c.f. Fig. 4.10), the summer trends are very different for individual sites, even with respect to the sign of the change, and one cannot assign much significance to the changes. Model-measurement comparison for OC are discussed further in Ch 4.8.3.

4.8.3 Discussion of EC and OC trends

Before discussing the trends shown in Ch 4.8.1-4.8.2 in more detail, it is important to note that ten years is a short period over which to assess such trends. In order to illustrate this, Table 4.15 shows trends assessed for three periods, 2008–2018, 2008–2019, and 2010–2019, all using the same methodology. It is seen that the magnitude of the trends can differ substantially depending on the time-window. For EC the values range from -2.2 %/yr to -4.2 %/yr, and for levoglucosan from -2.5 %/yr to -5.2 %/yr, with all values satisfying the p-value$<$0.05 significance test. Trend values for OC vary even more, but these trends were insignificant for all periods. Although we expect some of these trends to reflect changes in emissions, meteorological variation will also play a large role, especially in causing the high sensitivity of the calculated trends to small changes in the time window chosen.

Table 4.15: Relative trends (%/yr) (and p-values in parentheses) calculated for Birkenes using different time-windows.

		2008–2018$^{(a)}$	2008–2019	2010–2019
EC	annual	-3.0 (0.043)	-2.21 (0.034)	-4.24 (0.012)
OC	annual	-0.44 (0.876)	0.18 (–)$^{(b)}$	-0.64 (–)
Levoglucosan	annual	-2.5 (0.043)	-2.48 (0.024)	-5.2 (0.032)

Notes: (a) Values for 2008–2018 use same procedure as for 2008–2019 and 2010–2019. Due to minor screening differences, numbers differ slightly from results of Yttri et al. (2021), which had 2008–2018 trends of -4.2 %/yr for EC and -2.8 %/yr for levoglucosan; (b) dash (–) indicates highly insignificant p-value.

The 2010–2019 reduction of 4.2 %/yr in observed EC across all seasons is rather dramatic, though as noted above a different choice of time-window might suggest a lower magnitude of changes. As discussed in Ch 4.8.1 there is only a minor seasonal variability in the reduction of EC. This partly reflects the minor seasonal variability in most EC sources, but it is puzzling since residential heating (in GNFR sector C) should have clear winter maxima. Yttri et al. (2021) found that the reduction in EC was most pronounced in spring and summer at the Birkenes Observatory in southern Norway for 2001–2018, arguing that this was due to influence from less abated sources such as domestic heating in winter and fall. This argument was supported by a smaller change (-2.8 %/yr) for the biomass burning tracer levoglucosan (2008–2018) than for EC (-4.2 %/yr) (these trend numbers are from Yttri et al., and differ slightly from trends calculated for this report, c.f. Tab. 4.15). In this study, however, we calculated a -5.2 %/yr change (i.e. reduction) for the biomass burning tracer levoglucosan observed at the Birkenes Observatory for 2010–2019, which is greater than the -4.2 %/yr change calculated for EC. This finding seems to contradict the conclusion made by Yttri et al. (2021), but the differences in trends using different time-windows (c.f. Tab. 4.15) suggest that it is difficult to draw firm conclusions about these changes.

As the biomass burning emissions observed at the Birkenes Observatory are largely long-range transported from Continental Europe and Western Russia (Yttri et al. 2021), our findings for Birkenes are likely to be representative for a larger part of Europe. However, changing footprints for the Birkenes site may also affect both the trends and the relative contributions of biomass burning and residential wood combustion (RWC). Fig. 4.12 shows that for some countries, for example France, GNFR C $PM_{2.5}$ emissions have been in constant decline throughout the 2000s. Declines are seen in other countries from around 2010 onwards also, and most of these (arbitrarily chosen) countries show reduction of ca. 4 %/yr. Thus, abatemement of RWC emissions seem to be progressing for many countries within the Birkenes footprint area, though the magnitude of the contribution from different countries will of course vary from year to year.

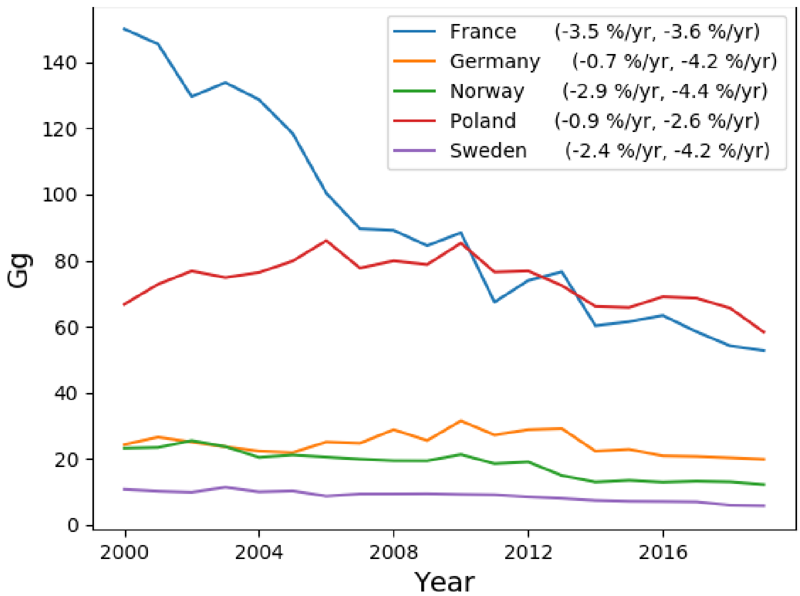

Figure 4.12: Trends in $PM_{2.5}$ emissions from the GNFR C emission sector (mainly residential heating). Values in parentheses give relative trends (here linear regression slopes), for the periods 2000–2019 and 2010–2019.

The issues with condensable organics (Ch 4.2.1) impact these estimates of $PM_{2.5}$ emissions and their trends also, and Fig. 4.12 is a good illustration of this. France is a country which includes condensables, and Germany is one that does not (Simpson et al. 2020b). This difference is a major reason for the magnitude of the French GNFR C emissions compared to those of the more highly populated Germany. We can note that Yttri et al. (2021) found a statistically significant trend of similar magnitude and sign (-4.2 %/yr) for EC for 2001–2018 as for 2010–2019 in the present study for the Norwegian Birkenes Observatory. As this site has a footprint that covers a large part of continental Europe (*ibid.*), this consistency suggests a large-scale reduction in EC emissions over the last two decades.

Unlike EC, the observed seasonal trends for OC (c.f. Fig. 4.9) are very variable, with strong (ca. 4 %) reductions in the winter months (both DJF and SON), and apparently no change in summertime. As already noted, the individual sites show a great variation in even the sign of the calculated trends, though statistically the trends are not significant (c.f. Fig. 4.10). The lack of clear trend in summertime is not surprising. OC has a substantial influence from natural sources, biogenic secondary organic aerosol (BSOA) and primary biological aerosol particles (PBAP), which prevail in the growing season (e.g. Gelencsér et al. 2007, Yttri et al. 2019). These biogenic emissions are not subject to abatement, but are very sensitive to meteorology, and thus summer-time OC trends are strongly influenced by year-to-year changes in meteorological conditions.

Anthropogenic OC emissions are likely best represented by winter-time data, and in DJF the observed trend of -4 %/yr for OC is rather similar to that found for EC (Tab. 4.14). As for EC, domestic heating is an important emission source all over Europe in the heating season (e.g. Yttri et al. 2019), but especially where RWC is utilised. At the Birkenes Observatory the winter-time reduction in OC (-4.1 %/yr) was only somewhat lower than for EC (-6.4 %/yr) and levoglucosan (-4.6 %/yr). These results also suggest that abatement of residential wood burning emissions has been quite effective for Europe in general, taking into account the considerations made about the length of the time series and the Birkenes Observatory as an indicator of European emissions (Ch 4.8.1).

The underprediction of the OC levels in wintertime seen in Fig. 4.9 should not be taken as an indication that the EMEP model itself is wrong, but is rather at least partly the result of the issues with missing ‘condensable’ organics (Ch 4.2.1). It has been demonstrated elsewhere that model results improve substantially when condensables are included (Denier van der Gon et al. 2015, Simpson et al. 2019, Fagerli et al. 2020). Unfortunately, we do not yet have a time-series of condensable organic emissions with which to perform trend analysis, but we hope to address that within the context of a new MSC-W led project funded by the Nordic Council of Ministers.

4.8.4 OC and EC fractions of PM

As focused abatement of anthropogenic secondary inorganic aerosol (SIA) precursors have reduced ambient SIA levels substantially (Ch 4.5–4.7), other, non-SIA fractions are likely to contribute an increasing fraction of PM. For the EC fraction of $PM_{2.5}$, however, there was a reduction, -2.4$\pm$1.1 %/yr, for 2010–2019 (Fig. 4.13, Tab. 4.16), showing that EC has been more efficiently abated than the overall PM mass concentration. The model calculated a comparable reduction (-1.7$\pm$1.3 %/yr) for the EC/$PM_{2.5}$ ratio but predicted a minor increase at two of the sites, which was not seen for observed EC/$PM_{2.5}$ ratios. For the few sites where measurements allow for a harmonized data set of EC, OC, SO_4^{2-} and $PM_{2.5}$, i.e., only including measurements on common days, the reduction in the EC fraction of $PM_{2.5}$ was typically equally high or higher than for the SO_4^{2-} fraction. The OC fraction of $PM_{2.5}$ showed no decrease or increase (0.2$\pm$2.8 %/yr) for 2010–2019 when considering all sites, which is largely explained by non-abatable natural sources making up a major part of OC. A substantial 4.5 %/yr increase in OC/$PM_{2.5}$ was calculated for the Norwegian sites, experiencing low (anthropogenic) aerosol levels and a high OC fraction from natural sources, thus one cannot exclude the possibility that part of this increasing trend is due to an increase in natural sources and not exclusively from a decrease in anthropogenic emissions. A 2.8 %/yr increase in the OC fraction was observed for the Spanish site Montseny, resembling the Norwegian sites with respect to a low aerosol level

Table 4.16: Absolute and relative change and the corresponding 95% confidence intervals in observed and modelled annual aggregated OC/$PM_{2.5}$ and EC/$PM_{2.5}$ ratios at 15 sites across Europe for 2010–2019. The number of sites with a significant outcome is provided.

EC/$PM_{2.5}$ (2010–2019)

	Number of sites		Absolute change (μg(C) m^{-3} yr^{-1})		Relative change (% yr^{-1})	
	total	sign.	abs	Conf. interv.	%/yr	Conf. interv.
Model	15	5	-0.0006	(-0.0009, -0.0004)	-1.71	(-2.32, -1.1)
Obs.	15	4	-0.0009	(-0.0012, -0.0006)	-2.41	(-2.96, -1.85)

OC/$PM_{2.5}$ (2010–2019)

	Number of sites		Absolute change (μg(C) m^{-3} yr^{-1})		Relative change (% yr^{-1})	
	total	sign.	abs	Conf. interv.	%/yr	Conf. interv.
Model	15	7	0.0029	(0.0018, 0.004)	2.35	(1.3, 3.4)
Obs.	15	2	0.0001	(-0.003, 0.0032)	0.19	(-1.24, 1.62)

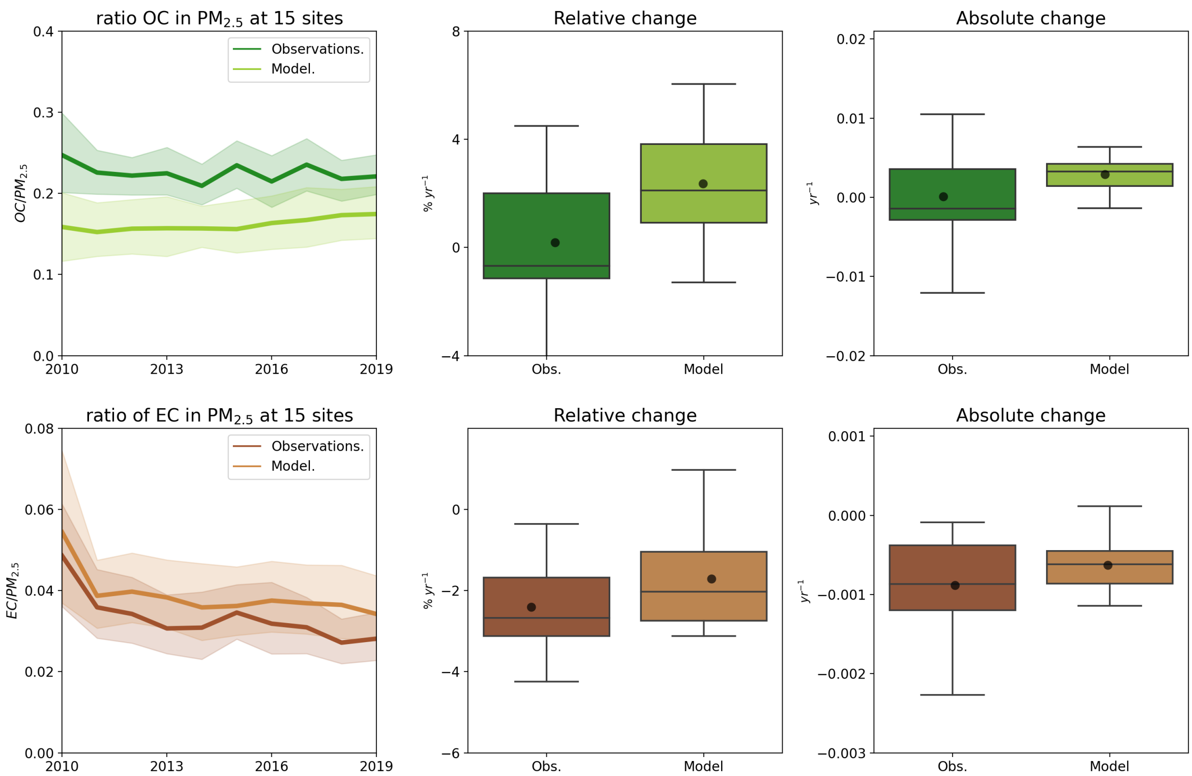

Figure 4.13: Observed and modelled ratios and trends of OC/$PM_{2.5}$ and EC/$PM_{2.5}$ for 15 EMEP sites across Europe for 2010–2019, showing the trends (left panels) of OC/$PM_{2.5}$ (upper) and EC (lower), aggregated annual relative changes (mid panels) for OC (upper) and EC (lower), and aggregated annual absolute changes (right panels) for OC (upper) and EC (lower). The solid line in the left panel shows the average annual mean for all sites and the shaded area the 95% confidence interval. For explanation of the statistics in the figure, see Fig. 4.9.

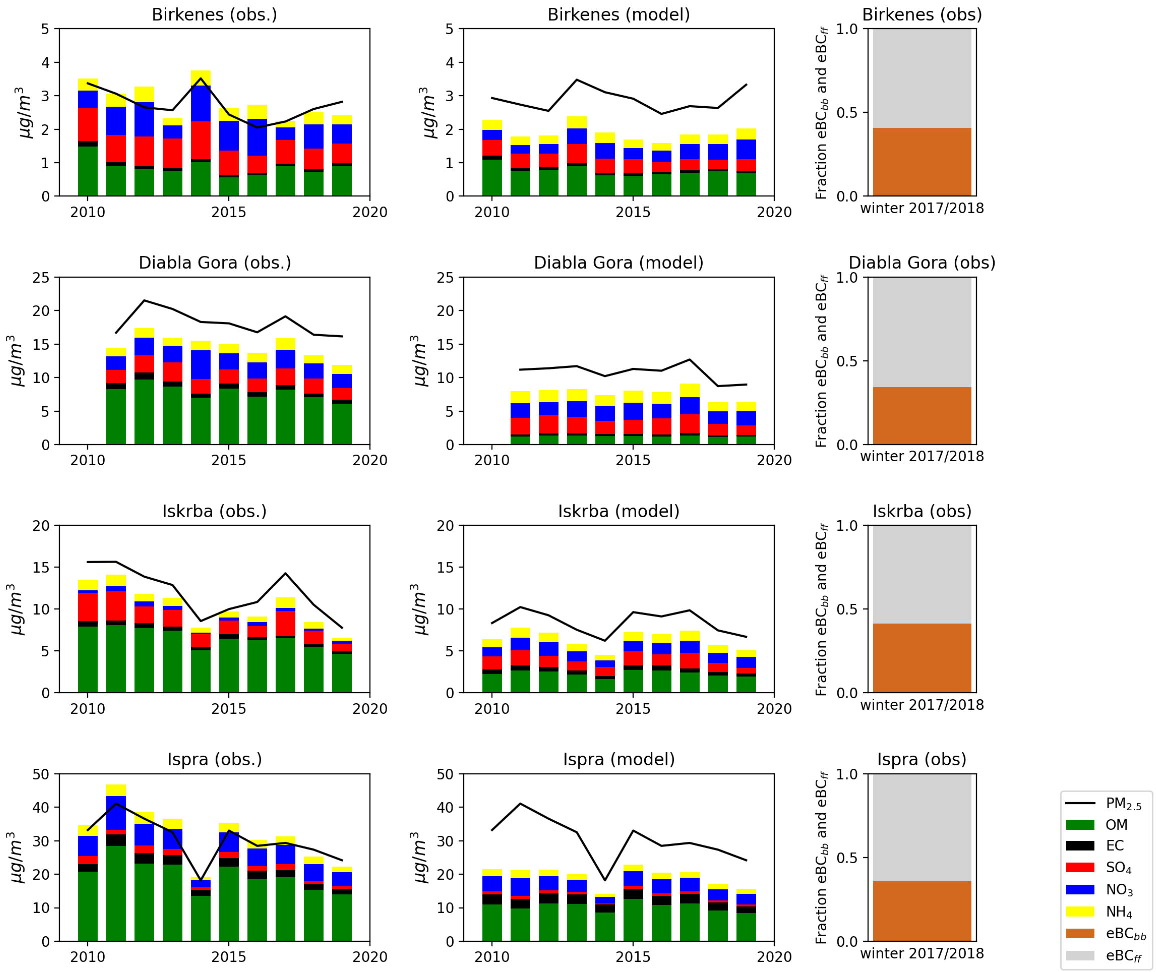

Figure 4.14: Mass balance of wintertime $PM_{2.5}$ at Birkenes (NO02), Diabla Gora (PL05), Iskrba (SI08) and Ispra (IT04) including OM, EC, SO_4^{2-}, NO_3^-, NH_4^+ from observations (left), modelled (middle) and apportionment of eBC into biomass burning/solid fuel (eBC_{bb}) and fossil fuel/liquid fuel (eBC_{ff}) for winter 2017/2018 (right). Note that at NO02 and PLO5 the SIA components in observations are from filterpack sampler with no cutoff and thus probably overestimate the $PM_{2.5}$ SIA.

and a high OC fraction from natural sources (Kulmala et al. 2011, Crippa et al. 2014). For the rest of continental Europe, a minor ±1 %/yr increase/decrease was seen at most sites and a ±2 %/yr for a few. The Kosetice (Czech Republic) (-5.3 %/yr) and Shauinsland (Germany) (-3.1 %/yr) sites experienced a substantial decrease in the OC fraction, which was larger than the corresponding decrease in the EC fraction, thus deviating from the pattern seen at all other sites where the decrease in $EC/PM_{2.5} > OC/PM_{2.5}$.

The relative contribution of carbonaceous aerosol, OM (assuming OM = OC × 1.4 for Ispra [2] and 1.7 for the other sites) and EC, to the $PM_{2.5}$ mass concentration along with the major SIA species illustrates the importance of the OM fraction for a further reduction in wintertime $PM_{2.5}$ mass concentration (Fig. 4.14). As a first step, the natural and the anthropogenic fraction of the carbonaceous aerosol must be separated, then further into abatable categories. Separation of eBC (equivalent BC, Petzold et al. 2013) into biomass burning/solid fuel (eBC_{bb})

[2]The lower factor is needed for Ispra to keep mass balance ≤100%.

and fossil fuel/liquid fuel (eBC_{ff}) is possible using data from the multi wavelength aethalometer, currently available at >25 EMEP/ACTRIS sites across Europe (Yttri et al. 2014, Platt et al. 2020a,b, Platt 2021). An obvious next step is to implement such analysis as part of regular monitoring, making it possible to validate not only model performance, but also the effort made in reducing carbonaceous aerosol from fossil fuel and biomass burning sources. Although not directly comparable to the multi-year plots presented in Fig. 4.14, results from the EIMPs Winter 2017/2018 nicely illustrates the split between eBC_{bb} and eBC_{ff} for winter 2017/2018 for the Italian site Ispra, (IT04), the Norwegian site Birkenes (NO02), the Polish site Diabla Gora (PL05) and the Slovenian site Iskrba (SI08). The apportionment of eBC can also be used to infer the corresponding fractions of OM.

4.8.5 Trends in EC and OC, conclusions

For EC and OC we have calculated observed and modelled trends for 15 sites across Europe for the period 2010–2019. It should be noted that this 10-year period is rather short for the calculation of robust trends (and we show that slightly different time-windows produce different statistics), and typically only a limited number of sites showed trends that were statistically significant for specific seasons, even for a specific time-window. However, some features of the trend analysis seem rather consistent, and we summarise the main points here.

A reduction (of ca. 4.5 %/yr) in observed EC was found across 15 sites across Europe for the period 2010–2019. The reduction in levoglucosan at the site Birkenes in southern Norway (which is significantly impacted by long-range transport of pollution from continental Europe) was found to be over 5% also (though this number was very sensitive to the time-window), which suggests that emissions from residential wood combustion were reduced significantly over this period; this is also consistent with reported changes in the GNFR C emissions from some countries at least. However, observed EC reduction levels were rather similar in all seasons, which suggests that emissions abatement of EC has been successful across a range of emission sources.

In the winter season (DJF), reductions in observed EC and OC were very similar, with -4.3 %/yr and -4.2 %/yr respectively. Given that the winter OC concentrations are mainly determined by primary emissions and with minimal SOA contributions, this consistency of EC and OC reductions is also consistent with reductions in wintertime anthropogenic sources. Trends in observed OC in other seasons were however very mixed, with some stations showing increases, and others decreases, and with little statistical significance. This variability in station-to-station OC trends in other seasons reflects increasing contributions from SOA formation, which are sensitive to meteorological factors and biogenic emissions.

The modelled trends in EC (reduction of ca. 4 %/yr) were rather similar to the observed trends, also across all seasons, and the station-mean EC concentrations themselves were well reproduced by the model across the 10 year period. For OC, the model substantially underpredicts the yearly concentrations over the whole period, and also underpredicts the trends.

The underprediction of OC may partly be due to general difficulties with modelling SOA formation, but a major problem is the omission of condensable organics in the reported $PM_{2.5}$ emissions from many countries (Ch 4.2.1). Although emissions estimates which include condensables are available (the so-called REF2 or REF2.1, Ch 3.3) and were used in the status and source-receptor calculations of this report, these emissions only exist for 2015; no time-series of REF2-type emissions yet exists. The lack of significance of the calculated OC trends may also be attributed to some extent to these problems with condensables. When some countries include, and some exclude, condensables, changes in modelled OC concentrations will be very sensitive to changes in the source areas for the primary OC emissions entering the model. Although modelling of EC is also impacted by the problems with condensables (due to the use of OC/EC ratios when interpreting $PM_{2.5}$ emission speciation, see Ch 4.2.1), the much better agreement found for wintertime EC levels than for OC probably reflects the fact that EC has a wider variety of emission sources in that season (e.g. vehicles) than OC, which is much more dominated by residential wood-burning.

The EC fraction of $PM_{2.5}$ decreased at all sites (average of -2.4±1.1 %/yr), and at a level equal to, or higher than, the SO_4^{2-} fraction. The change in OC fraction was more scattered with a substantial and consistent 4.5 %/yr increase at the northernmost sites, whereas there was no increase or decrease (0.2±2.8 %/yr) when considering all sites. The influence of OC from natural sources likely has a profound impact on the general lack of decrease observed for the OC fraction of $PM_{2.5}$. These observations points to a continuous change in the aerosol chemical composition and in the relative source composition across Europe. It is clear that organic aerosol comprises a major fraction of $PM_{2.5}$, but major efforts are needed to separate and understand its natural and anthropogenic components, in order to get a quantitative overview of the abatable fractions.

4.9 Trends in PM_{10} and $PM_{2.5}$

Figure 4.15 and Tables 4.17 - 4.18 present annual and seasonal observed and modelled trends in PM_{10} and $PM_{2.5}$ for the period of 2000 to 2019.

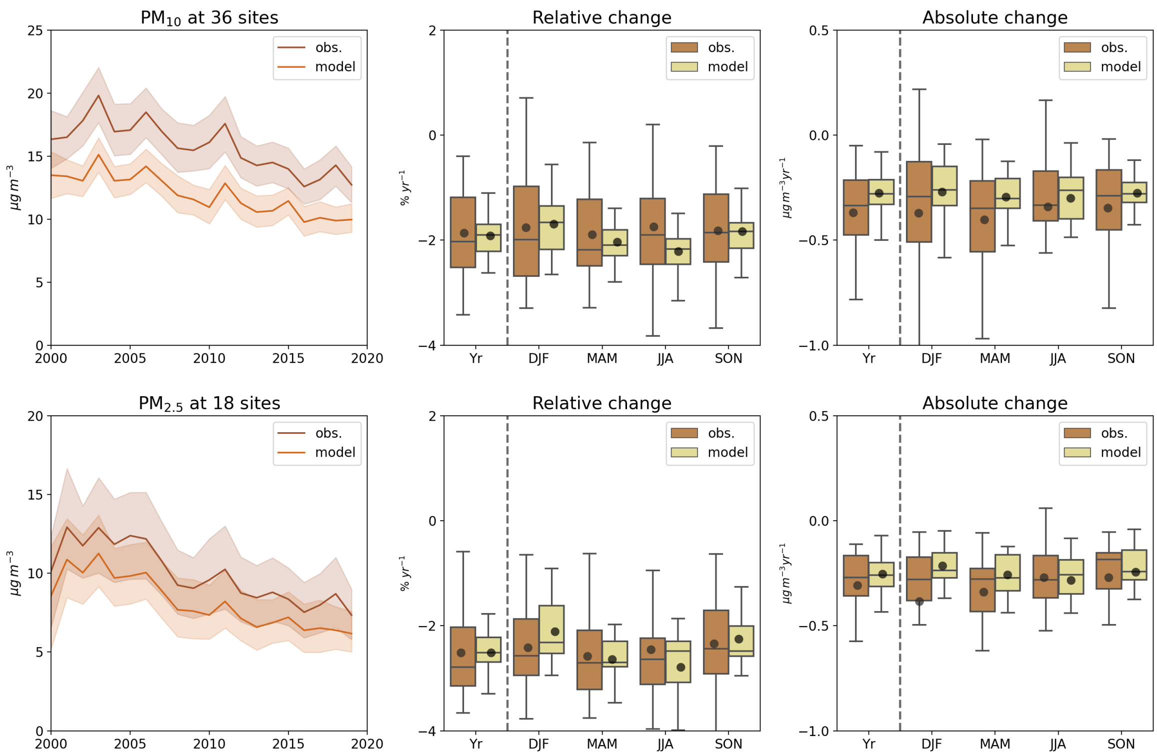

Figure 4.15: As Fig. 4.1, but for PM_{10} (top) and $PM_{2.5}$ (bottom).

Table 4.17: As Tab. 4.1, but for PM_{10}.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3}/yr) obs.	conf.interval	mod.	conf.interval	Relative change (%/yr) obs.	conf.interval	mod.	conf.interval
2000-2019	all	37	29	36	-0.36	(-0.43, -0.29)	-0.29	(-0.32, -0.25)	-1.83	(-2.09, -1.57)	-1.95	(-2.11, -1.79)
	winter	34	18	20	-0.36	(-0.47, -0.25)	-0.26	(-0.31, -0.21)	-1.73	(-2.07, -1.4)	-1.64	(-1.83, -1.45)
	spring	34	24	32	-0.39	(-0.47, -0.31)	-0.30	(-0.35, -0.25)	-1.84	(-2.11, -1.56)	-2.10	(-2.29, -1.9)
	summer	36	27	31	-0.34	(-0.42, -0.25)	-0.32	(-0.37, -0.26)	-1.72	(-2.09, -1.35)	-2.25	(-2.47, -2.03)
	autumn	35	22	29	-0.34	(-0.42, -0.26)	-0.30	(-0.34, -0.26)	-1.81	(-2.1, -1.51)	-1.91	(-2.09, -1.74)
2005-2019	all	54	29	38	-0.33	(-0.41, -0.25)	-0.23	(-0.27, -0.19)	-1.82	(-2.23, -1.41)	-1.79	(-2.07, -1.51)
2010-2019	all	56	17	23	-0.32	(-0.42, -0.21)	-0.16	(-0.21, -0.11)	-1.84	(-2.45, -1.23)	-1.38	(-1.81, -0.95)
2000-2010	all	36	14	24	-0.46	(-0.56, -0.36)	-0.35	(-0.46, -0.24)	-2.36	(-2.77, -1.95)	-2.40	(-2.97, -1.83)

Table 4.18: As Tab. 4.1, but for $PM_{2.5}$.

Period	Seasons	Number of sites Tot.	sign. obs.	sign. mod.	Absolute change (μg m^{-3}/yr) obs.	conf.interval	mod.	conf.interval	Relative change (%/yr) obs.	conf.interval	mod.	conf.interval
2000-2019	all	19	16	19	-0.29	(-0.39, -0.2)	-0.26	(-0.31, -0.22)	-2.42	(-2.84, -2.0)	-2.52	(-2.71, -2.32)
	winter	18	12	12	-0.36	(-0.54, -0.18)	-0.21	(-0.25, -0.17)	-2.29	(-2.74, -1.85)	-2.08	(-2.35, -1.82)
	spring	19	14	19	-0.32	(-0.41, -0.24)	-0.27	(-0.31, -0.22)	-2.47	(-2.91, -2.03)	-2.69	(-2.88, -2.51)
	summer	18	14	17	-0.26	(-0.33, -0.19)	-0.30	(-0.36, -0.23)	-2.36	(-2.91, -1.82)	-2.81	(-3.16, -2.47)
	autumn	18	12	16	-0.26	(-0.36, -0.15)	-0.26	(-0.33, -0.18)	-2.22	(-2.71, -1.74)	-2.29	(-2.5, -2.07)
2005-2019	all	36	23	28	-0.33	(-0.42, -0.23)	-0.21	(-0.25, -0.17)	-2.66	(-3.16, -2.16)	-2.28	(-2.55, -2.01)
2010-2019	all	43	20	19	-0.34	(-0.43, -0.25)	-0.18	(-0.23, -0.13)	-3.14	(-3.7, -2.57)	-2.21	(-2.67, -1.74)
2000-2010	all	20	7	12	-0.36	(-0.5, -0.21)	-0.36	(-0.46, -0.26)	-2.65	(-3.56, -1.73)	-2.93	(-3.58, -2.27)

In the trend analysis in the period 2000-2019, 37 and 19 sites with satisfactory data coverage have been included for PM_{10} and $PM_{2.5}$, respectively. The annual series of PM_{10} and $PM_{2.5}$ (Figure 4.15, left panels) show clear concentration decreases from 2000 to 2019, both from observations and model simulations. In general, the model underestimates the concentrations, but reproduces quite well observed year-to-year changes in PM_{10} and $PM_{2.5}$, including enhanced PM levels due to meteorological conditions e.g. in 2003 (dry hot summer, EMEP CCC & MSC-W 2005) and 2011 (dry year in Western/Central/Southern Europe, EMEP CCC & MSC-W 2013). It should be noted that the emission data used for the model runs does not include condensable organics consistently across countries (see Ch 4.2.1). Thus, part of the underestimation of PM can be related to the lack of condensable organics in the emissions.

Statistically significant PM_{10} and $PM_{2.5}$ trends have been identified for the majority of the sites. For PM_{10}, the observed and simulated with the model relative reductions are on average 1.8 %/yr and 1.9 %/yr respectively, whilst reductions are on average 2.4 %/yr and 2.5 %/yr for $PM_{2.5}$. The smaller reductions in PM_{10} compared to $PM_{2.5}$ can be explained by the larger natural contribution of sea salt and dust in the coarse fraction.

Figure 4.15 reveals a considerably larger variation of observed trends between the sites in comparison to modelled trends, still with modelled median (and mean) trends lying within 25-75% inter-quartile range (IQR) of the observed ones. A larger spatial variability of observed trends with respect to model simulated ones can also be seen on the maps of relative trends in Fig. 4.15.

PM is a complex pollutant, consisting of aerosol species both emitted directly and formed from gaseous precursors. Therefore, changes both in primary PM emissions, as well as SO_x,

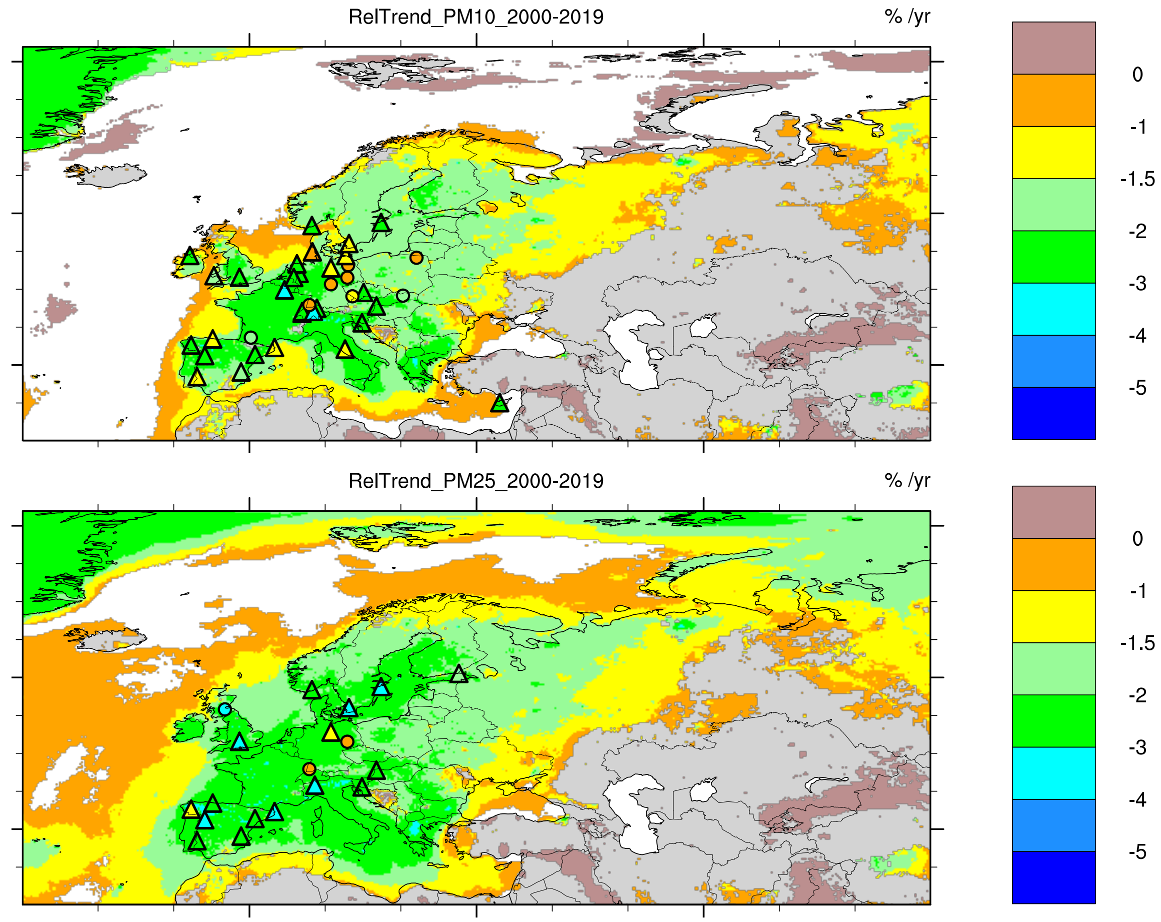

Figure 4.16: As fig. 4.2, but for PM_{10} (top) and $PM_{2.5}$ (bottom).

NO_2, NH_3 and NMVOC emissions cause changes in PM concentrations.

During the 2000–2019 period, SO_4^{2-}, NO_2 and NH_4^+ decreased on average by 3.2, 2.0 and 2.6 %/yr respectively, derived from the long term EMEP observations and by 3.8, 2.5 and 2.6 %/yr from the model simulations. Those reductions in SIA concentrations contributed substantially to the PM_{10} and $PM_{2.5}$ decreases. In the western parts of the EMEP domain (EU, UK & EFTA), where the considered sites are located, the emissions of primary PM_{10} and $PM_{2.5}$ were reduced by 32 and 35 %, respectively, from 2000 to 2019. Carbonaceous aerosols, elemental carbon and primary organic aerosol, comprise a major part of PM emissions, especially of primary $PM_{2.5}$.

Due to the lack of consistent observational data for carbonaceous aerosols in the 2000s, the trends of elemental (EC) and organic (OC) carbon (in the $PM_{2.5}$ size fraction only) have only been analysed for a 2010–2019 period (see discussion in Ch 4.8). During this 10-year period, a substantial decrease (around 4.5 %/yr) was observed for EC, while the average decrease for OC was smaller (2.4 %/yr). A similar to EC decrease was found for wintertime OC concentrations, whereas the trends in summertime OC were much less clear. Thus, decreases of both secondary inorganic aerosols as well as primary (probably due to larger contribution of biogenic SOA) and secondary organic compounds have contributed to the decreases in PM concentrations. Some examples of the changes in the chemical composition of $PM_{2.5}$ from 2000(2002) to 2019 are given in Figure 4.14.

Summarizing trend results for the 2000–2019 period, the average PM_{10} and $PM_{2.5}$ trends,

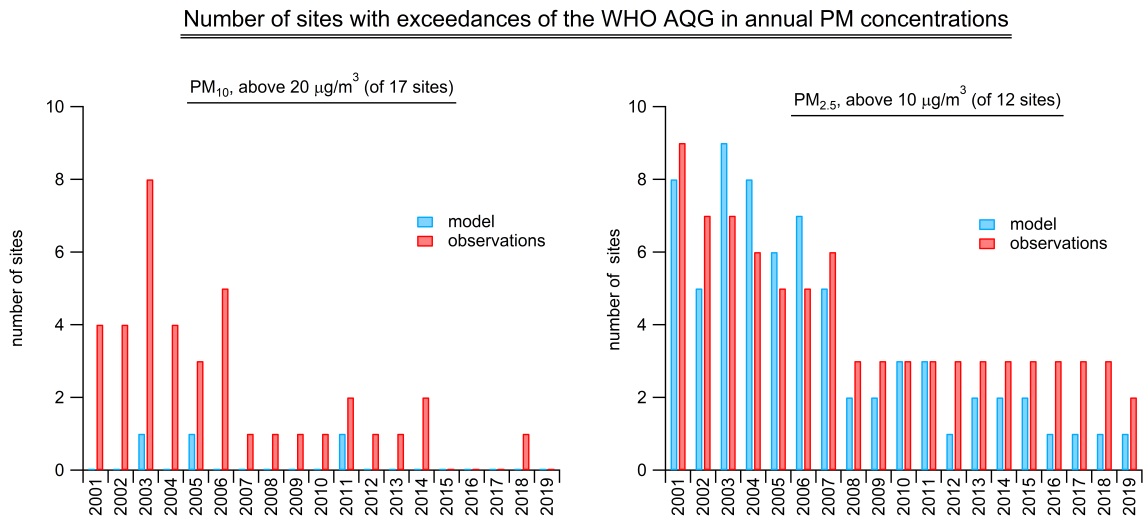

Figure 4.17: Number of EMEP sites with exceedances of WHO AQG recommended levels for annual mean PM_{10} and $PM_{2.5}$ from 2001 to 2019, observed (red) and modelled with the EMEP MSC-W model (blue).

derived from observational data and model simulations, are decreasing. During this 20-year period, PM_{10} concentrations decreased on average 35% in observations (37% in model simulations) at the considered sites. On average, $PM_{2.5}$ decreased by 46% in observations (48% in model calculations). We find good correspondence between observed and model simulated trends in PM concentrations.

Figure 4.17 presents the changes in the number of sites at which the annual mean PM_{10} and $PM_{2.5}$ exceeded WHO AQG recommended levels (20 and 10 μg m^{-3} respectively) for the period 2001 to 2019. Both results from observations and model calculations are shown. Same as for PM trend analysis, only the sites with observations satisfying a criteria of 75% data coverage for each year have been included. The additional requirement here was that the observations at each site should be available for all analysed years (while for the PM trend analysis, the 75% coverage requirement was applied, resulting in a minimum of 14 years for the 2000-2019 period, see Ch 4.4). For the analysis of the number of sites with PM exceedances, it is essential that the number of sites included are the same for all the years. As much fewer sites satisfied the data time coverage criteria for 2000, we excluded this year and analyzed the period 2001–2019.

Figure 4.17 indicates that the number of sites with exceedances of WHO AQG decrease for both PM_{10} and $PM_{2.5}$ in the observations, although these results cannot be considered very robust as the number of sites with exceedances is small. The model results also show a decrease in the number of sites with exceedances for $PM_{2.5}$, whereas the model in general fails to reproduce the exceedances for PM_{10}. One reason for that is that the model underestimation of observed PM_{10} is typically larger than $PM_{2.5}$. Besides, the geographical location of the sites with observations available for this study was rather different, i.e. mostly Central European sites were included for PM_{10}, while $PM_{2.5}$ sites were dominated by Spanish ones and also included the very polluted site Ispra in the Po Valley. As discussed above, the model manages to reproduce PM exceedances better in Southern Europe, whereas it tends to underestimate those in Central Europe.

4.10 Trends in O_3

Trend studies of surface ozone require a somewhat different approach than other species since ambient ozone levels are the result of a substantial baseline level with episodes on top. Whereas NOx often leads to ozone formation in rural areas in the summer season, it can cause depletion of ozone by titration in and downwind of urban areas, especially in winter. Thus, the effect of man-made emissions of ozone precursors such as NOx (in combination with VOCs) is to change the distribution of hourly and daily ozone concentrations during a year with high ozone levels in the summer half year and low ozone levels in the winter half year. Furthermore, the extent of these perturbations is significantly determined by the weather conditions and thereby by the ongoing climate change. Harmful levels of surface ozone are closely linked to high-pressure situations with elevated temperatures and strong solar radiation.

Thus, the selection of ozone metrics is decisive for the estimated trends (e.g. Lefohn et al. 2018). The annual mean concentration used for evaluating other species is of little interest when studying ozone. A common procedure is to look at the trend in the probability distribution of ozone, e.g. by calculating trends for various percentiles of the distribution (e.g. Simpson et al. 2014).

As explained above, the trends in six percentiles (10, 50, 75, 95, 98 and 99) of the daily maximum O_3 values were calculated for stations with at least 330 valid daily data each year. This corresponds to 90% data capture in the individual years. The 10th percentile corresponds to the 37th lowest daily maximum value while the 99th percentile corresponds to the 4th highest daily maximum.

Fig. 4.18 shows the calculated Sen's slopes for these six percentiles for the period 2000–2019 for EMEP sites north and south of 49°N based on observed and modelled data. Both significant and non-significant slopes were included, but stations above 1200 m altitude were not included in the trend statistics. The reason for differing the altitude criteria for trend calculations vs that for evaluating the 2019 levels as discussed in Ch 2.4.1 (1200 m vs 500 m) was that the latter is more focused on individual daily data whereas the trends are based on aggregated statistics (annual data).

For both the observed and modelled data the trends show an increase in the 10th percentile and with a gradually stronger decrease in the higher percentiles. This is as expected when the emission of precursors (NOx) is reduced with time. The increase in the 10th percentile is explained by reduced titration by NOx while the the decreasing trend in the highest percentiles is explained by reduced photochemical formation of ozone in summer. The net result of these trends is a narrowing of the distribution of O_3 concentrations.

Fig. 4.18 shows the trends in annual percentiles for sites north and south of 49°N. In general the agreement is rather good, with the model agreeing very well with the observations for the high percentiles for stations N of 49°, though overestimating somewhat the decrease of the high percentiles (95–99) for stations south of 49°N. This is an important finding since these percentiles are the main indicators for surface ozone pollution events. Fig. 4.18 furthermore shows that the spread in the observed data is significantly larger than the spread in modelled data which is as expected. A grid model will inevitably reduce local geographical differences and produce smoothed concentrations fields.

For the 10th percentile, the model overestimates the increase both north and south of 49° N. It is not obvious what this overestimation is due to. It could reflect that NOx in winter is not reduced as much as the emissions and the model assume, or it could e.g. reflect deficiencies in the model description of atmospheric vertical stability and exchange of pol-

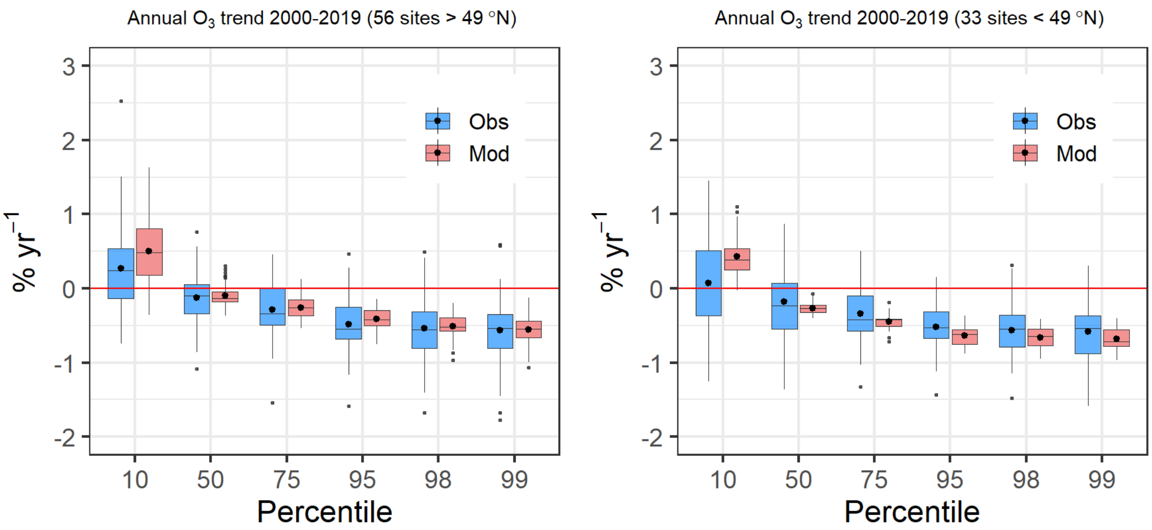

Figure 4.18: Boxplot of trends in annual percentiles of daily max O_3 from 2000–2019 for EMEP observations and model calculations for stations north (left) and south (right) of 49°N. The boxes mark the 25 and the 75 percentiles with the median given as a thin line inside. The upper whisker extends from the hinge to the highest value that is within 1.5*IQR of the hinge, where IQR is the inter-quartile range, or distance between the first and third quartiles. The lower whisker extends from the hinge to the lowest value within 1.5*IQR of the hinge. Data beyond the end of the whiskers are outliers and plotted as points. The mean values are shown as black circles. Both significant and non-significant trend values were included. Only sites below 1200 m asl and with at least 15 years of data are included.

lutants in winter. A possible underprediction of European NOx emissions was suggested as a likely cause of model underprediction of peak ozone and over prediction of low ozone by Oikonomakis et al. (2018).

The relative trends shown in Fig. 4.18 are based on the Sen's slopes and use the value of these trend lines the first year (i.e. in 2000) as the reference for the modelled and observed data separately. The results given in Fig. 4.18 thus show the estimated relative changes without any reference to the absolute levels of the modelled and observed data.

The trends in the absolute levels are given in Figures 4.19 and 4.20. Annual O_3 percentile values for the observed and modelled data during 2000–2019 are shown in Figures 4.19 and 4.20 for stations north and south of 49°N, respectively. The solid lines mark the mean of all stations while the shaded areas mark the 25th and 75th percentile of these station-based values. All stations below 1200 m asl and with at least 15 years of data were included.

These results show that the modelled 10th and 50th percentiles are higher than the observations whereas the observed high percentiles (95–99) are higher than modelled. The bias in the high percentiles are particularly strong for stations south of 49°N. For the 75th percentile, the absolute levels of the modelled and observed data agree very well.

The interannual variation in the higher percentiles, i.e. the change in levels from year to year, is however very well reproduced by the model. Peak years as 2003 and 2006 in both regions as well as 2015 in the south and 2018 and 2019 in the north is reproduced by the model but with a substantial offset. This implies that the episodes leading to the peak values are captured by the model but that the ozone levels during the episodes are underestimated.

Trends in ozone metrics linked to harmful effects on vegetation (AOT40) and on human health (SOMO35) are shown in Figures 4.21 - 4.23 for sites north and south of 49°N, respectively. The absolute levels of these metrics are very sensitive to the baseline O_3 concentration

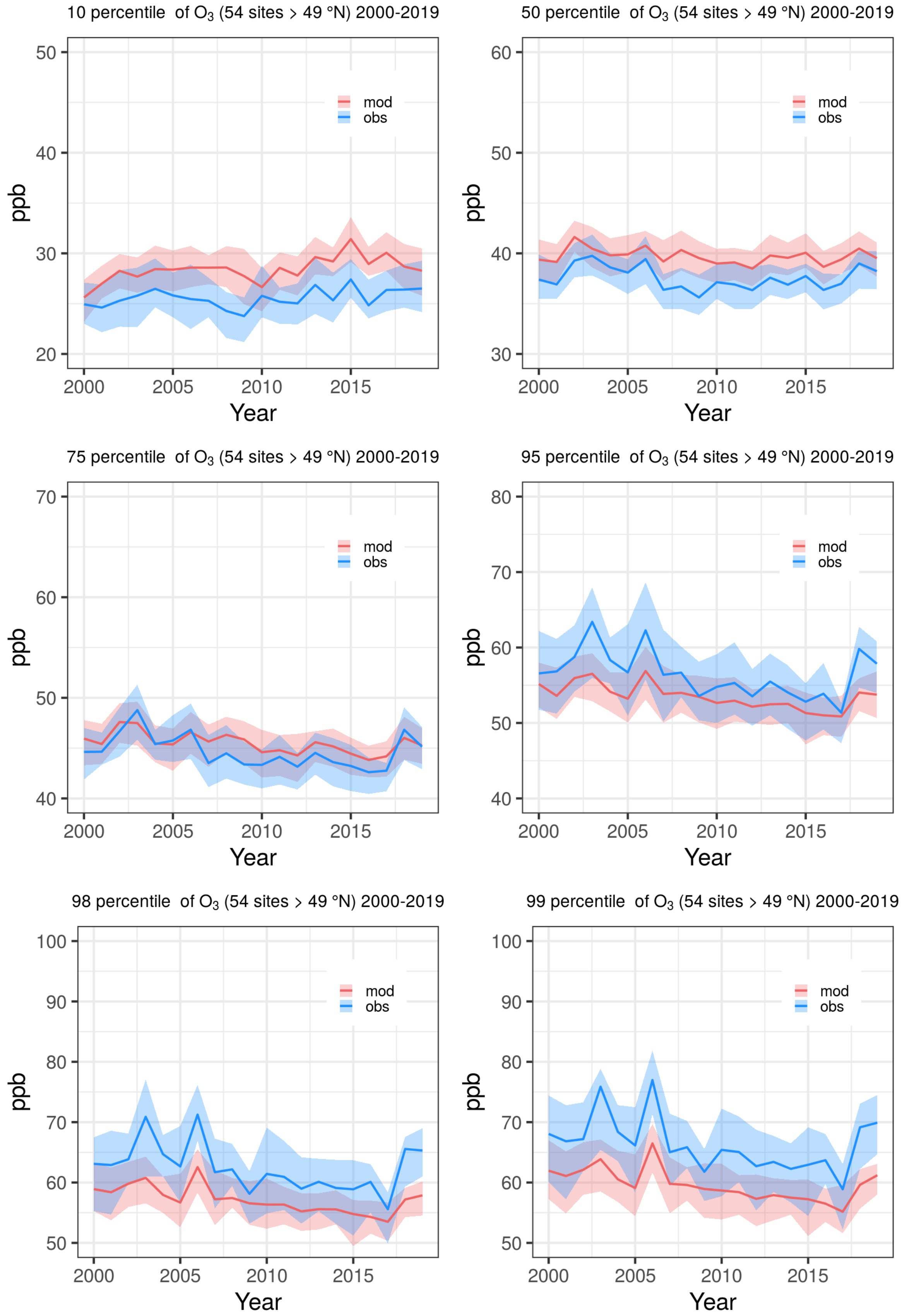

Figure 4.19: Trends in annual percentiles of daily max O_3 from 2000–2019 for EMEP observations and model calculations for sites north of 49°N: The solid line indicates the mean, and the shaded area marks the 25th and 75th percentile. Only sites below 1200 m asl and with at least 15 years of data are included.

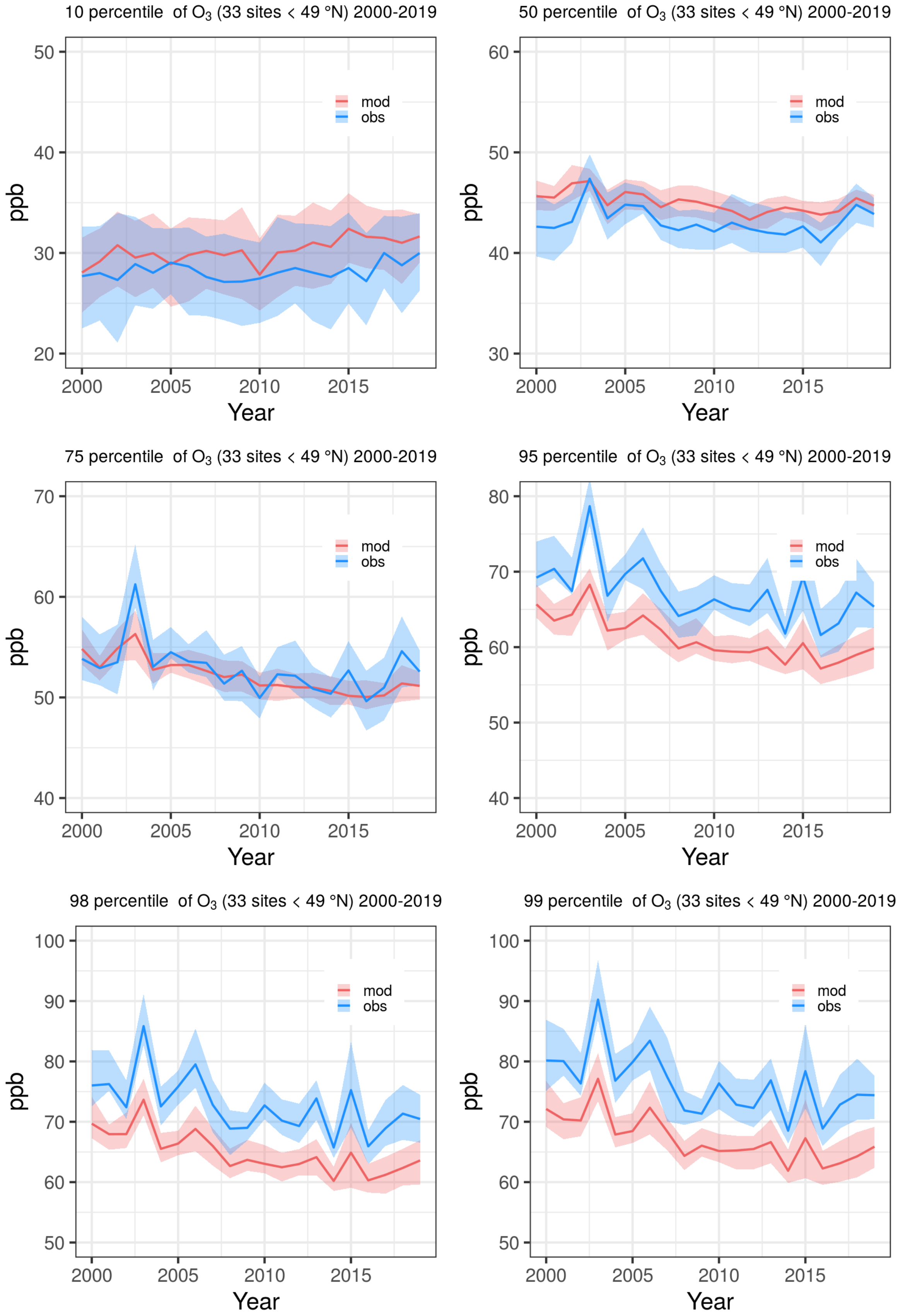

Figure 4.20: As Fig. 4.19, but for sites south of of 49°N.

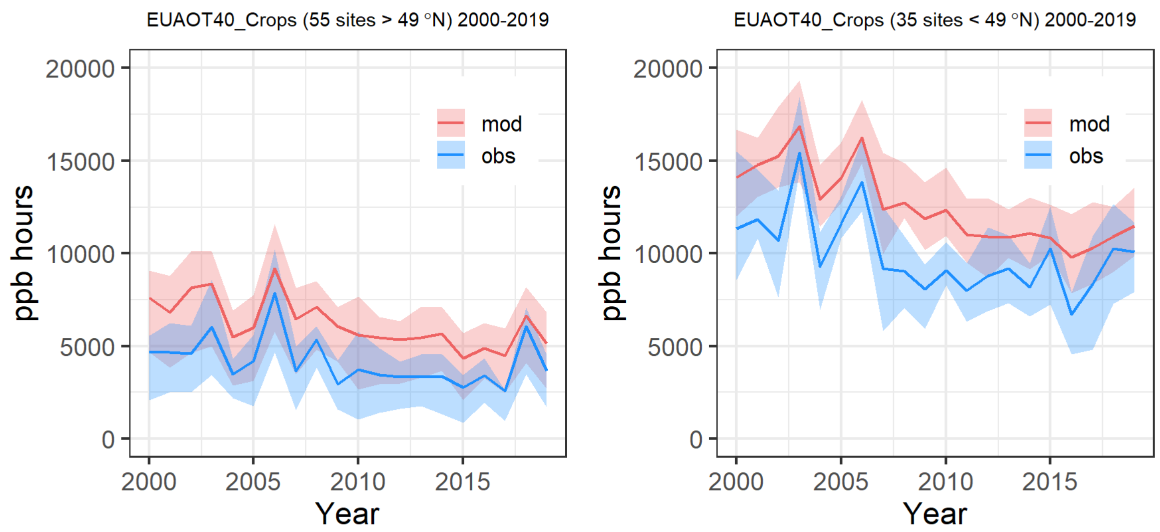

Figure 4.21: As Fig. 4.19, but for trends in 3-months AOT40 (May-July) for crops from 2000–2019 for EMEP observations and model calculations for sites north (left) and south (right) of 49°N.

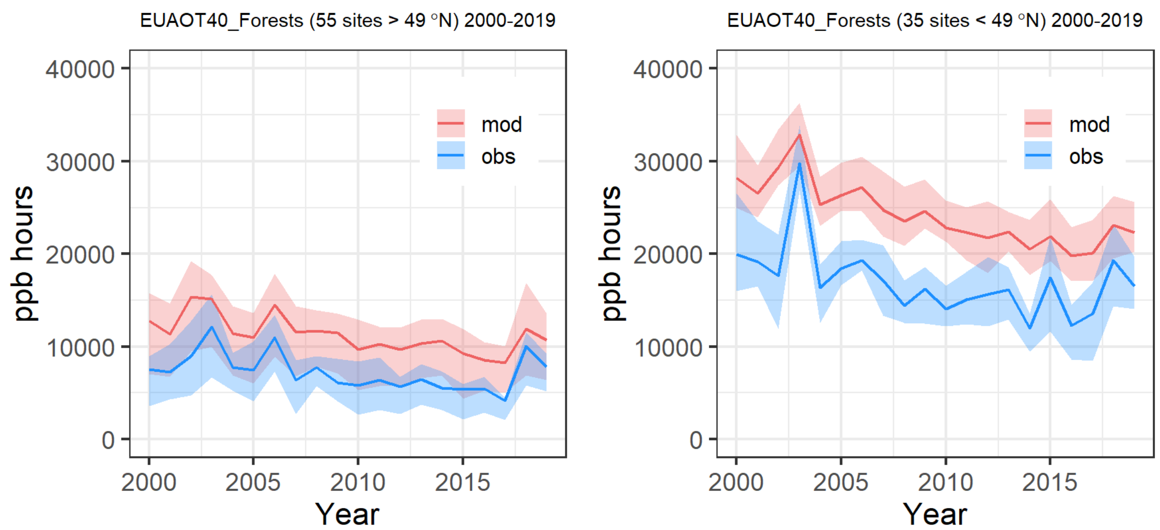

Figure 4.22: As Fig. 4.19, but for trends in 6-months AOT40 (Apr-Sep) for forests from 2000–2019 for EMEP observations and model calculations for sites north (left) and south (right).

level (Sofiev and Tuovinen 2001) which is close to the 35–40 ppb range. Thus, comparisons between modelled and observed data can be difficult (though as shown in SI Fig.S6, Etzold et al. 2020, the EMEP model can often reproduce AOT40 quite well).

Figures 4.21 and 4.22 show a clear underestimation by the model compared to the observed data, in particular for the southern sites. Both the modelled and observed data do however indicate a marked decreasing trend during 2000–2019. For SOMO35 (Fig.4.23), the model calculations agree very well with the observed data, both with respect to the absolute levels and the trends. For the southern sites, a slight underestimation is seen in the peak years (2003 and 2018) though.

Summary statistics for the observed and modelled trends during 2000–2019 for the 75th and 99th percentiles as well as SOMO35, AOT40 for crops and AOT40 for forests are given

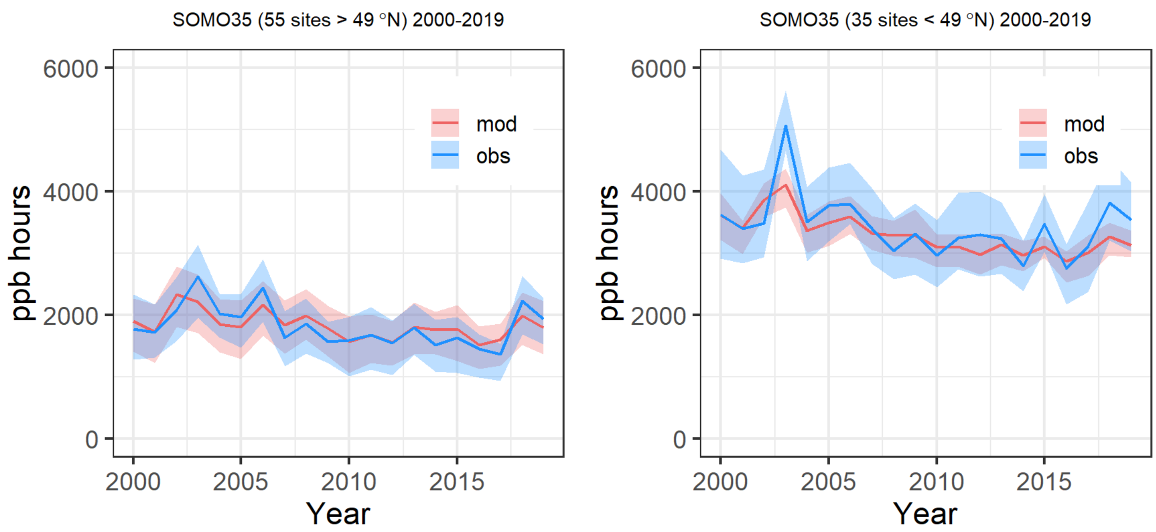

Figure 4.23: As Fig. 4.19, but for trends in SOMO35 from 2000-2019 for EMEP observations and model calculations for sites north (left) and south (right) of 49°N.

in Table 4.19 for sites north and south of 49°N. These data show the mean trend (as absolute values and relative to 2000 in percent) as calculated by the Theil-Sen's slope. The slopes for the percentiles were calculated by the pyaerocom tool as explained above while the slopes for SOMO35 and AOT40 were calculated by the R libraries 'Kendall' (McLeod 2011) and 'zyp' (Bronaugh and Werner 2019).

In addition to the mean trends, the confidence intervals for these mean values are also given. The confidence intervals were computed by standard bootstrapping techniques (Davison and Hinkley 1997) using the R library 'boot' (basic bootstrap method with 1000 resamples). Various bootstrap method were tested out and compared to direct calculations of the confidence intervals based on the sample mean and sample standard deviation. These comparisons showed that the various methods produced very similar estimates of the confidence intervals for the mean values and thus we conclude that the confidence intervals for the means

Table 4.19: As Tab. 4.1, but for O_3 metrics based on stations north and south of 49°N. Results are given for the 75th and 99th percentile of daily maximum ozone, as well as for SOMO35 and AOT40 for crops (AOT40c) forests (AOT40f). Note that here we use the EU definition of AOT40 (c.f. Ch 1.2).

Area	Parameter	Number of sites			Absolute change (ppb)				Relative change (%/yr)			
		Tot.	sign. obs	sign. mod	obs.	conf.interval	mod.	conf.interval	obs.	conf.interval	mod.	conf.interval
N of 49N	75p	52	19	30	-0.15	(-0.19, -0.10)	-0.13	(-0.14, -0.10)	-0.31	(-0.40, -0.21)	-0.26	(-0.30, -0.22)
N of 49N	99p	52	13	39	-0.41	(-0.48, -0.33)	-0.34	(-0.37, -0.30)	-0.58	(-0.68, -0.47)	-0.54	(-0.59, -0.49)
N of 49N	SOMO35	55	9	33	-18.29	(-26.3, -11.2)	-17.92	(-21.1, -14.7)	-0.54	(-1.41, 0.021)	-0.85	(-1.02, -0.70)
N of 49N	AOT40c	55	12	42	-71.63	(-91.2, -52.4)	-153.35	(-175., -132.)	-1.35	(-2.03, -0.73)	-2.10	(-2.32, -1.88)
N of 49N	AOT40f	55	9	43	-121.11	(-156., -85.5)	-220.10	(-250., -191.)	-1.10	(-1.86, -0.47)	-1.75	(-1.92, -1.56)
S of 49N	75p	40	16	38	-0.20	(-0.27, -0.13)	-0.26	(-0.27, -0.23)	-0.35	(-0.46, -0.21)	-0.46	(-0.49, -0.43)
S of 49N	99p	40	18	37	-0.48	(-0.59, -0.36)	-0.51	(-0.54, -0.46)	-0.57	(-0.71, -0.43)	-0.70	(-0.74, -0.65)
S of 49N	SOMO35	35	14	31	-36.74	(-54.9, -18.6)	-40.59	(-45.3, -36.2)	-0.77	(-1.27, -0.28)	-1.12	(-1.23, -1.01)
S of 49N	AOT40c	35	13	33	-190.26	(-247., -128.)	-286.65	(-313., -260.)	-1.49	(-1.97, -1.02)	-1.98	(-2.17, -1.80)
S of 49N	AOT40f	35	16	31	-312.64	(-422., -196.)	-480.46	(-537., -425.)	-1.36	(-1.87, -0.85)	-1.74	(-1.94, -1.55)

are fairly robust. These confidence intervals could be used to judge if the mean observed trends differ from the mean modelled trends.

First of all, it is interesting to note that downward trends are found for all the five metrics both north and south of 49°N and for both observed and modelled data. This is a strong signal that there has been a real reduction in these ozone metrics during the 2000-2019 period. Furthermore, for sites north of 49°N, the results indicate that there are no significant difference between the observed and modelled trends in the 75th and 99th percentiles. For sites south of 49°N the mean absolute trends agree very well for the observed and modelled data, but the relative changes in the observations are clearly lower than the modelled changes (reflecting that the model underpredicts the absolute level of the high percentiles). It could be noted that the number of statistically significant trends are considerably lower for the observed data compared to the modelled ones.

For SOMO35 and AOT40 the number of sites with significant trends in the observations are rather low and substantially lower than the number of statistically significant modelled trends. For all three metrics the model calculates stronger mean reductions than observed. For SOMO35 north of 49 °N, the mean observed and modelled absolute trends are very close, but the modelled relative trend is somewhat larger than observed.

4.11 Exceedances of critical loads of acidification and eutrophication in 2000 to 2019.

The exceedances of European critical loads (CLs) are computed for the total nitrogen (N) and sulfur (S) depositions modelled on the 0.1°× 0.1° longitude-latitude grid (approx. 11 x 5.5 km^2 at 60°N). Exceedances are calculated for the European critical loads documented in Hettelingh et al. (2017), while a description of the methods is given in De Vries et al. (2015). The critical loads data for eutrophication by N (CL eut N) and for acidification by N and S (CL acid) are also used by the EMEP Centre CIAM (located at IIASA) in their integrated assessment modelling. The exceedance in a grid cell is the so-called 'average accumulated exceedance' (AAE), which is calculated as the area-weighted average of the exceedances of the critical loads of all ecosystems in this grid cell. The units for critical loads and their exceedances are equivalents (eq; same as *moles of charge*, molc) per area and time, making S and N depositions comparable on their impacts, which is important for acidity CLs.

Critical loads are available for about 4 million ecosystems in Europe covering an area of about 3 million km^2 (west of 42°E). The exceedances (AAE) of those critical loads are computed on a 0.1°× 0.1° longitude-latitude grid, and maps for the deposition in the years 2000, 2005, 2010, 2015 and 2019 are shown in Figures 4.25 and 4.26. As indicated in the maps, the critical loads for eutrophication are exceeded in practically all countries in all years. The share of ecosystems where the critical load for eutrophication is exceeded decreases relatively slowly, starting at 76.4% in 2000 and ending at 65.5% in 2019. European average AAE is about 452 eq ha^{-1} yr^{-1} (2000) and 276 eq ha^{-1} yr^{-1} (2019). The highest exceedances of CLs are found in the Po Valley in Italy, the Dutch-German-Danish border areas and in north-eastern Spain. By contrast, critical loads of acidity are exceeded in a much smaller area. Hot spots of exceedances can be found in the Netherlands and its border areas to Germany and Belgium, and some smaller maxima in southern Germany and Czechia, whereas most of Europe is not exceeded (grey areas). Acidity exceedances occur on 16.2% (2000) and 5.0% (2019) of the ecosystem area and the European average AAE is about 133 eq ha^{-1} yr^{-1} (2000) and 25 eq ha^{-1} yr^{-1} (2019). Overall statistics for the share of critical load exceedance and European average of AAE are shown in Figures 4.24.

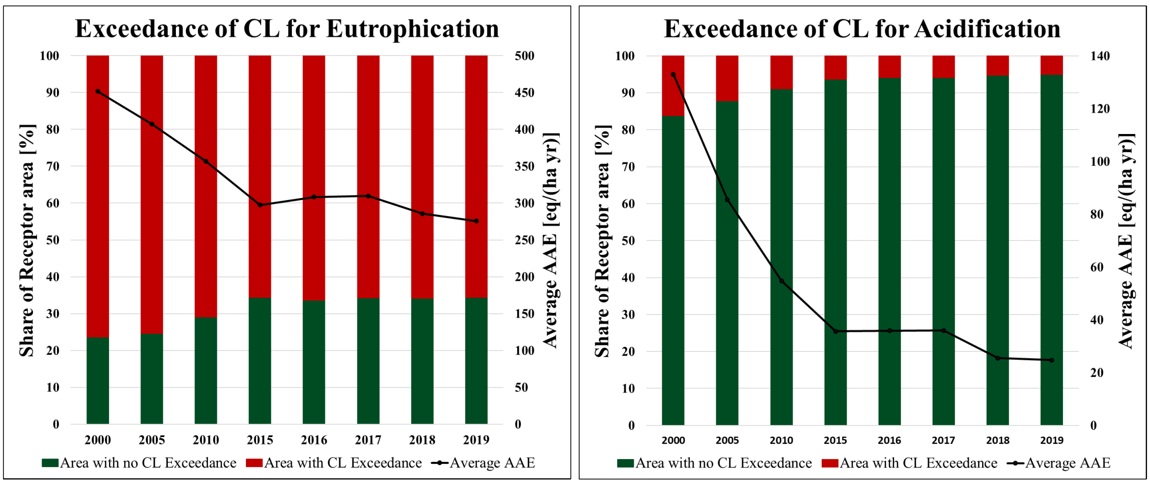

Figure 4.24: Summary for exceedance of critical load for eutrophication (left) and acidification (right).

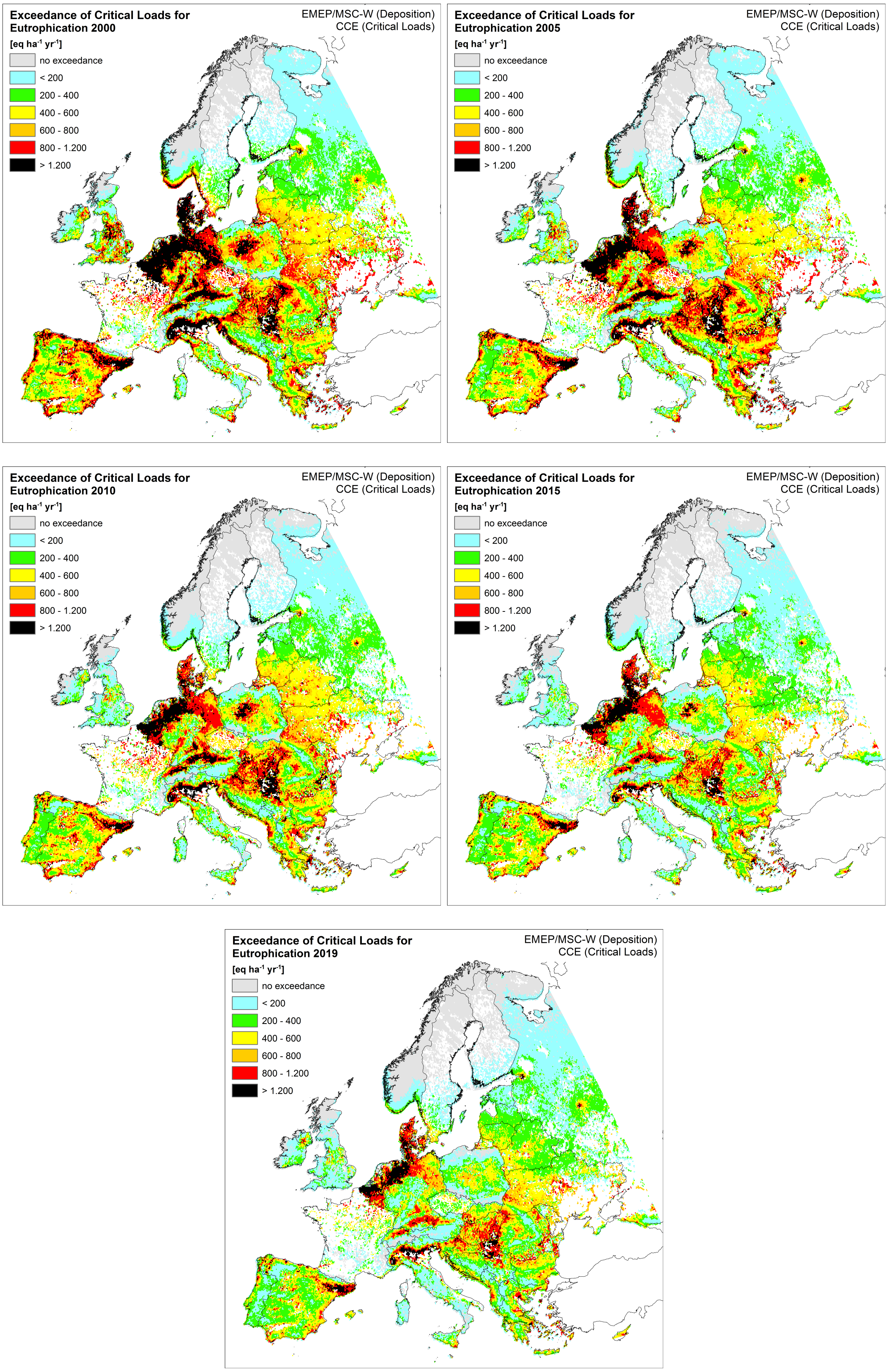

Figure 4.25: Exceedance of critical load for eutrophication for the years 2000, 2005, 2010, 2015 and 2019.

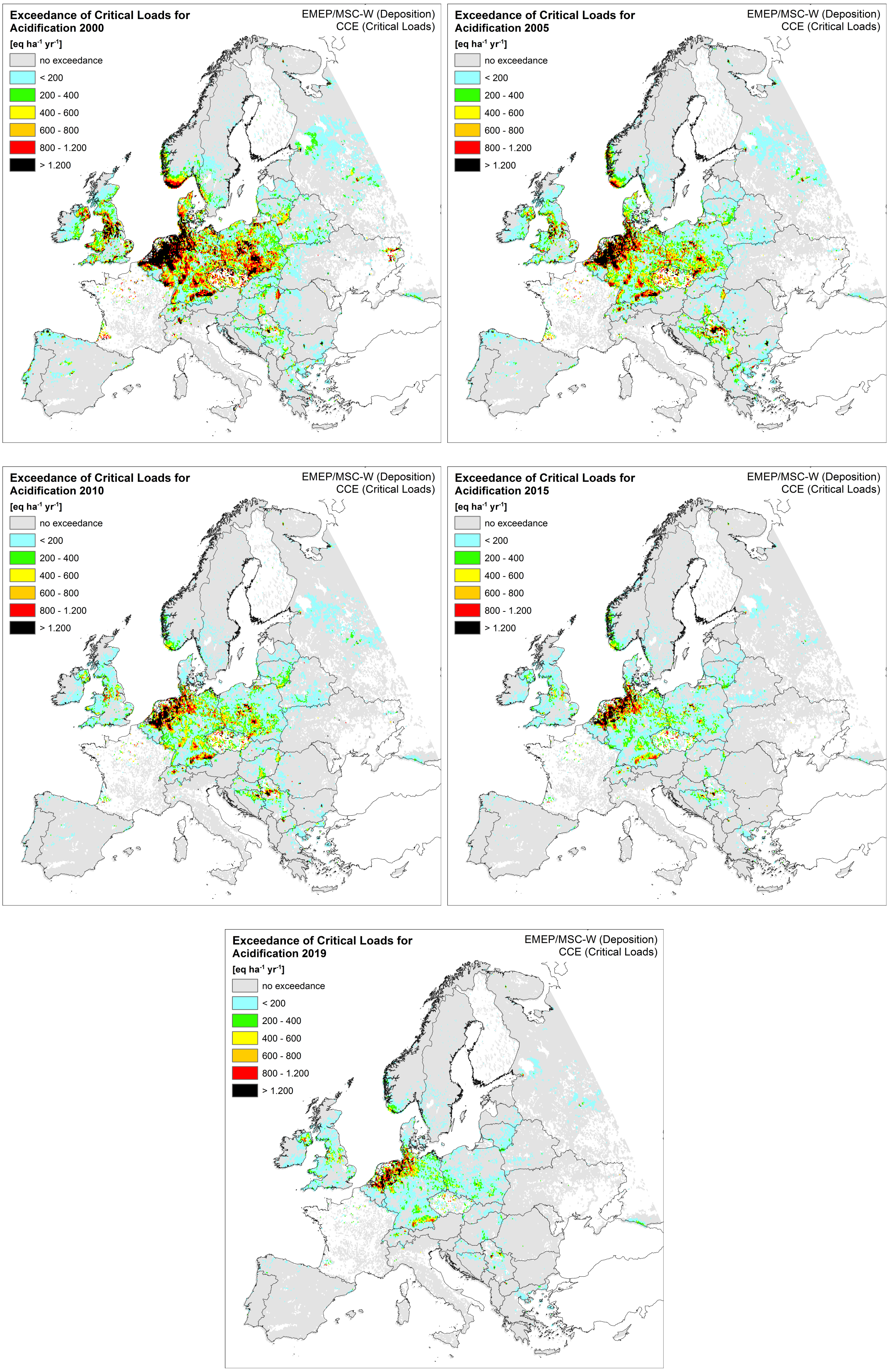

Figure 4.26: Exceedance of critical load for acidification for the years 2000, 2005, 2010, 2015 and 2019.

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Part III

Technical EMEP Developments

CHAPTER 5

Updates to the EMEP MSC-W model, 2020–2021

David Simpson, Michael Gauss, Qing Mu, Svetlana Tsyro, Alvaro Valdebenito and Peter Wind

This chapter summarises the changes made to the EMEP MSC-W model since Simpson et al. (2020b), and along with changes discussed in Simpson et al. (2013, 2015, 2016, 2017, 2019, 2020b) and Tsyro et al. (2014), updates the standard description given in Simpson et al. (2012). The model version used for reporting this year is denoted rv4.42, which has had some major updates (especially with regard to emissions) compared to the rv4.35 version reported in Simpson et al. (2020b). Table 5.2 summarises the changes made in the EMEP model since the version documented in Simpson et al. (2012), and these changes are discussed in more detail in Ch 5.1-5.5.

5.1 Overview of changes

The major changes can be summarised:

- The default emissions system in the model was changed to a 19-sector system denoted GNFR-CAMS – see Ch 5.2.1.
- Introduced new soil-NO, DMS and aircraft emissions, from CAMS-81 project (Ch 5.2).
- Modified fine/coarse split of sea-salt (Ch 5.2.5) and particulate nitrate (Ch 5.5).
- Emissions speciation. New default and country-specific emission speciations for $PM_{2.5}$ have been implemented. See Ch 5.2.6.
- New country-based monthly timefactors were produced for countries outside of Europe. See Ch 5.2.7.
- Revised methods for vertical diffusion (Kz) and Hmix (Ch 5.3).

- Upgraded Local Fractions capabilities (Ch 5.4).

- Numerous small changes to make the code more flexible and/or to fix various bugs.

In addition to these changes, articles on GenChem (EMEP's chemical pre-processing system) and the fine-scale uEMEP system have now been published (Simpson et al. 2020a, Denby et al. 2020)

5.2 Updates in Emission Systems

5.2.1 New model basis for emission sectors: GNFR_CAMS

Gridded anthropogenic emissions from CEIP were previously categorized into 11 SNAP sectors, but for many years now EMEP emission reporting has been conducted and prepared for modelling using the 13-sector GNFR system[1]. In 2020 a 19-sector emission system ('GNFR_CAMS') was implemented in the EMEP model, to take care of emissions provided by TNO as part of the Copernicus CAMS project (Granier et al. 2019, Kuenen et al. 2021). This extended emissions system enables for example four road traffic sectors, F1–F4, with e.g. F1 representing exhaust emissions from gasoline vehicles. Such emission sectors are characterised in the model by release heights, timefactors and species-splits (e.g. NOx to NO and NO_2, or NMVOC to individual VOC surrogates) for each sector, with each characteristic defined by a mapping index.

It should be noted that this 19-sector system is designed as a practical super-set of likely emission sectors present in emission files, and the user is free to use GNFR, SNAP or other inventories when running the model. The user-guide gives more details about the usage of different emission options, use of the mapping indices, and the potential to define own emission sectors. Table 5.1 summarises the new GNFR_CAMS sectors, and the mapping indices used.

5.2.2 Soil NO emissions

The EMEP model now makes uses of a new global dataset for soil NO emissions. This dataset, described in detail in Simpson and Darras (2021), provides gridded monthly data and the corresponding 3-hourly weight factors at $0.5° \times 0.5°$ degrees horizontal resolution, over the period 2000-2018. The basic methodology merges methods from Yienger and Levy (1995), with various updates to reflect recent literature (especially Steinkamp and Lawrence 2011), and some simplifications which reflect lack of availability of some key data.

[1]GNFR=Gridding nomenclature for reporting/UNECE nomenclature for reporting of emissions to air, e.g. Matthews and Wankmueller 2020

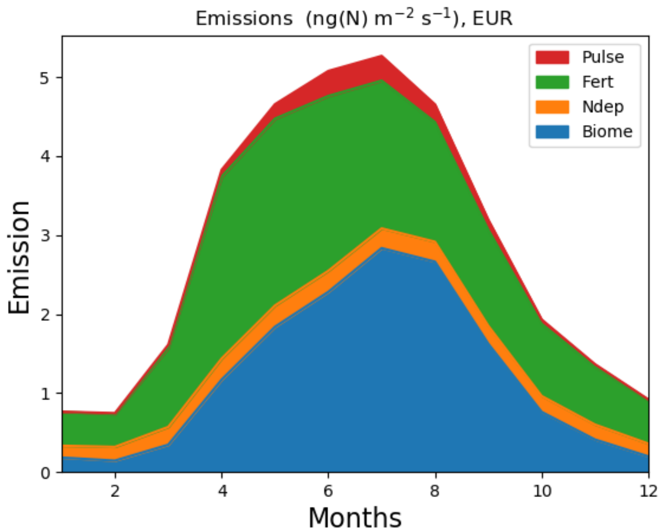

Figure 5.1: CAMS-GLOB-SOIL: monthly above canopy NO emissions (ng(N) $m^{-2}s^{-1}$) calculated for the year 2010 for Europe.

The CAMS-GLOB-SOIL v2.2 NOx inventory provides estimate of soil NO emissions from four categories:

Biome - a background emission rate for each landcover type, modified by temperature and soil moisture

Fert - emissions resulting from applied fertilizer and manure inputs to soils. (We assume that 0.7% of the N-inputs are re-emitted as NO.)

Ndep - emissions resulting from atmospheric N deposition (also 0.7%)

Pulsing - emissions resulting from rain and/or soil moisture changes after a dry period

In developing CAMS-GLOB-SOIL, we expressed the total soil emission fluxes as the sum of these terms:

$$F_{soil} = F_{biome} + F_{Fert} + F_{Ndep} + F_{pulse} \tag{5.1}$$

Where $F_{nonFert}$ then is the sum of the F_{biome}, F_{Ndep}, and F_{pulse} terms, and where the flux terms have units ng(N) $m^{-2}s^{-1}$. The calculations of F_{biome}, F_{Fert}, F_{Ndep} and F_{pulse} are detailed in Simpson and Darras (2021). Figure 5.1 illustrates the contribution of these terms for the European region.

Table 5.1: The 'GNFR_CAMS' 19-sector system, and mapping indices for release heights, timefactors and species-splits, which is now default in EMEP model.

code	No	Index			sector	SNAP
		timefac	height	emissplit		equivalent
A	01	1	1	1	Public Power	1
B	02	3	3	2	Industry	3, 4
C	03	2	2	3	Other Stationary Combustion	2
D	04	5	5	4	Fugitive	5
E	05	6	2	5	Solvents	6
F	06	7	2	6	Road Transport	7
G	07	8	8	7	Shipping	8
H	08	8	7	8	Aviation	8
I	09	8	2	9	Offroad	8
J	10	9	6	10	Waste	9
K	11	10	2	11	Agri - Livestock	10
L	12	10	2	12	Agri - Other	10
M	13	5	5	13	Other	11
A1	14	1	1	1	PublicPower - Point	1
A2	15	1	3	1	PublicPower - Area	1
F1	16	7	2	16	Road Transport - Exhaust Gasoline	7
F2	17	7	2	17	Road Transport - Exhaust Diesel	7
F3	18	7	2	18	Road Transport - Exhaust LPGgas	7
F4	19	7	2	19	Road Transport - NonExhaust Other	7

Risk of double-counting?

An important issue arose during the construction of this inventory - the risk of double-counting soil-NO emissions, since some anthropogenic emission inventories include and some exclude emissions from agricultural soils. Indeed, within the LRTAP Convention, most countries mainly report NOx emissions due to agricultural activities using the EMEP/EEA Emissions Inventory Guidebook (Hutchings et al. 2019). The Guidebook provides methods for calculating soil-NO data from fertilizer and other inputs. Simpson and Darras (2021) present the main sources for which soil NO emissions areas covered by the Guidebook, and compare the nationally submitted emissions following this system with the CAMS estimates. It is shown that for the vast majority of countries the main emission categories are NFR 3Da1,3Da2a-c,and 3Da3, which together are roughly equivalent to the 'Fert' emissions from CAMS-GLOB-SOIL.

When using EMEP emissions derived from officially reported data (with soil NO emissions as given in GNFR L), for example in EMEP MSC-W reporting runs, Simpson and Darras (2021) recommended to retain the official GNFR L data, but but add biome, N-dep and pulse emissions from CAMS-GLOB-SOIL.

Simpson and Darras (2021) also give recommendations for ECLIPSE v5 and v6 inventories, and for CAMS-GLOB and CAMS-REG. In some cases the CAMS-GLOB-SOIL N_{Fert} emissions should be used, but in other cases not. In the EMEP model this choice is governed by the config_emep.nml variable `USES%SOILNOX_METHOD`, which can be set to either 'Total', or 'NoFert'.

5.2.3 DMS emissions

A new option to calculate biogenic emissions of dimethyl sulfide (DMS) has been added to the EMEP model. It is based on the climatology of sea surface DMS concentrations published by Lana et al. (2011) and the meteorological data driving the EMEP model, and it has been used for this year's status run.

At each location and timestep, the model calculates the Schmidt number (Sc) from the sea surface temperature (SST, given in °C) with the 4th-degree formula of Wanninkhof (2014):

$$Sc = 2855.7 - 177.63\,SST + 6.0438\,SST^2 - 0.11645\,SST^3 + 0.00094743\,SST^4 \quad (5.2)$$

The transfer velocity K_w (given in cm hour^{-1}) is then calculated from the Schmidt number and the 10-meter wind speed u_{10} (given in m s^{-1}) with the formula of Nightingale et al. (2000):

$$K_w = (0.222\,u_{10}^2 + 0.333\,u_{10})\sqrt{\frac{600}{Sc}} \quad (5.3)$$

Following Tarrasón et al. (1995) we assume that 66% of the DMS in air is converted into SO_2. The DMS emission is thus implemented in the model as an SO_2 flux as:

$$F_{\mathrm{SO_2}} = 0.66\,O_{\mathrm{DMS}}\,(K_w\,0.01/3600)\,g\,\rho\,A\,/p \quad (5.4)$$

where O_{DMS} is the surface water DMS concentration (in nanomol L^{-1}), g is standard gravity (9.807 m s^{-2}), ρ is the ambient density of air (kg m^{-3}), p is ambient air pressure, and A is Avogadro's number (6.023e+23 mol^{-1}).

The options to calculate the Schmidt number and transfer velocity, and also to use the older climatology of Kettle et al. (1999), are still available in the EMEP model.

5.2.4 Aircraft emissions

LTO (landing/take-off) emission data are, as before, taken from CEIP, i.e. based on aircraft emissions officially reported by countries for up to 3000 feet above the surface. However, the high distribution in the EMEP model has been slightly revised. We assume that, in approximation, half of the LTO emissions (from CEIP) occur below 50 meters above the surface, while the other half is evenly distributed over the height range between 50 meters and about 3000 feet. Furthermore, aircraft emissions at higher altitudes than 3000 feet are now based on a new dataset (CAMS-GLOB-AIR, Granier et al. 2019), given separately for all years from 2000 to 2019, with monthly variation and a spatial resolution of 0.5° × 0.5° × 610 m. This dataset has been provided through the Copernicus Atmosphere Monitoring Service and can be downloaded from the Atmosphere Data Store of ECMWF (`https://ads.atmosphere.copernicus.eu/`).

In the EMEP model, CAMS-GLOB-AIR emissions between 0 and 610m (2000 ft) above the surface are not used, and half of the CAMS-GLOB-AIR emissions between 610 and 1220m are evenly distributed over the model layers corresponding to that height range. The assumption behind this approach is that emissions up to 3000 feet should already be fully included in the CEIP (LTO) emissions. Above 1220m (4000ft), CAMS-GLOB-AIR emissions are used in full, and interpolated to the relevant model grid during model runtime.

The option of using the old QUANTIFY data (`www.pa.op.dlr.de/quantify`) instead of CAMS-GLOB-AIR for non-LTO emissions is still available in the EMEP model.

5.2.5 Revised fine/coarse splits of sea-salt emissions

The split of sea salt between the fine and coarse fractions have been revised based on the results of comparison of modelled $\mathrm{Na+}$ in $PM_{2.5}$ and PM_{10} with EMEP observations. Namely, the fraction of sea salt emitted in $PM_{2.5}$ fraction has been slightly increased (while the total sea salt emissions in PM_{10} remain unchanged).

More specifically, sea salt is emitted in seven size bins up to 10 μmin diameter, from which the smallest four bins were previously assigned to the $PM_{2.5}$ fraction and the remaining three bins comprised coarse sea salt. Now, the fifth bin is split 50/50 % between the $PM_{2.5}$ and $PM_{2.5\text{-}10}$ fractions.

This modification has a minor effect on formation of coarse NO_3^- as the surface area of coarse sea salt has slightly decreased.

5.2.6 Emission speciation and ‘rnr’ splits

The emissions speciation of primary PM (PPM) were updated to reflect recent data available from ECLIPSE v6b dataset (`https://iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv6.html`). These emissions were provided for the years 2000-2016 (plus 2020 and some future scenarios), and give country-specific fine and coarse emissions of EC, OM and remaining PPM (remPPM) in fine and coarse modes.

In many previous studies we have distinguished estimated wood-burning and fossil-fuel emissions, but for the runs presented in this report we have made the simpler distinction between GNFR category C (mainly residential emissions), and other GNFR sectors. We denote this split the ‘rnr’ (residential-non-residential) split, and have slightly modified the EmChem19a chemical mechanism to cope with the addition of ‘remPPM’ from GNFR C.

5.2.7 Monthly timefactors for global modelling.

New country-based monthly timefactors were produced for countries outside of Europe. These factors were derived by making country-average factors from global gridded SNAP-based data from the ECLIPSE v6b dataset. ECLIPSE factors only created for "robust" sectors (SNAP-1, 2, 3, 4, and 10), since other sectors showed either no monthly variation (e.g. traffic), or very sporadic events that are not expected to be representative for all years (e.g. shipping, or waste-burning). For SNAP-10 (agr) the NH3 data are from ECLIPSE ‘agr_NH3’, otherwise from ‘agr’.

5.3 Revised PBL parametrisations

The new default calculation of eddy diffusivity coefficient Kz (‘TROENKz’) follows the method described in Troen and Mahrt (1986). Unlike the old Kz method (JericevicKz) which does not consider the stability within the boundary layer, this new Kz method differentiates Kz formulation in the stable and unstable boundary layer conditions. Therefore, the new method performs reasonably well in cases of weak surface heat flux and transitions between stable and unstable cases (Troen and Mahrt 1986). However, we have not seen significant changes in modelled concentrations. The formulation of Kz is given as below. In the unstable boundary layer:

$$\phi_h = (1 - 16 \times \min(z, z_{surf}) \times \frac{1}{L})^{-\frac{1}{2}} \tag{5.5}$$

while in the stable boundary layer:

$$\phi_h = 1 + 5 \times z \times \frac{1}{L} \tag{5.6}$$

with *Kz* given as:

$$Kz = 0.4 \times \frac{u_*}{\phi_h} \times z \times (1 - \frac{z}{h})^2 \tag{5.7}$$

in which z is the height from surface, h is boundary layer depth, z_{surf} is the height of surface layer which is assumed to be 10% of the boundary layer depth h, L is the Monin-obukhov length (Garratt 1992), and u_* is friction velocity.

The default calculation of PBL is updated to the HmixMethod JcRb_t2m. Compared with the old HmixMethod JcRb, the new one uses temperature at 2 m instead of temperature at the middle of the lowest grid cell to formulate PBL in the stable conditions. For unstable conditions, the new formulation is the same as the JcRb method. The differences in concentrations are unnoticeable between the two methods, but this update is more accurate according to the original reference paper (Jeričević et al. 2010).

5.4 Local Fractions

The Local Fractions method (Wind et al. 2020) is a framework that allows the tracking of thousands of sources in a single run at a low computational cost. It is fully implemented for primary particles, but also reduced nitrogen compounds can be treated. The tracking of other species is less accurate, but progress is being made to eventually include a correct description for all species.

Since last year, the range of applications of the Local Fractions has been extended. The sources can be defined by either a list of countries or group of countries, as small squares surrounding the receptor grid (with user defined range and square sizes), or as regions defined as "masks" given in a NetCDF file. Wet and dry deposition (separately) per source country can now also be computed.

5.5 Other

A number of smaller changes have been made:

IAM_CROP A new generic crop type has been introduced for integrated assessment modelling outputs. This is an updated version of the previously used IAM_CR species (Simpson et al. 2012), in which the phenology factor (f_{phen}) has been set to 1.0 across the ozone flux accumulation period. The IAM_CR parameters gave a reduction in f_{phen}towards the end of the period, and hence lower POD than the new category gives (c.f.Fig 5.2).

fracPM25 A fraction of coarse nitrate particulate mass has been allocated to the $PM_{2.5}$ fraction in order to represent the fact that some of the particles from the coarse fraction

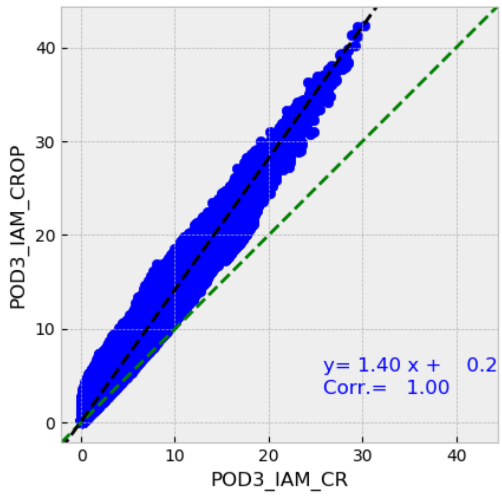

Figure 5.2: Comparison of POD3 values for the new generic IAM_CROP category compared to the IAM_CR used previously. Statistics refer to grid-cells where either category had non-zero POD3 values.

have aerodynamic diameters of less than 2.5 μm. The value of this fraction was previously 27% (Simpson et al. 2012). In the latest version this fraction was reduced to 13%, in order to better account for the differences between mass-median and aerodynamic diameters.

Pollen emissions Although the effect of pollen on $PM_{2.5}$ concentrations is negligible, it is an important allergen. Therefore, it has been included as part of the model forecast capabilities. Optional birch, olive, ragweed and grass pollen emissions based on Sofiev et al. (2015, 2017) were included in version rv4.34, and later expanded to include alder and mugwort pollen emissions.

Timezones A global map of time-zones was produced to enable more accurate calculations for global-scale modelling. The new system also estimates summer and winter times where appropriate. (The previous system used simple longitude methods to estimate local time, and had no accounting for summer/winter time.)

Shipping emissions Shipping emissions now spread as 20% below 20m, 80% between 20-90m.

RH limits RH limits (giving maximum values) were added to the Gerber-calculations of aerosol size: 99% for rural aerosol, and 99.99% for sea-salt, following Gerber (1985). This change prevents excessive buildup of surface area in certain conditions.

RH-2m NWP model rh2m now used in place of earlier sub-grid calculation. This simplification was made since temperature and heat flux data also had no sub-grid calculation.

Table 5.2: Summary of major EMEP MSC-W model versions from 2012–2020. Extends Table S1 of Simpson et al. 2012.

Version	Update	Ref$^{(a)}$
v4.42	19-sector emissions system (GNFR-CAMS) introduced; Emissions for soil NO, DMS, and aircraft updated using results from CAMS81 project; Modified various parameters concerning fine/coarse fractions for sea-salt and nitrate; Added RH limits on Gerber functions; 'rnr' emission split and EmChem19r introduced; Revised global monthly emission factors produced (and use of global time.zone map); Changed default Kz and Hmix schemes (Ch 5.3); upgraded local fraction methods; cleaned up various config options.	This report
rv4.36	Public domain (Nov. 2020); Updated NO_3 photolysis; Allow physical height and topography settings in sites/sondes output; better time resolution on Hmix outputs; allow hourly time-factors per country and species; Various emission coding improvements	
rv4.35	Various updates, including heavy refactoring of local-fraction code, bug-fixes in MARS module, and updates in chemical mechanisms, default PM and NMVOC speciation and GenChem systems	R2020
rv4.34	Public domain (Feb. 2020); EmChem19a, EmChem19p	R2020
rv4.33	Public domain (June 2019); EmChem19, PAR bug-fix, EQSAM4clim	R2019
rv4.32	Used for EMEP course, April 2019	
rv4.30	Moved to new GenChem-based system	
rv4.17a	Used for R2018. Small updates	R2018
rv4.17	Public domain (Feb. 2018); Corrections in global land-cover/deserts; added 'LOTOS' option for European NH_3 emissions; corrections to snow cover	R2018
rv4.16	New radiation scheme (Weiss&Norman); Added dry and wet deposition for N_2O_5; (Used for Stadtler et al. 2018, Mills et al. 2018b)	R2018
rv4.15	EmChem16 scheme; New global land-cover and BVOC	R2017
rv4.10	Public domain (Oct. 2016) (Used for Mills et al. 2018a)	R2016
rv4.9	Updates for GNFR sectors, DMS, sea-salt, dust, S_A and γ, N_2O_5	
rv4.8	Public domain (Oct. 2015); ShipNOx introduced. Used for EMEP HTAP2 model calculations, see special issue: `www.atmos-chem-phys.net/special_issue390.html`, and Jonson et al. (2017).	R2015
rv4.7	Used for reporting, summer 2015; New calculations of aerosol surface area; New gas-aerosol uptake and N_2O_5 hydrolysis rates; Added 3-D calculations of aerosol extinction and AODs; Emissions - new flexible mechanisms for interpolation and merging sources; Global - monthly emissions from ECLIPSE project; Global - LAI changes from LPJ-GUESS model; WRF meteorology (Skamarock and Klemp 2008) can now be used directly in EMEP model.	R2015
rv4.6	Used for Euro-Delta SOA runs Revised boundary condition treatments ; ISORROPIA capability added	R2015
rv4.5	Sixth open-source (Sep 2014) ; Improved dust, sea-salt, SOA modelling ; AOD and extinction coefficient calculations updated ; Data assimilation system added ; Hybrid vertical coordinates replace earlier sigma ; Flexibility of grid projection increased.	R2014
rv4.4	Fifth open-source (Sep 2013) ; Improved dust and sea-salt modelling ; AOD and extinction coefficient calculations added ; gfortran compatibility improved	R2014, R2013
rv4.3	Fourth public domain (Mar. 2013) ; Initial use of namelists ; Smoothing of MARS results ; Emergency module for volcanic ash and other events; Dust and road-dust options added as defaults ; Advection algorithm changed	R2013
rv4.0	Third public domain (Sep. 2012), as Simpson et al. (2012)	R2013

Notes: (a) R2018 refers to EMEP Status report 1/2018, etc.

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CHAPTER 6

Developments in the monitoring network, data quality and database infrastructure

Wenche Aas, Anne Hjellbrekke and Kjetil Tørseth

6.1 Compliance with the EMEP monitoring strategy

The monitoring obligations of EMEP were updated in 2019 and is defined by the Monitoring Strategy for 2020-2030 (UNECE (2019)).

The complexity in the monitoring program with respect to the number of variables and sites, whether parameters are at level 1 or level 2, and the required time resolution (hourly, daily, weekly), makes it challenging to assess whether a country is in compliance. CCC has developed an index to illustrate to what extent the Parties comply, how implementation compares with other countries, and how activities evolve with time.

The index is defined for level 1 parameters only, and is calculated based on the data reported in comparison with the expected. EMEP recommends one site pr 50.000 km^2, but this target number is adjusted for very large countries (i.e. KZ, RU, TR and UA). The components and number of variables to be measured in accordance to the strategy are as follows: major inorganic ions in precipitation (10 variables), major inorganic components in air (13 variables), ozone (1 variable), PM mass (2 variables) and heavy metals in precipitation (7 variables). For heavy metals, the sampling frequency is weekly, and for the other components it is daily or hourly (ozone). Based on the relative implementation of the different variables, the index has been given the following relative weights: Inorganics in precipitation: 30%, inorganics in air: 30%, ozone: 20%, PM mass: 10%, heavy metals: 10%.

Figure 6.1 summarises implementation in 2019 compared to 2000, 2005 and 2010. The countries are sorted from left to right with increasing index for 2019. Slovakia, Estonia, The Netherlands, Denmark, and Switzerland have almost complete programs with an index of 90% or higher. Small countries generally comply better (due to more easily satisfying the site density requirements). Since 2010, 35% of the Parties have improved their monitoring

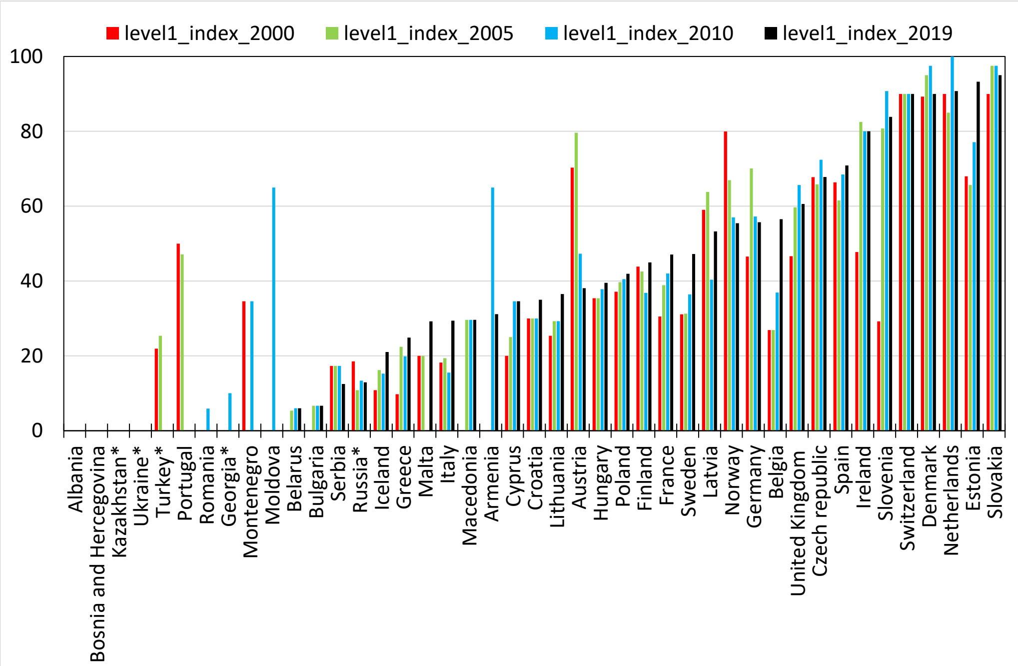
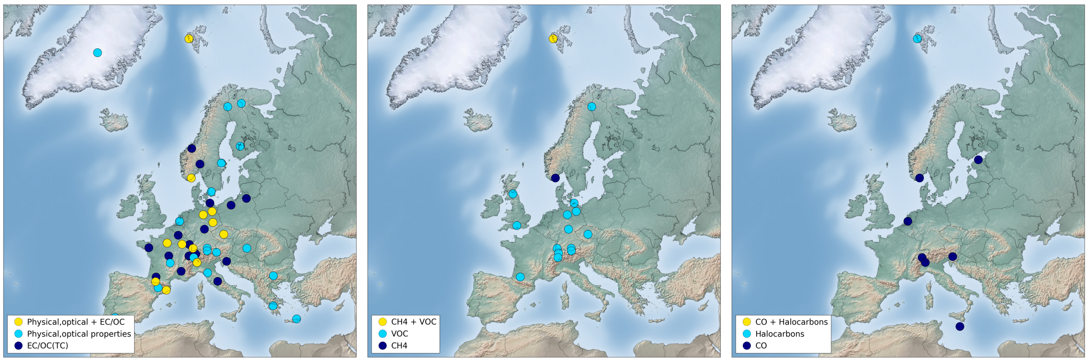


Figure 6.1: Index for implementation of the EMEP monitoring strategy, level 1 based on what has been reported for 2000, 2005, 2010 and 2019. * means adjusted land area.

programme, while 37% have a decrease. Improvements are seen in e.g. France, Croatia and Belgium. One Party, Malta, has reported data in 2019 and not in 2010, while Georgia, Moldova, Montenegro and Romania have stopped reporting/measuring. In Figure 2.4 in Ch 2.2, the geographical distribution of level 1 sites is shown for 2019. In large parts of Europe, implementation of the EMEP monitoring strategy is far from satisfactory.

For the level 2 parameters, an index has not been defined, but mapping the site distribution illustrate the compliance to the monitoring strategy. 56 sites from 21 different Parties reported at least one of the required EMEP level 2 parameters relevant to this report (aerosols (50 sites), photo-oxidants (16 sites) and atmospheric tracers (8 sites)). One should note that some of these sites have been reporting data to ACTRIS (the European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases) and not to EMEP, but they have been included here in the overview since the observations are still comparable with those of EMEP. The sites with measurements of POPs and heavy metals are covered in the EMEP status report published by MSC-E (EMEP Status report 2/2021). Figure 6.2 shows that level 2 measurements of aerosols have better spatial coverage than oxidant precursors (VOC + methane) and atmospheric tracers. Few sites have a complete measurement program, the aerosol program is most developed with 12 sites having a complete aerosol program. For oxidant precursors and atmospheric tracers, there are ongoing improvement in the measurement capabilities resulting from development in ACTRIS in co-operation with EMEP and the WMO Global Atmospheric Watch Programme (GAW).



(a) Particulate matter (b) Oxidant precursors (c) Atmospheric tracers

Figure 6.2: Sites measuring and reporting EMEP level 2 parameters for the year 2019.

6.2 Updates in reporting templates and guidelines

In addition to the requirement that variables has to be measured as defined in the EMEP monitoring strategy discussed above, it is important that the data are reported in time to ensure that they can be quality assured and included in the database. This allows them to be included in the annual model validation, interpretations for the EMEP status reports, as well as other regional assessments and studies carried out beyond EMEP.

Figure 6.3 shows the status of the submission of data for 2019 and to what extent the data were reported in time. It is obvious that large volumes of data are reported late and some not at all. Of the 33 Parties reporting either level 1 or level 2 data, about 60% reported within the deadline of 31 July 2020.

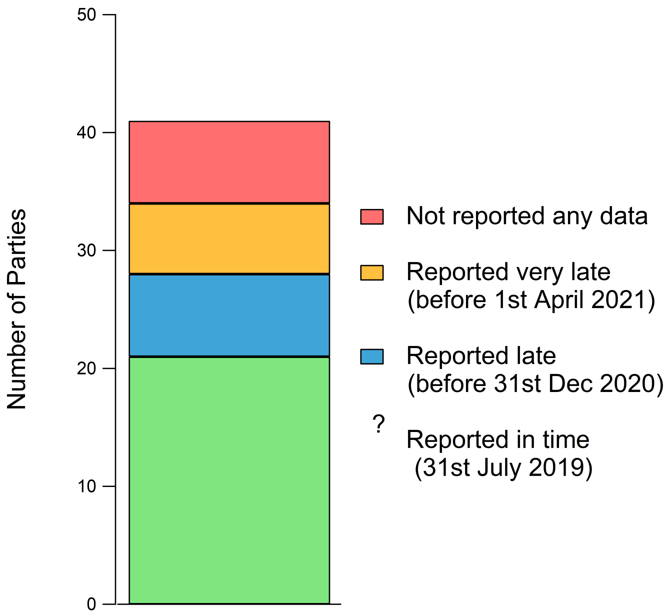


Figure 6.3: Submission of 2019 data to EMEP/CCC.

An online data submission and validation tool (`http://ebas-submit-tool.nilu.no`) was developed in 2016 improve the timeliness and quality of the data reporting. The tool is designed to give the data submitters direct feedback on the formatted NASA Ames files, and suggestions on how to correct the files. The format checker is directly linked to all (approx. 40) data format templates located at `http://ebas-submit.nilu.no/`, and it is continuously being improved and updated, after feedback from the users or when new templates are developed.

The requirement of checking the data files using the submission tool has significantly improved the correctness in the data files submitted, but still there are Parties not using the submission tool and report by e-mails. EMEP/CCC strongly encourage all the Parties to use the submission tool, which in fact is mandatory for submitting all the data to EMEP, unless otherwise have been agreed upon. In the coming years there will be further focus on improving the data submission tools to make it easier for the data provider to report correct and consistent data.

The EMEP data are extensively used. In 2009, a user statistic was implemented for the EBAS database infrastructure. The statistic counts how much data are downloaded, displayed or plotted. Figure 6.4 shows the access requests for EMEP data per year (about 300 thousand annual datasets). There was a big jump in 2013. This was the year when an automatic system for distributing all the data in EBAS to specific users was implemented. The number of downloads increased somewhat in 2020 compared to 2019.

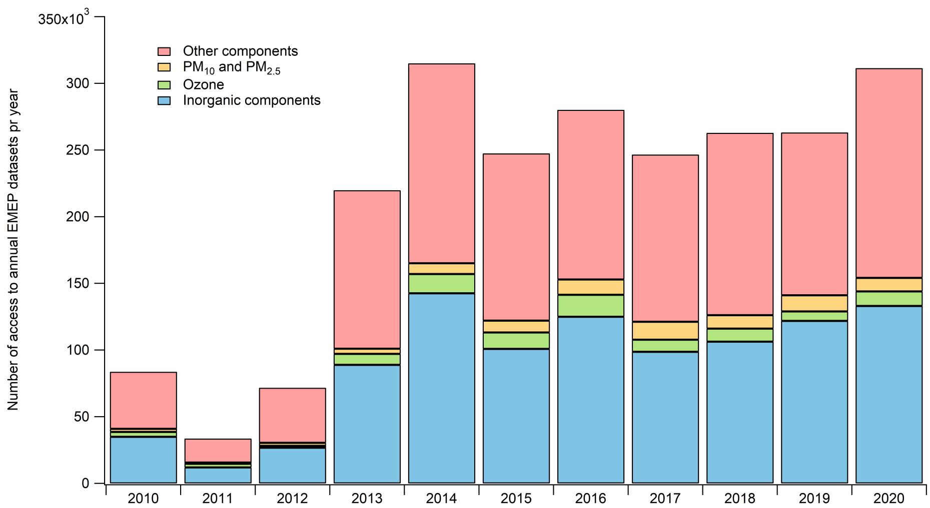


Figure 6.4: Access of EMEP data, number of annual dataset (compounds) per year.

There is ongoing work to make the access of data even more flexible to meet several of the user needs. In example using other platforms, like THREDDS (`https://thredds.nilu.no/thredds/catalog/ebas/catalog.html`) where NetCDF files are extracted from EBAS allowing faster access and the possibility to create more individual specific defined outputs for plotting, statistics, aggregates etc.: Further, a system for issuing Persistent Identifiers of datasets (Digital Object Identifiers – DOIs) is currently under development/implementation. The development of the database infrastructure is scoped to comply with the FAIR principles (findable, accessible, interoperable and reusable).

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Part IV

Appendices

APPENDIX A

National emissions for 2019 in the EMEP domain

This appendix contains the national emission data for 2019 used throughout this report for main pollutants and primary particle emissions in the new EMEP domain, which covers the geographic area between 30°N–82°N latitude and 30°W–90°E longitude.

These are the emissions that are used as basis for the 2019 source-receptor calculations. Results of these source-receptor calculations are presented in Appendix D.

The land-based emissions for 2019 have been derived from the 2021 official data submissions to UNECE CLRTAP (Pinterits et al. 2021). This year, two different estimates for primary PM emissions have been available for the modeling: 1) EMEP emissions as prepared by CEIP based on the official data submissions for 2019, and 2) EMEP PM emissions where condensable organics from small-scale combustion are accounted for by using expert emission estimates for GNFR sector C from the TNO REF2.1 data set for the following countries: Albania, Austria, Bosnia and Herzegovina, Belarus, Switzerland, Cyprus, Germany, Estonia, France, Ireland, Lithuania, Montenegro, Poland, Russian Federation, Slovakia, Turkey and Ukraine. In this report (1) is referred to as EMEP and (2) is referred to as EMEPwREF2.1C. National emission totals for both data sets are shown in Table A:2.

Emissions from international shipping occurring in different European seas within the EMEP domain are not reported to UNECE CLRTAP, but derived from other sources. This year's update uses the CAMS global shipping emissions (Granier et al. 2019) developed by FMI (Finnish Meteorological Institute).

Natural marine emissions of dimethyl sulfide (DMS) are calculated dynamically during the model run and vary with current meteorological conditions.

SO_x emissions from passive degassing of Italian volcanoes (Etna, Stromboli and Vulcano) are reported by Italy.

Note that emissions in this appendix are given in different units than used elsewhere in this report in order to keep consistency with the reported data.

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Table A:1: National total emissions of main pollutants for 2019 in the EMEP domain. Unit: Gg. (Emissions of SO_x and NO_x are given as $Gg(SO_2)$ and $Gg(NO_2)$, respectively.)

Area/Pollutant	SO_x	NO_x	NH_3	NMVOC	CO
Albania	6	28	20	34	77
Armenia	6	42	15	26	76
Austria	11	144	64	109	498
Azerbaijan	79	294	79	378	665
Belarus	45	128	134	276	696
Belgium	30	160	66	113	369
Bosnia and Herzegovina	93	51	22	100	242
Bulgaria	88	97	44	72	254
Croatia	8	54	37	75	216
Cyprus	16	14	7	9	11
Czechia	80	172	85	215	819
Denmark	10	99	75	103	209
Estonia	19	25	11	23	131
Finland	29	120	32	85	345
France	100	774	593	956	2375
Georgia	21	47	33	31	109
Germany	264	1137	587	1121	2883
Greece	80	250	64	144	464
Hungary	17	114	79	119	354
Iceland	58	21	5	5	106
Ireland	11	101	125	114	68
Italy	105	627	355	894	2062
Kazakhstan	2210	869	109	595	1458
Kyrgyzstan	39	62	32	42	206
Latvia	4	33	18	41	120
Liechtenstein	0	0	0	0	0
Lithuania	12	52	35	52	116
Luxembourg	1	19	6	11	21
Malta	0	5	1	3	7
Moldova	7	41	20	77	174
Monaco	0	0	0	0	2
Montenegro	25	13	4	9	34
Netherlands	23	238	123	237	626
North Macedonia	116	21	8	24	55
Norway	16	151	29	153	400
Poland	427	682	317	647	2112
Portugal	44	148	59	161	293
Romania	99	217	178	230	894
Russian Federation	1368	3133	1219	3838	12373
Serbia	395	129	76	121	330
Slovakia	16	61	31	100	279
Slovenia	4	29	18	31	97
Spain	149	646	471	608	1600
Sweden	16	127	53	134	336
Switzerland	4	61	54	81	161
Tajikistan	42	49	34	86	526
Turkey	2455	862	765	1121	1674
Turkmenistan	113	265	73	187	903
Ukraine	508	614	246	384	2835
United Kingdom	163	843	272	813	1585
Uzbekistan	325	346	200	317	1174
Asian areas	5289	6651	3301	9368	33748
North Africa	1230	1266	408	1602	3241
Baltic Sea	11	349	0	3	28
Black Sea	50	112	0	1	10
Mediterranean Sea	750	1519	0	13	120
North Sea	36	758	0	7	67
North-East Atlantic Ocean	494	931	0	8	75
Natural marine emissions	2926	0	0	0	0
Volcanic emissions	943	0	0	0	0
TOTAL	21486	25803	10691	26105	80709

Table A:2: National total emissions of particulate matter for 2019 in the EMEP domain. Unit: Gg.

Area/Pollutant	BC	$PM_{2.5}$ EMEP	PM_{co} EMEP	PM_{10} EMEP	$PM_{2.5}$ EMEPwREF2.1C	PM_{co} EMEPwREF2.1C	PM_{10} EMEPwREF2.1C
Albania	2	13	3	15	12	2	14
Armenia	1	8	2	10	8	2	10
Austria	4	14	12	26	34	12	46
Azerbaijan	9	38	10	48	38	10	48
Belarus	8	56	18	73	55	17	72
Belgium	3	18	9	27	18	9	27
Bosnia and Herzegovina	6	46	10	56	36	9	46
Bulgaria	4	30	17	46	30	17	46
Croatia	4	29	12	41	29	12	41
Cyprus	0	1	1	2	1	1	2
Czechia	5	36	11	47	36	11	47
Denmark	2	13	10	23	13	10	23
Estonia	2	6	3	9	15	4	19
Finland	4	17	13	30	17	13	30
France	21	121	81	202	183	84	266
Georgia	6	24	4	28	24	4	28
Germany	12	92	112	204	122	111	233
Greece	9	37	24	61	37	24	61
Hungary	6	40	22	62	40	22	62
Iceland	0	1	1	2	1	1	2
Ireland	2	12	16	28	10	16	26
Italy	18	139	33	172	139	33	172
Kazakhstan	17	137	71	208	137	71	208
Kyrgyzstan	1	14	5	19	14	5	19
Latvia	3	20	9	29	20	9	29
Liechtenstein	0	0	0	0	0	0	0
Lithuania	1	5	6	11	21	6	27
Luxembourg	0	1	1	2	1	1	2
Malta	0	0	1	1	0	1	1
Moldova	3	27	5	32	27	5	32
Monaco	0	0	0	0	0	0	0
Montenegro	1	7	1	9	5	1	6
Netherlands	2	15	12	28	15	12	28
North Macedonia	1	8	5	13	8	5	13
Norway	3	24	9	32	24	9	32
Poland	14	122	97	218	251	70	321
Portugal	7	50	20	71	50	20	71
Romania	13	112	41	153	112	41	153
Russian Federation	46	303	425	729	659	436	1096
Serbia	6	46	16	61	46	16	61
Slovakia	2	18	5	23	19	6	25
Slovenia	2	11	3	13	11	3	13
Spain	29	135	60	195	135	60	195
Sweden	2	18	19	37	18	19	37
Switzerland	1	6	8	14	12	8	20
Tajikistan	5	30	9	40	30	9	40
Turkey	32	384	169	553	413	141	554
Turkmenistan	4	26	8	34	26	8	34
Ukraine	25	281	132	413	358	132	490
United Kingdom	18	109	62	171	109	62	171
Uzbekistan	9	63	19	82	63	19	82
Asian areas	257	1329	904	2233	1329	904	2233
North Africa	257	163	128	291	163	128	291
Baltic Sea	4	11	0	11	11	0	11
Black Sea	3	8	0	8	8	0	8
Mediterranean Sea	44	110	0	110	110	0	110
North Sea	10	26	0	26	26	0	26
North-East Atlantic Ocean	28	70	0	70	70	0	70
Natural marine emissions	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0
TOTAL	978	4477	2675	7152	5196	2632	7828

APPENDIX B

National emission trends

This appendix contains trends of national emission data for main pollutants and primary particle emissions for the years 2000–2019 in the EMEP domain, which covers the geographic area between 30°N–82°N latitude and 30°W–90°E longitude.

The land-based emissions for 2000–2019 have been derived from the 2021 official data submissions to UNECE CLRTAP (Pinterits et al. 2021). For primary PM in 2019, two different sets of emissions have been used: 1) EMEP emissions as prepared by CEIP based on the official data submissions for 2019, and 2) EMEP PM emissions where condensable organics from small-scale combustion are accounted for by using expert emission estimates for GNFR sector C from the TNO REF2.1 data set for the following countries: Albania, Austria, Bosnia and Herzegovina, Belarus, Switzerland, Cyprus, Germany, Estonia, France, Ireland, Lithuania, Montenegro, Poland, Russian Federation, Slovakia, Turkey and Ukraine. In this report 1) is referred to as EMEP and 2) is referred to as EMEPwREF2.1C. Please note that the trend calculations which are discussed in Ch 4 are based only on 1) EMEP emissions, while 2) EMEPwREF2.1C emissions are used in the status run (Ch 2 and in source-receptor calculations (Appendix D).

Emissions from international shipping occurring in different European seas within the EMEP domain are not reported to UNECE CLRTAP, but derived from other sources. This year, emissions for the sea regions are based on the CAMS global shipping emission dataset (Granier et al. 2019, ECCAD 2019) for the years 2000 to 2019, developed by the Finish Meteorological Institute using AIS (Automatic Identification System) tracking data.

Natural marine emissions of dimethyl sulfide (DMS) are calculated dynamically during the model run and vary with current meteorological conditions.

SO_x emissions from passive degassing of Italian volcanoes (Etna, Stromboli and Vulcano) are those reported by Italy. SO_x and PM emissions from volcanic eruptions of Icelandic volcanoes in the period 2000-2019 (Eyjafjallajökull in 2010, Grímsvötn in 2011 and Barðarbunga in 2014-2015) are reported by Iceland.

Note that emissions in this appendix are given in different units than used elsewhere in this report in order to keep consistency with the reported data.

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Table B:1: National total emission trends of sulphur (2000-2009), as used for modelling at the MSC-W (Gg of SO_2 per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	9	10	12	13	14	16	14	12	10	9
Armenia	1	1	1	1	1	1	2	2	2	2
Austria	32	32	31	31	27	26	27	23	20	15
Azerbaijan	214	194	173	153	133	112	97	82	67	53
Belarus	214	192	169	147	124	102	101	100	84	158
Belgium	171	165	157	152	155	143	134	123	95	74
Bosnia and Herzegovina	192	198	205	211	218	225	235	245	256	266
Bulgaria	863	829	758	826	791	779	765	824	575	442
Croatia	60	59	63	64	52	58	55	60	53	56
Cyprus	48	45	45	47	40	38	31	29	22	18
Czechia	233	229	223	218	215	208	207	212	170	169
Denmark	33	30	28	35	29	26	30	27	21	16
Estonia	97	91	87	100	88	76	70	88	69	55
Finland	82	96	90	101	84	70	83	81	67	59
France	616	559	519	502	482	462	429	405	347	293
Georgia	11	10	9	7	6	5	5	6	6	6
Germany	651	630	566	539	498	477	476	459	454	396
Greece	553	567	552	560	561	579	537	522	450	392
Hungary	427	346	272	246	151	43	39	36	36	30
Iceland	39	42	45	41	36	43	42	61	77	72
Ireland	144	142	107	83	73	73	61	55	46	33
Italy	756	705	623	526	489	411	389	348	293	241
Kazakhstan	1499	1565	1631	1696	1762	1828	1908	1989	2070	2150
Kyrgyzstan	25	25	25	25	25	26	28	31	33	36
Latvia	18	14	13	11	9	9	8	8	7	7
Lithuania	39	43	37	24	25	28	26	22	20	19
Luxembourg	4	4	3	3	3	3	3	2	2	2
Malta	9	11	11	11	12	12	12	13	10	7
Moldova	5	4	5	8	6	6	7	4	6	6
Montenegro	22	17	26	25	24	20	22	17	25	13
Netherlands	78	79	71	67	69	67	68	64	53	40
North Macedonia	106	108	96	95	96	96	94	98	77	104
Norway	27	25	23	23	25	23	22	20	20	15
Poland	1341	1316	1231	1211	1161	1132	1196	1106	880	746
Portugal	295	278	277	185	189	190	165	158	104	72
Romania	492	509	509	588	558	603	648	516	522	443
Russian Federation	2584	2580	2576	2572	2568	2564	2427	2290	2153	2016
Serbia	464	459	484	509	519	445	463	472	482	434
Slovakia	117	123	99	102	93	86	85	69	68	63
Slovenia	93	63	63	60	51	40	17	15	13	10
Spain	1389	1328	1470	1217	1248	1205	1074	1044	382	284
Sweden	45	42	42	42	38	36	36	32	29	27
Switzerland	16	17	15	15	15	14	13	12	12	10
Tajikistan	9	12	14	14	17	18	23	35	39	44
Turkey	2242	1983	1872	1791	1779	2003	2160	2523	2558	2662
Turkmenistan	40	38	39	41	42	44	45	54	60	60
Ukraine	2310	1844	1329	1252	1048	1192	1446	1363	1386	1290
United Kingdom	1296	1227	1104	1073	910	794	748	652	550	452
Uzbekistan	322	319	314	311	306	301	301	284	278	278
Asian areas	2531	2625	2720	2814	2908	3003	3151	3300	3448	3596
North Africa	731	764	796	829	861	894	910	926	942	958
Baltic Sea	237	231	229	226	223	217	145	114	105	101
Black Sea	57	57	56	55	55	54	53	52	48	46
Mediterranean Sea	969	956	934	918	901	882	867	854	777	739
North Sea	465	458	446	435	429	420	308	255	238	230
North-East Atlantic Ocean	596	590	574	564	557	546	537	526	481	459
Natural marine emissions	2364	2318	2380	2232	2298	2338	2376	2352	2386	2356
Volcanic emissions	5746	4279	5300	3556	2701	1205	1308	840	973	950
TOTAL	34029	31484	31556	29206	27799	26317	26528	25913	24458	23578

Table B:2: National total emission trends of sulphur (2010-2019), as used for modelling at the MSC-W (Gg of SO_2 per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Albania	7	6	6	5	5	4	5	5	6	6
Armenia	2	2	2	3	3	3	3	4	5	6
Austria	16	15	15	14	15	14	13	13	12	11
Azerbaijan	38	43	49	54	59	65	68	72	75	79
Belarus	59	63	68	61	53	57	56	48	47	45
Belgium	61	53	47	43	41	41	34	32	32	30
Bosnia and Herzegovina	277	280	283	286	290	293	243	193	143	93
Bulgaria	387	514	328	194	187	142	105	103	89	88
Croatia	35	29	25	17	14	16	15	13	10	8
Cyprus	22	21	16	14	17	13	16	16	17	16
Czechia	164	167	160	145	134	129	115	110	97	80
Denmark	15	14	13	13	11	10	10	11	11	10
Estonia	83	73	43	42	47	36	35	39	31	19
Finland	66	60	50	48	44	41	40	35	33	29
France	269	222	220	201	158	151	136	130	122	100
Georgia	7	7	7	7	7	7	11	14	18	21
Germany	405	389	372	361	339	336	312	303	292	264
Greece	230	160	143	122	104	102	81	90	86	80
Hungary	30	34	30	29	26	24	23	28	23	17
Iceland	76	84	87	72	65	61	52	50	55	58
Ireland	27	25	24	24	18	16	14	15	15	11
Italy	222	199	180	149	133	127	119	117	109	105
Kazakhstan	2231	2213	2195	2177	2159	2141	2158	2175	2192	2210
Kyrgyzstan	38	42	46	49	53	56	52	48	43	39
Latvia	4	4	4	4	4	4	3	4	4	4
Lithuania	18	19	17	14	13	15	15	13	13	12
Luxembourg	2	1	2	2	2	1	1	1	1	1
Malta	8	8	8	5	5	2	2	1	0	0
Moldova	6	6	6	6	5	6	5	6	5	7
Montenegro	28	29	29	26	26	28	23	23	27	25
Netherlands	36	35	35	30	30	31	28	27	25	23
North Macedonia	86	104	90	81	83	76	65	56	61	116
Norway	19	19	17	17	17	17	16	15	16	16
Poland	817	771	739	702	660	639	533	526	495	427
Portugal	63	57	52	48	44	46	46	47	45	44
Romania	356	326	261	210	183	158	109	89	84	99
Russian Federation	1878	1857	1775	1733	1719	1715	1804	1498	1411	1368
Serbia	404	459	422	437	344	364	372	369	347	395
Slovakia	68	67	57	52	44	67	26	28	20	16
Slovenia	10	11	11	10	8	5	5	5	5	4
Spain	243	279	283	219	241	258	215	218	196	149
Sweden	29	26	26	23	21	18	18	18	17	16
Switzerland	10	8	9	8	7	6	5	5	5	4
Tajikistan	49	51	20	19	24	32	34	37	39	42
Turkey	2557	2562	2668	1939	2149	1942	2247	2354	2519	2455
Turkmenistan	72	76	85	89	87	86	93	100	106	113
Ukraine	1216	1320	1339	1422	922	854	948	801	654	508
United Kingdom	460	433	468	405	331	268	197	193	178	163
Uzbekistan	267	256	274	267	259	248	267	286	306	325
Asian areas	3745	3815	3884	3954	4023	4093	4373	4676	4992	5289
North Africa	974	1000	1026	1052	1078	1104	1116	1163	1200	1230
Baltic Sea	93	79	78	77	76	9	9	9	10	11
Black Sea	49	48	47	46	45	44	44	45	44	50
Mediterranean Sea	746	738	730	715	645	680	676	691	692	750
North Sea	209	183	183	180	171	32	32	31	31	36
North-East Atlantic Ocean	483	478	473	463	414	441	440	439	442	494
Natural marine emissions	2314	2446	2368	2434	2250	2454	2390	2394	2440	2926
Volcanic emissions	1070	1243	943	943	11823	2070	943	943	943	943
TOTAL	23154	23532	22836	21762	31735	21695	20813	20775	20937	21486

Table B:3: National total emission trends of nitrogen oxides (2000-2009), as used for modelling at the MSC-W (Gg of NO_2 per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	19	22	25	27	30	33	32	32	31	31
Armenia	17	17	18	18	19	19	21	24	26	28
Austria	212	222	230	241	241	247	238	231	218	204
Azerbaijan	99	105	110	116	121	127	130	133	136	139
Belarus	135	135	137	140	148	171	187	181	189	189
Belgium	360	348	337	332	342	327	311	301	273	242
Bosnia and Herzegovina	37	42	47	52	56	61	64	66	69	72
Bulgaria	144	150	166	170	168	174	148	143	146	139
Croatia	91	91	94	93	92	89	89	91	87	80
Cyprus	22	22	22	22	22	22	22	22	20	20
Czechia	298	303	294	296	295	290	285	284	267	252
Denmark	226	224	221	230	214	205	205	190	174	155
Estonia	46	48	48	49	46	42	41	45	42	36
Finland	241	244	242	249	237	208	224	211	194	176
France	1709	1672	1631	1586	1544	1497	1408	1344	1247	1166
Georgia	29	24	25	25	26	28	29	33	30	35
Germany	1905	1848	1786	1741	1693	1642	1652	1608	1545	1455
Greece	430	456	451	461	464	483	483	481	455	435
Hungary	189	189	181	185	183	179	172	168	162	151
Iceland	33	29	31	31	32	28	28	31	28	28
Ireland	182	182	174	173	175	177	173	168	153	128
Italy	1504	1475	1418	1397	1348	1289	1238	1171	1052	964
Kazakhstan	444	414	438	474	522	609	570	575	543	555
Kyrgyzstan	28	29	30	31	32	33	38	43	48	52
Latvia	42	45	44	46	45	44	45	45	41	39
Lithuania	61	63	64	61	61	63	63	64	62	53
Luxembourg	41	43	44	46	55	57	51	46	43	38
Malta	10	9	9	9	9	10	10	10	10	9
Moldova	20	22	23	25	27	28	26	26	28	27
Montenegro	9	8	9	9	9	10	11	12	13	11
Netherlands	472	460	443	438	423	416	409	394	388	354
North Macedonia	44	41	41	36	37	39	39	42	38	41
Norway	222	220	215	215	214	218	217	220	214	204
Poland	885	862	827	839	856	886	906	905	876	862
Portugal	292	290	296	271	273	277	256	245	227	215
Romania	294	302	309	314	315	331	329	309	303	256
Russian Federation	3630	3602	3574	3546	3519	3491	3379	3267	3155	3043
Serbia	148	155	165	167	183	169	170	177	174	165
Slovakia	108	109	103	101	101	104	98	97	98	88
Slovenia	59	59	59	55	54	54	55	54	57	49
Spain	1351	1319	1352	1344	1368	1346	1299	1291	1088	971
Sweden	215	206	199	196	192	189	188	183	176	164
Switzerland	102	99	94	93	92	93	92	91	91	86
Tajikistan	8	9	9	9	10	11	12	12	12	12
Turkey	761	734	707	714	726	775	799	860	858	850
Turkmenistan	141	140	147	160	169	177	176	183	185	188
Ukraine	1000	996	993	990	986	983	957	931	905	878
United Kingdom	2049	2002	1903	1860	1797	1777	1709	1638	1469	1272
Uzbekistan	400	401	393	380	370	361	357	345	340	333
Asian areas	2986	3154	3321	3488	3656	3823	3952	4081	4209	4337
North Africa	752	778	804	830	856	881	900	918	936	955
Baltic Sea	424	416	412	407	401	393	387	384	352	336
Black Sea	138	136	135	134	132	130	128	126	118	113
Mediterranean Sea	1846	1819	1783	1759	1732	1702	1676	1653	1515	1433
North Sea	930	916	898	880	869	855	843	825	770	737
North-East Atlantic Ocean	1166	1152	1127	1109	1096	1076	1059	1041	954	902
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	29010	28857	28659	28669	28685	28750	28386	28052	26840	25753

Table B:4: National total emission trends of nitrogen oxides (2010-2019), as used for modelling at the MSC-W (Gg of NO_2 per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Albania	30	30	30	30	30	30	30	29	29	28
Armenia	30	32	34	36	38	40	40	41	42	42
Austria	204	196	191	190	182	179	172	163	151	144
Azerbaijan	142	150	158	165	173	181	209	238	266	294
Belarus	170	171	175	167	159	145	143	138	133	128
Belgium	245	227	216	207	197	198	187	176	169	160
Bosnia and Herzegovina	74	73	71	69	68	66	62	59	55	51
Bulgaria	125	133	129	112	118	116	110	100	96	97
Croatia	72	69	63	61	58	58	58	58	54	54
Cyprus	19	22	21	15	16	14	14	13	13	14
Czechia	248	237	224	212	209	204	193	192	184	172
Denmark	150	140	129	125	115	114	114	111	106	99
Estonia	42	41	37	36	35	31	31	31	30	25
Finland	187	171	162	158	151	139	135	130	127	120
France	1144	1086	1060	1040	969	949	902	872	812	774
Georgia	37	38	40	41	47	49	49	47	53	47
Germany	1471	1445	1436	1436	1392	1364	1341	1292	1210	1137
Greece	364	326	285	274	269	263	262	268	259	250
Hungary	148	138	131	127	126	128	120	121	120	114
Iceland	26	24	24	23	23	23	21	22	22	21
Ireland	122	109	111	113	112	115	115	111	110	101
Italy	934	896	848	779	756	719	699	646	639	627
Kazakhstan	666	674	711	726	780	779	784	818	850	869
Kyrgyzstan	57	61	65	68	72	76	73	69	66	62
Latvia	40	37	37	36	36	35	34	34	35	33
Lithuania	56	55	55	52	52	54	54	52	53	52
Luxembourg	39	40	37	34	32	28	26	23	21	19
Malta	10	9	10	8	8	7	6	6	5	5
Moldova	30	32	30	31	33	32	35	37	41	41
Montenegro	12	12	11	10	10	11	11	12	13	13
Netherlands	350	333	314	301	281	282	270	259	253	238
North Macedonia	42	43	41	35	23	21	22	21	20	21
Norway	209	210	206	199	191	180	170	162	160	151
Poland	877	859	820	776	724	706	716	749	725	682
Portugal	198	181	167	163	160	164	157	160	154	148
Romania	242	251	246	227	222	220	211	220	222	217
Russian Federation	2931	2974	3035	3065	3074	3055	3101	3155	3133	3133
Serbia	151	165	155	156	129	148	140	139	131	129
Slovakia	86	79	76	74	75	73	69	68	67	61
Slovenia	48	47	46	43	39	35	34	34	32	29
Spain	911	903	861	762	768	772	728	724	690	646
Sweden	169	162	156	153	151	147	145	140	137	127
Switzerland	85	81	81	81	77	73	71	68	65	61
Tajikistan	12	12	26	32	41	44	45	47	48	49
Turkey	851	912	850	883	916	932	916	935	923	862
Turkmenistan	200	206	211	223	226	236	243	250	257	265
Ukraine	852	819	786	753	720	687	669	651	633	614
United Kingdom	1245	1166	1192	1130	1057	1026	936	902	876	843
Uzbekistan	316	323	315	309	309	308	317	327	336	346
Asian areas	4465	4602	4738	4875	5011	5147	5499	5881	6278	6651
North Africa	973	1006	1039	1072	1104	1137	1149	1198	1236	1266
Baltic Sea	359	348	342	333	312	306	311	306	309	349
Black Sea	118	117	114	111	107	106	102	106	101	112
Mediterranean Sea	1541	1510	1493	1451	1290	1351	1331	1360	1366	1519
North Sea	771	752	745	725	664	671	670	650	654	758
North-East Atlantic Ocean	972	952	935	907	802	850	839	838	848	931
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	25873	25685	25523	25223	24740	24824	24889	25256	25418	25803

Table B:5: National total emission trends of ammonia (2000-2009), as used for modelling at the MSC-W (Gg of NH_3 per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	18	17	17	17	17	17	17	17	17	17
Armenia	9	10	10	10	11	11	11	12	12	13
Austria	61	61	60	60	60	60	61	62	62	63
Azerbaijan	50	51	54	58	61	63	66	66	67	69
Belarus	142	137	128	120	121	135	134	144	147	150
Belgium	93	91	89	85	80	78	78	75	73	73
Bosnia and Herzegovina	14	14	15	15	15	16	16	16	17	17
Bulgaria	51	48	47	49	50	48	48	47	46	44
Croatia	44	47	46	46	49	46	46	46	48	40
Cyprus	10	11	11	11	11	10	10	10	10	9
Czechia	106	110	106	106	102	99	98	100	95	88
Denmark	97	95	93	92	93	89	86	85	84	80
Estonia	9	9	9	10	10	10	10	10	11	10
Finland	35	35	36	37	37	38	37	37	36	36
France	662	657	642	633	626	621	611	618	623	614
Georgia	44	46	48	49	47	47	41	37	37	37
Germany	627	631	619	616	601	607	603	610	614	617
Greece	75	75	74	74	77	75	73	73	70	66
Hungary	85	84	85	86	84	80	80	80	73	71
Iceland	5	5	5	4	4	4	5	5	5	5
Ireland	120	120	120	120	118	120	121	115	117	117
Italy	454	454	442	442	437	419	415	416	406	390
Kazakhstan	76	80	84	88	92	96	98	99	101	102
Kyrgyzstan	24	24	25	25	26	26	27	28	28	29
Latvia	14	14	14	15	14	14	15	15	15	15
Lithuania	34	34	36	37	38	37	37	39	37	38
Luxembourg	6	6	6	6	6	6	5	6	6	6
Malta	2	2	2	2	2	2	2	2	2	2
Moldova	24	24	25	24	23	24	24	19	19	20
Montenegro	8	7	8	8	5	5	5	5	5	5
Netherlands	173	167	160	156	155	153	155	152	140	137
North Macedonia	13	13	12	12	12	11	11	11	11	10
Norway	29	29	29	30	30	30	31	31	31	31
Poland	362	351	345	331	321	338	343	349	337	324
Portugal	77	73	71	65	65	65	63	64	62	60
Romania	197	190	196	200	212	215	216	216	213	205
Russian Federation	1175	1172	1170	1167	1165	1163	1132	1102	1072	1041
Serbia	109	105	109	105	114	111	108	110	100	104
Slovakia	33	35	36	34	32	33	30	32	29	29
Slovenia	22	22	22	21	20	20	20	21	20	20
Spain	524	520	509	519	515	483	479	486	443	440
Sweden	60	59	59	59	59	58	57	57	57	54
Switzerland	61	61	60	59	58	59	60	60	60	59
Tajikistan	21	22	26	26	27	27	26	26	29	30
Turkey	640	580	573	618	615	633	646	612	573	578
Turkmenistan	40	49	54	61	65	75	80	77	78	77
Ukraine	271	262	252	243	233	224	227	230	233	236
United Kingdom	303	295	292	286	285	279	274	271	255	258
Uzbekistan	125	129	133	139	147	150	153	162	165	172
Asian areas	2064	2116	2169	2221	2274	2326	2369	2412	2456	2499
North Africa	289	296	304	312	319	327	329	331	332	334
Baltic Sea	0	0	0	0	0	0	0	0	0	0
Black Sea	0	0	0	0	0	0	0	0	0	0
Mediterranean Sea	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0
North-East Atlantic Ocean	0	0	0	0	0	0	0	0	0	0
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	9586	9547	9540	9610	9640	9685	9687	9704	9575	9541

Table B:6: National total emission trends of ammonia (2010-2019), as used for modelling at the MSC-W (Gg of NH_3 per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Albania	17	17	17	17	17	17	18	19	19	20
Armenia	13	13	14	14	14	14	14	15	15	15
Austria	63	62	63	63	63	64	65	66	65	64
Azerbaijan	70	71	72	73	74	75	76	77	78	79
Belarus	151	154	157	149	141	143	136	138	130	134
Belgium	73	72	72	71	69	70	70	69	68	66
Bosnia and Herzegovina	17	17	18	18	19	19	20	20	21	22
Bulgaria	43	43	43	44	45	45	46	45	44	44
Croatia	42	44	42	35	34	38	36	39	39	37
Cyprus	10	9	9	8	8	8	8	8	9	7
Czechia	91	92	86	95	98	107	90	86	86	85
Denmark	81	78	76	74	73	75	75	78	77	75
Estonia	10	10	10	11	11	10	10	11	10	11
Finland	37	35	35	35	35	34	33	32	32	32
France	618	607	608	605	609	616	616	612	606	593
Georgia	37	37	40	43	37	37	36	34	33	33
Germany	619	625	631	637	645	641	638	624	601	587
Greece	71	70	68	68	65	64	64	64	63	64
Hungary	71	72	72	73	74	78	79	80	79	79
Iceland	5	5	5	4	5	5	5	5	5	5
Ireland	115	110	117	118	114	120	125	129	135	125
Italy	377	379	389	376	364	364	377	371	358	355
Kazakhstan	104	105	105	106	106	107	108	108	109	109
Kyrgyzstan	30	30	30	31	31	31	31	32	32	32
Latvia	15	15	16	17	17	17	17	18	17	18
Lithuania	37	36	36	34	37	37	36	37	36	35
Luxembourg	6	5	5	5	5	5	6	6	6	6
Malta	2	1	1	2	1	1	1	1	1	1
Moldova	21	20	18	17	20	18	18	19	20	20
Montenegro	4	4	4	4	4	4	5	4	4	4
Netherlands	134	132	126	125	129	131	130	132	129	123
North Macedonia	11	11	10	10	10	10	10	10	10	8
Norway	31	30	30	31	30	30	30	30	31	29
Poland	316	315	305	310	304	304	305	319	330	317
Portugal	59	59	57	56	58	59	60	60	59	59
Romania	187	187	183	185	186	190	185	182	182	178
Russian Federation	1011	1035	1062	1066	1083	1128	1145	1171	1170	1219
Serbia	95	96	98	95	90	89	87	87	82	76
Slovakia	29	28	30	30	30	30	31	32	32	31
Slovenia	20	19	19	18	18	19	19	19	18	18
Spain	435	423	418	422	444	453	457	476	475	471
Sweden	55	54	53	55	55	55	53	54	54	53
Switzerland	59	58	57	56	57	56	55	55	55	54
Tajikistan	31	31	31	32	32	33	33	33	34	34
Turkey	589	616	679	719	717	697	760	796	728	765
Turkmenistan	78	76	74	73	71	71	72	72	73	73
Ukraine	239	239	240	241	241	242	243	244	245	246
United Kingdom	261	259	258	255	267	271	275	275	274	272
Uzbekistan	177	181	185	188	192	194	195	197	199	200
Asian areas	2542	2544	2547	2549	2552	2554	2729	2919	3116	3301
North Africa	336	342	348	354	360	366	370	385	398	408
Baltic Sea	0	0	0	0	0	0	0	0	0	0
Black Sea	0	0	0	0	0	0	0	0	0	0
Mediterranean Sea	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0
North-East Atlantic Ocean	0	0	0	0	0	0	0	0	0	0
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	9544	9577	9673	9718	9765	9847	10106	10394	10491	10691

Table B:7: National total emission trends of non-methane volatile organic compounds (2000-2009), as used for modelling at the MSC-W (Gg of NMVOC per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	33	34	34	34	35	35	35	34	34	33
Armenia	23	24	25	26	26	27	29	31	33	35
Austria	181	176	171	167	154	158	160	156	150	137
Azerbaijan	117	129	141	152	164	176	204	233	261	289
Belarus	367	367	366	366	365	365	366	367	387	362
Belgium	232	226	210	200	188	182	175	165	158	145
Bosnia and Herzegovina	57	55	52	49	46	43	43	44	44	44
Bulgaria	108	96	104	103	92	95	93	89	88	94
Croatia	103	101	103	107	114	114	115	111	109	95
Cyprus	13	13	14	15	15	16	16	16	15	13
Czechia	314	304	292	287	278	270	270	264	259	258
Denmark	185	175	170	162	158	153	149	146	143	133
Estonia	37	35	35	33	34	32	31	28	26	24
Finland	178	175	166	162	157	146	140	136	120	111
France	2044	1949	1821	1774	1661	1581	1479	1352	1273	1198
Georgia	40	41	41	42	42	35	35	36	36	35
Germany	1804	1709	1618	1537	1533	1486	1483	1421	1359	1245
Greece	308	306	319	331	341	334	310	288	261	250
Hungary	190	190	177	182	177	174	161	146	138	137
Iceland	9	8	8	8	8	7	7	7	7	6
Ireland	123	123	123	121	121	121	121	120	117	114
Italy	1630	1567	1472	1452	1349	1340	1305	1287	1265	1184
Kazakhstan	368	386	405	424	442	461	488	515	542	570
Kyrgyzstan	21	23	25	27	29	32	34	36	39	41
Latvia	54	57	56	55	54	54	54	53	48	48
Lithuania	61	57	60	58	57	63	64	64	64	59
Luxembourg	16	16	16	15	16	15	14	12	14	12
Malta	4	4	4	3	3	3	3	3	2	3
Moldova	33	37	41	43	46	52	46	41	43	42
Montenegro	9	8	9	10	9	8	9	9	10	9
Netherlands	335	306	291	283	262	267	260	263	256	258
North Macedonia	46	39	38	37	37	32	33	34	35	35
Norway	415	425	382	335	299	251	221	214	181	165
Poland	784	754	774	742	769	766	822	801	822	774
Portugal	238	234	228	217	210	198	190	185	176	161
Romania	290	274	278	293	302	325	326	304	322	278
Russian Federation	3839	3832	3825	3819	3812	3805	3745	3686	3626	3566
Serbia	149	147	148	151	154	149	147	151	146	145
Slovakia	153	154	141	140	141	150	143	138	135	125
Slovenia	55	56	52	51	49	48	46	46	44	41
Spain	934	907	870	838	818	787	758	743	676	618
Sweden	223	213	208	209	206	204	200	205	196	181
Switzerland	154	146	135	127	118	115	112	109	107	103
Tajikistan	22	23	24	24	27	28	30	32	33	34
Turkey	1608	1473	1291	1248	1180	1111	1091	987	1086	1092
Turkmenistan	84	86	92	96	100	99	98	100	101	99
Ukraine	610	616	623	629	635	641	623	604	585	566
United Kingdom	1648	1570	1481	1366	1278	1197	1147	1107	1026	921
Uzbekistan	226	224	218	216	209	211	216	219	222	230
Asian areas	5626	5792	5958	6125	6291	6457	6492	6527	6562	6597
North Africa	1211	1228	1244	1261	1277	1294	1302	1311	1320	1328
Baltic Sea	3	3	3	3	3	3	3	3	3	3
Black Sea	1	1	1	1	1	1	1	1	1	1
Mediterranean Sea	12	12	12	12	11	11	11	11	11	10
North Sea	6	6	6	6	6	6	6	6	6	5
North-East Atlantic Ocean	8	8	7	7	7	7	7	7	7	7
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	27345	26920	26409	26178	25920	25742	25469	25004	24726	24071

Table B:8: National total emission trends of non-methane volatile organic compounds (2010-2019), as used for modelling at the MSC-W (Gg of NMVOC per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Albania	33	32	32	31	31	30	31	32	33	34
Armenia	37	38	40	41	43	44	40	35	30	26
Austria	138	133	131	125	118	113	112	112	109	109
Azerbaijan	318	329	340	351	361	372	374	375	376	378
Belarus	308	346	347	339	330	310	291	286	281	276
Belgium	144	132	129	125	118	118	117	115	114	113
Bosnia and Herzegovina	45	60	75	89	104	119	115	110	105	100
Bulgaria	85	88	86	83	78	81	78	77	73	72
Croatia	92	87	81	77	70	71	73	70	71	75
Cyprus	13	11	10	9	8	9	9	11	10	9
Czechia	255	243	237	235	231	230	224	224	223	215
Denmark	131	125	120	121	112	115	111	109	108	103
Estonia	23	23	23	23	22	22	22	23	22	23
Finland	113	104	102	96	94	89	90	87	85	85
France	1206	1129	1076	1067	1050	1023	1001	1003	979	956
Georgia	35	36	36	36	37	36	37	35	32	31
Germany	1361	1273	1257	1212	1174	1147	1142	1147	1125	1121
Greece	215	200	193	176	172	165	157	153	146	144
Hungary	132	135	136	133	124	128	129	126	120	119
Iceland	6	6	5	5	5	6	6	6	6	5
Ireland	111	108	109	111	108	109	110	115	115	114
Italy	1117	1026	1030	999	928	901	884	925	897	894
Kazakhstan	597	605	614	623	631	640	629	617	606	595
Kyrgyzstan	44	47	51	55	59	63	57	52	47	42
Latvia	45	45	45	44	44	42	40	40	45	41
Lithuania	58	57	56	55	54	52	52	51	52	52
Luxembourg	12	12	12	12	11	11	11	11	11	11
Malta	4	3	3	4	3	3	3	3	3	3
Moldova	45	46	44	43	52	56	60	67	72	77
Montenegro	10	10	10	9	9	9	9	9	9	9
Netherlands	268	264	258	256	243	251	247	248	240	237
North Macedonia	27	30	30	30	27	26	26	26	25	24
Norway	169	160	161	160	169	165	163	160	157	153
Poland	738	728	704	652	648	668	696	711	680	647
Portugal	162	152	148	146	151	153	150	152	154	161
Romania	268	259	259	251	245	239	237	240	236	230
Russian Federation	3506	3559	3635	3642	3645	3676	3714	3787	3838	3838
Serbia	137	137	131	130	119	126	124	123	120	121
Slovakia	125	122	118	116	98	112	113	111	103	100
Slovenia	40	37	36	35	32	33	33	33	32	31
Spain	617	593	568	556	557	577	586	598	610	608
Sweden	177	174	166	158	154	155	148	140	136	134
Switzerland	100	97	95	93	89	86	84	83	82	81
Tajikistan	36	38	47	50	57	59	66	72	79	86
Turkey	1103	1077	1130	1072	1065	1108	1085	1110	1089	1121
Turkmenistan	107	111	111	118	124	127	142	157	172	187
Ukraine	547	526	504	483	461	440	426	412	398	384
United Kingdom	880	865	854	826	821	820	799	807	820	813
Uzbekistan	227	227	225	221	214	216	241	266	291	317
Asian areas	6631	6755	6878	7002	7125	7249	7745	8283	8842	9368
North Africa	1337	1357	1377	1398	1418	1438	1454	1515	1563	1602
Baltic Sea	3	3	3	3	2	2	2	2	2	3
Black Sea	1	1	1	1	1	1	1	1	1	1
Mediterranean Sea	11	10	11	11	10	10	10	10	10	13
North Sea	6	6	6	5	5	5	5	5	5	7
North-East Atlantic Ocean	7	7	7	7	6	7	6	6	6	8
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	23959	23781	23894	23746	23673	23862	24312	25085	25599	26105

Table B:9: National total emission trends of carbon monoxide (2000-2009), as used for modelling at the MSC-W (Gg of CO per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	79	81	82	84	85	87	84	81	78	75
Armenia	106	106	107	107	107	108	109	111	112	113
Austria	726	699	668	670	653	628	628	604	585	564
Azerbaijan	330	350	369	388	408	427	450	474	497	520
Belarus	1186	1159	1132	1105	1079	1052	1042	1033	1063	990
Belgium	981	910	950	905	853	794	737	612	619	425
Bosnia and Herzegovina	162	157	151	145	139	133	138	142	147	151
Bulgaria	370	337	380	391	346	332	347	324	315	292
Croatia	463	442	421	444	422	414	398	387	338	336
Cyprus	30	29	28	28	28	26	24	19	16	15
Czechia	1070	1053	1007	1020	1008	925	930	930	882	906
Denmark	477	468	443	446	428	428	414	418	397	362
Estonia	199	201	185	183	173	153	142	157	156	156
Finland	601	601	583	562	547	524	504	490	457	437
France	6433	6047	5856	5590	5674	5193	4617	4372	4183	3732
Georgia	132	140	140	141	139	95	99	111	108	106
Germany	5135	4938	4639	4390	4143	3916	3899	3861	3852	3294
Greece	1009	1014	965	928	916	869	884	827	761	695
Hungary	857	865	716	841	773	696	604	562	500	540
Iceland	75	72	70	70	72	52	57	71	109	111
Ireland	247	243	231	222	219	217	200	188	179	158
Italy	4751	4450	3855	3931	3394	3467	3323	3379	3510	3112
Kazakhstan	1318	1328	1337	1347	1356	1366	1521	1676	1831	1986
Kyrgyzstan	102	114	126	138	150	162	177	193	209	224
Latvia	263	270	259	260	248	234	232	214	198	207
Lithuania	182	182	181	176	174	178	183	183	180	170
Luxembourg	47	50	46	43	43	39	37	39	33	30
Malta	16	15	15	10	9	9	8	8	6	15
Moldova	58	59	58	70	68	71	71	64	70	64
Montenegro	41	38	44	47	47	46	47	48	47	43
Netherlands	762	760	749	745	756	730	733	709	704	658
North Macedonia	144	113	115	116	121	91	88	91	88	92
Norway	591	577	570	558	542	542	524	511	502	457
Poland	3382	3202	3191	3011	3003	2961	3148	2916	2941	2873
Portugal	683	637	615	591	562	523	490	464	426	403
Romania	888	817	833	892	994	1203	1120	1109	1150	1037
Russian Federation	13096	12886	12675	12464	12253	12042	11768	11493	11218	10943
Serbia	452	497	491	477	540	510	450	498	464	455
Slovakia	547	563	484	511	515	559	512	509	471	414
Slovenia	205	217	184	186	173	183	161	167	159	143
Spain	2513	2344	2151	2180	1977	1857	1814	1770	1632	1627
Sweden	676	635	601	588	549	538	507	501	484	469
Switzerland	401	377	351	342	327	314	293	278	270	254
Tajikistan	71	80	90	90	120	121	140	163	149	157
Turkey	3273	2895	2853	2819	2728	2605	2610	2632	2930	3008
Turkmenistan	411	421	449	469	512	503	496	462	465	433
Ukraine	3629	3666	3704	3741	3778	3815	3640	3465	3290	3115
United Kingdom	4525	4534	4047	3689	3469	3215	3016	2803	2644	2167
Uzbekistan	1074	1057	1022	1006	936	947	945	965	985	1019
Asian areas	19098	19550	20001	20453	20905	21356	21507	21658	21809	21960
North Africa	2394	2443	2491	2539	2587	2635	2602	2569	2535	2502
Baltic Sea	25	24	24	24	24	23	23	23	23	24
Black Sea	9	9	9	9	9	9	8	8	9	9
Mediterranean Sea	108	107	105	104	104	102	101	100	105	105
North Sea	59	58	57	56	56	55	55	54	55	56
North-East Atlantic Ocean	71	70	69	68	68	67	66	66	69	69
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	86535	84957	82981	82414	81312	80149	78730	77565	77019	74282

Table B:10: National total emission trends of carbon monoxide (2010-2019), as used for modelling at the MSC-W (Gg of CO per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Albania	72	71	70	70	69	69	71	73	75	77
Armenia	115	120	125	130	136	141	125	109	93	76
Austria	580	562	561	564	528	539	534	525	484	498
Azerbaijan	543	573	603	633	664	694	686	679	672	665
Belarus	870	880	878	860	843	767	760	739	717	696
Belgium	497	399	343	515	320	370	355	288	332	369
Bosnia and Herzegovina	156	182	209	235	261	288	276	265	253	242
Bulgaria	312	313	304	281	273	273	285	285	265	254
Croatia	325	302	288	277	244	266	257	251	231	216
Cyprus	14	13	13	12	12	12	12	12	11	11
Czechia	930	899	884	887	858	844	846	844	842	819
Denmark	353	311	293	279	255	260	250	239	223	209
Estonia	157	131	142	134	129	129	140	138	131	131
Finland	454	412	409	389	383	360	371	359	350	345
France	4126	3407	3099	3139	2628	2586	2612	2554	2425	2375
Georgia	108	114	114	125	137	130	140	132	113	109
Germany	3617	3550	3291	3252	3089	3190	3060	3082	2958	2883
Greece	616	598	641	552	559	538	481	493	469	464
Hungary	542	551	566	547	468	455	440	431	370	354
Iceland	110	107	108	110	109	111	109	113	113	106
Ireland	145	134	127	120	113	111	104	92	82	68
Italy	3073	2432	2680	2503	2260	2271	2195	2261	2052	2062
Kazakhstan	2141	2129	2118	2107	2096	2084	1928	1771	1615	1458
Kyrgyzstan	240	265	291	316	342	367	327	287	246	206
Latvia	167	169	168	150	142	118	115	121	125	120
Lithuania	164	157	153	141	131	124	122	120	122	116
Luxembourg	29	27	28	27	26	22	23	23	21	21
Malta	15	13	12	11	11	10	9	10	8	7
Moldova	68	73	69	71	98	104	109	135	192	174
Montenegro	46	48	45	38	37	38	38	37	35	34
Netherlands	666	650	619	585	564	562	581	596	628	626
North Macedonia	70	81	81	81	63	63	67	58	59	55
Norway	473	450	447	420	401	408	405	408	406	400
Poland	2980	2682	2648	2507	2257	2230	2340	2407	2318	2112
Portugal	402	370	355	335	317	325	311	327	285	293
Romania	1037	989	974	953	956	870	885	892	891	894
Russian Federation	10669	10998	11438	11656	11706	11755	11961	12152	12373	12373
Serbia	443	442	390	366	354	352	334	325	328	330
Slovakia	456	423	437	413	321	363	378	373	320	279
Slovenia	143	140	134	133	113	121	120	115	105	97
Spain	1641	1618	1384	1588	1416	1517	1494	1491	1639	1600
Sweden	459	440	412	404	390	376	377	368	346	336
Switzerland	247	224	218	211	189	181	177	170	165	161
Tajikistan	169	158	256	271	321	346	391	436	481	526
Turkey	2968	2662	2909	2155	2078	2336	2153	2115	1619	1674
Turkmenistan	486	517	493	547	572	594	671	748	826	903
Ukraine	2940	2898	2856	2813	2771	2729	2755	2782	2809	2835
United Kingdom	2080	1891	1870	1870	1779	1734	1604	1595	1598	1585
Uzbekistan	964	962	906	856	799	772	872	973	1074	1174
Asian areas	22111	22912	23712	24512	25312	26113	27901	29839	31853	33748
North Africa	2469	2557	2645	2734	2822	2910	2941	3066	3163	3241
Baltic Sea	22	21	21	21	20	20	20	20	21	28
Black Sea	8	8	8	8	8	8	8	8	8	10
Mediterranean Sea	97	96	96	95	92	94	91	93	94	120
North Sea	53	52	52	51	48	50	49	48	48	67
North-East Atlantic Ocean	63	63	63	62	60	61	59	59	60	75
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	74704	73252	74058	74125	72954	74161	75729	77937	79142	80709

Table B:11: National total emission trends of fine particulate matter (2000-2009), as used for modelling at the MSC-W (Gg of $PM_{2.5}$ per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	9	10	10	10	11	11	11	11	11	11
Armenia	4	4	4	4	4	4	4	4	4	4
Austria	24	24	23	23	23	23	22	21	20	19
Azerbaijan	16	16	16	17	17	17	18	19	21	22
Belarus	61	61	61	61	61	60	60	60	59	59
Belgium	40	39	37	37	37	34	35	33	33	29
Bosnia and Herzegovina	19	20	21	22	23	25	25	25	25	25
Bulgaria	25	24	28	31	30	30	32	31	31	29
Croatia	35	38	38	44	43	44	40	39	38	38
Cyprus	3	2	2	2	2	2	2	2	2	2
Czechia	49	50	47	47	47	43	44	42	41	42
Denmark	21	21	21	21	21	22	22	24	23	21
Estonia	15	16	17	14	15	13	10	13	12	10
Finland	26	27	27	27	27	26	26	25	23	22
France	317	304	283	283	269	247	222	205	197	185
Georgia	31	29	27	25	23	22	22	22	22	22
Germany	169	163	156	150	144	138	135	130	126	114
Greece	67	71	69	68	69	69	68	68	64	62
Hungary	50	54	39	48	45	42	42	42	38	49
Iceland	2	2	1	2	2	2	2	2	2	2
Ireland	20	20	19	19	19	19	19	18	18	17
Italy	195	186	156	175	152	173	180	204	217	201
Kazakhstan	116	116	116	116	116	116	127	138	149	161
Kyrgyzstan	8	9	9	10	11	11	12	13	14	15
Latvia	27	28	28	29	30	28	28	27	26	28
Lithuania	7	8	8	8	8	8	9	9	9	8
Luxembourg	2	3	2	3	3	3	2	2	2	2
Malta	1	1	1	1	1	1	1	1	1	0
Moldova	5	5	5	6	5	6	6	5	6	5
Montenegro	2	3	5	7	9	10	10	10	9	9
Netherlands	35	33	32	31	30	29	29	27	26	24
North Macedonia	30	19	19	29	32	24	22	17	18	13
Norway	42	41	42	39	37	37	35	35	34	32
Poland	164	162	159	156	156	155	159	153	150	143
Portugal	74	71	71	67	68	67	63	61	59	55
Romania	106	86	89	105	118	121	116	115	134	126
Russian Federation	479	475	470	465	461	456	443	430	418	405
Serbia	44	48	48	47	51	48	44	49	45	51
Slovakia	43	43	32	32	29	36	32	28	25	23
Slovenia	14	16	14	15	14	16	15	16	16	14
Spain	164	156	152	164	152	147	149	149	136	141
Sweden	33	32	31	32	31	31	29	29	28	26
Switzerland	12	11	11	11	11	11	10	10	10	9
Tajikistan	5	5	6	8	8	9	9	11	10	11
Turkey	393	388	382	377	372	367	382	398	413	429
Turkmenistan	18	17	18	21	20	21	21	16	18	17
Ukraine	397	401	404	408	411	415	400	385	370	355
United Kingdom	153	152	135	136	132	131	128	122	120	114
Uzbekistan	59	60	58	53	53	52	52	55	55	56
Asian areas	730	753	776	798	821	844	869	895	921	947
North Africa	113	117	122	126	130	134	134	133	133	132
Baltic Sea	31	30	30	29	29	28	22	19	18	17
Black Sea	8	8	8	8	8	8	8	8	7	7
Mediterranean Sea	126	125	122	121	119	118	116	115	106	102
North Sea	63	62	61	60	59	58	48	43	41	40
North-East Atlantic Ocean	78	77	76	75	74	73	72	71	66	63
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	4782	4741	4646	4720	4691	4683	4643	4635	4619	4566

Table B:12: National total emission trends of fine particulate matter (2010-2019), as used for modelling at the MSC-W (Gg of $PM_{2.5}$ per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019 EMEP	2019 EMEPwREf2.1C
Albania	11	11	11	11	11	10	11	12	12	13	12
Armenia	4	6	7	8	10	11	10	10	9	8	8
Austria	20	19	18	18	16	16	15	15	14	14	34
Azerbaijan	23	23	24	25	25	26	29	32	35	38	38
Belarus	58	57	56	55	53	52	53	54	55	56	55
Belgium	31	25	25	26	21	22	22	20	19	18	18
Bosnia and Herzegovina	25	32	39	45	52	59	55	52	49	46	36
Bulgaria	31	33	33	32	31	32	32	31	30	30	30
Croatia	38	37	35	35	30	33	32	30	29	29	29
Cyprus	2	1	1	1	1	1	1	1	1	1	1
Czechia	45	43	44	44	42	41	40	41	40	36	36
Denmark	21	19	18	18	17	17	17	16	15	13	13
Estonia	14	18	9	12	9	10	8	9	7	6	15
Finland	24	21	21	20	19	18	19	18	18	17	17
France	189	161	164	164	140	141	140	134	126	121	183
Georgia	22	23	24	25	25	26	25	25	24	24	24
Germany	120	115	114	112	104	103	97	96	95	92	122
Greece	48	47	49	44	45	43	40	40	38	37	37
Hungary	51	57	60	60	50	53	51	49	42	40	40
Iceland	2	2	2	2	2	2	1	1	1	1	1
Ireland	16	15	14	15	14	14	13	13	14	12	10
Italy	196	149	176	170	152	158	153	160	142	139	139
Kazakhstan	172	169	166	164	161	158	153	147	142	137	137
Kyrgyzstan	16	17	17	17	17	18	17	16	15	14	14
Latvia	22	22	23	21	21	18	18	20	20	20	20
Lithuania	8	9	8	7	6	6	6	6	6	5	21
Luxembourg	2	2	2	2	2	1	1	1	1	1	1
Malta	1	1	1	1	1	0	0	0	0	0	0
Moldova	6	6	6	7	13	14	15	20	31	27	27
Montenegro	8	8	8	8	8	7	7	7	7	7	5
Netherlands	23	21	20	19	18	18	17	17	16	15	15
North Macedonia	16	22	22	24	17	15	13	9	9	8	8
Norway	35	32	33	28	26	26	25	25	25	24	24
Poland	152	145	140	134	126	126	130	133	130	122	251
Portugal	56	57	54	52	51	51	51	51	50	50	50
Romania	130	120	123	115	115	110	110	111	111	112	112
Russian Federation	392	384	386	373	369	348	320	315	310	303	659
Serbia	50	50	49	44	44	45	47	45	45	46	46
Slovakia	26	24	26	24	16	21	21	21	17	18	19
Slovenia	15	14	14	14	12	13	13	12	11	11	11
Spain	137	139	122	135	120	128	125	124	136	135	135
Sweden	26	26	24	23	20	19	19	20	19	18	18
Switzerland	9	8	8	8	7	7	7	7	6	6	12
Tajikistan	11	11	14	16	21	24	25	27	29	30	30
Turkey	444	432	421	409	397	385	385	384	384	384	413
Turkmenistan	18	19	20	20	19	20	22	23	25	26	26
Ukraine	341	328	315	302	289	276	278	279	280	281	358
United Kingdom	123	111	116	119	112	112	110	110	112	109	109
Uzbekistan	55	56	53	53	51	49	52	56	59	63	63
Asian areas	973	984	995	1006	1017	1028	1099	1175	1255	1329	1329
North Africa	132	135	138	140	143	146	148	154	159	163	163
Baltic Sea	17	16	16	15	15	9	9	9	11	11	11
Black Sea	7	7	7	7	7	7	7	7	7	8	8
Mediterranean Sea	105	104	103	102	92	97	97	99	103	110	110
North Sea	39	36	36	36	34	22	22	22	25	26	26
North-East Atlantic Ocean	67	66	66	65	58	62	62	62	65	70	70
Natural marine emissions	0	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	1673	13185	0	0	0	0	0	0	0	0	0
TOTAL	6297	17679	4494	4447	4295	4273	4295	4374	4434	4477	5196

Table B:13: National total emission trends of particulate matter (2000-2009), as used for modelling at the MSC-W (Gg of PM_{10} per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	11	12	12	13	13	13	13	13	13	13
Armenia	5	5	5	5	5	5	5	5	5	6
Austria	38	38	37	36	36	36	35	34	33	31
Azerbaijan	21	21	21	22	22	22	23	25	26	28
Belarus	84	83	82	81	81	80	79	78	78	77
Belgium	55	53	50	51	50	46	46	43	43	38
Bosnia and Herzegovina	34	36	38	40	41	43	43	43	43	42
Bulgaria	46	44	47	53	54	56	59	61	58	51
Croatia	45	47	50	59	59	59	55	54	56	52
Cyprus	5	4	4	4	4	4	4	4	4	3
Czechia	66	66	62	61	61	58	59	57	55	55
Denmark	33	33	32	32	32	33	33	35	39	32
Estonia	32	32	28	24	25	21	16	23	19	15
Finland	43	44	44	45	44	42	43	41	39	37
France	420	406	382	383	368	341	314	294	284	267
Georgia	34	32	30	29	27	25	25	25	25	26
Germany	303	288	280	267	258	248	246	237	234	217
Greece	128	134	134	129	135	126	129	124	131	121
Hungary	74	81	63	75	77	74	66	64	66	78
Iceland	3	3	3	3	4	3	4	4	4	4
Ireland	39	39	38	40	40	41	42	41	39	38
Italy	248	240	208	226	203	223	227	251	261	240
Kazakhstan	177	177	177	178	178	178	192	206	219	233
Kyrgyzstan	11	12	13	14	14	15	17	18	19	21
Latvia	32	33	33	34	43	37	37	37	36	36
Lithuania	14	14	14	14	14	14	14	14	15	14
Luxembourg	3	3	3	4	3	3	3	3	3	3
Malta	1	1	1	1	1	1	1	1	1	1
Moldova	7	7	8	8	8	9	10	9	9	9
Montenegro	2	5	7	9	11	14	13	13	12	12
Netherlands	49	47	46	44	43	42	42	41	39	37
North Macedonia	44	28	28	42	46	37	34	28	28	22
Norway	51	50	51	48	45	46	44	45	43	41
Poland	288	286	285	279	276	279	290	277	271	259
Portugal	110	122	126	109	110	109	109	97	97	95
Romania	139	121	123	143	161	159	155	158	172	163
Russian Federation	987	982	976	971	966	961	935	908	882	855
Serbia	59	62	63	61	66	63	60	64	60	65
Slovakia	53	52	41	41	38	44	40	35	32	30
Slovenia	17	20	18	18	18	20	19	20	20	17
Spain	249	241	240	254	243	238	242	242	213	209
Sweden	52	51	50	51	50	50	49	49	46	44
Switzerland	19	19	18	18	18	18	18	18	18	17
Tajikistan	7	7	8	10	11	12	12	14	14	15
Turkey	517	508	499	491	482	473	495	517	538	560
Turkmenistan	24	23	24	28	26	27	28	22	24	22
Ukraine	587	592	597	603	608	613	590	568	545	522
United Kingdom	242	248	218	232	215	210	204	192	183	174
Uzbekistan	79	80	77	71	71	69	69	74	73	74
Asian areas	1226	1262	1298	1334	1370	1406	1444	1483	1521	1560
North Africa	196	205	213	222	230	238	239	239	239	239
Baltic Sea	31	30	30	29	29	28	22	19	18	17
Black Sea	8	8	8	8	8	8	8	8	7	7
Mediterranean Sea	126	125	122	121	119	118	116	115	106	102
North Sea	63	62	61	60	59	58	48	43	41	40
North-East Atlantic Ocean	78	77	76	75	74	73	72	71	66	63
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	7315	7300	7206	7301	7295	7273	7236	7202	7168	7049

Table B:14: National total emission trends of particulate matter (2010-2019), as used for modelling at the MSC-W (Gg of PM_{10} per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019 EMEP	2019 EMEPwREf2.1C
Albania	13	13	13	13	13	13	13	14	15	15	14
Armenia	6	7	9	10	12	13	12	12	11	10	10
Austria	32	31	30	30	28	28	28	28	26	26	46
Azerbaijan	29	30	30	31	32	33	36	40	44	48	48
Belarus	77	75	74	73	71	70	71	72	73	73	72
Belgium	40	33	34	35	29	31	31	30	28	27	27
Bosnia and Herzegovina	42	50	57	64	71	78	73	67	62	56	46
Bulgaria	53	57	55	52	52	55	48	47	47	46	46
Croatia	50	48	47	47	41	44	43	41	41	41	41
Cyprus	3	3	2	2	2	2	2	2	2	2	2
Czechia	58	55	56	56	53	52	51	52	51	47	47
Denmark	33	30	29	29	28	27	27	26	25	23	23
Estonia	23	34	14	20	15	14	12	14	11	9	19
Finland	39	36	35	34	34	31	33	31	31	30	30
France	273	244	247	246	219	222	221	217	207	202	266
Georgia	26	27	28	28	29	30	30	29	29	28	28
Germany	228	227	224	226	218	214	200	202	207	204	233
Greece	91	78	76	72	76	70	69	68	61	61	61
Hungary	74	77	75	79	74	75	72	67	63	62	62
Iceland	4	3	3	3	2	2	2	2	2	2	2
Ireland	35	29	29	29	28	29	28	29	29	28	26
Italy	234	186	211	204	186	191	186	193	174	172	172
Kazakhstan	247	243	239	235	231	227	222	217	213	208	208
Kyrgyzstan	22	22	22	23	23	23	22	21	20	19	19
Latvia	30	32	33	30	30	29	27	28	29	29	29
Lithuania	14	15	14	12	12	12	12	12	12	11	27
Luxembourg	3	2	2	2	2	2	2	2	2	2	2
Malta	1	1	1	1	1	1	1	1	1	1	1
Moldova	9	10	10	10	17	18	18	24	36	32	32
Montenegro	11	11	11	10	10	10	10	9	9	9	6
Netherlands	36	35	33	32	32	31	30	30	29	28	28
North Macedonia	28	35	34	37	27	22	20	14	14	13	13
Norway	43	41	43	37	34	34	33	34	33	32	32
Poland	271	258	250	237	225	226	232	237	233	218	321
Portugal	89	95	86	75	69	70	72	73	70	71	71
Romania	167	158	163	153	153	148	145	144	147	153	153
Russian Federation	829	823	830	811	808	782	749	745	738	729	1096
Serbia	65	65	63	58	57	59	62	60	60	61	61
Slovakia	32	30	31	30	22	28	26	27	23	23	25
Slovenia	17	16	16	16	14	15	15	15	14	13	13
Spain	202	201	179	191	175	186	187	184	198	195	195
Sweden	44	45	42	43	39	38	38	39	38	37	37
Switzerland	17	16	16	16	15	15	15	15	14	14	20
Tajikistan	15	14	19	21	27	31	33	35	37	40	40
Turkey	582	577	571	566	560	555	554	554	553	553	554
Turkmenistan	24	25	26	27	25	27	28	30	32	34	34
Ukraine	500	482	464	446	429	411	412	412	413	413	490
United Kingdom	190	173	173	182	173	172	173	179	176	171	171
Uzbekistan	73	75	71	70	68	64	69	73	77	82	82
Asian areas	1599	1625	1650	1676	1702	1728	1846	1974	2107	2233	2233
North Africa	239	244	248	253	257	261	264	275	284	291	291
Baltic Sea	17	16	16	15	15	9	9	9	11	11	11
Black Sea	7	7	7	7	7	7	7	7	7	8	8
Mediterranean Sea	105	104	103	102	92	97	97	99	103	110	110
North Sea	39	36	36	36	34	22	22	22	25	26	26
North-East Atlantic Ocean	67	66	66	65	58	62	62	62	65	70	70
Natural marine emissions	0	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	5970	47039	0	0	0	0	0	0	0	0	0
TOTAL	13064	54010	6946	6906	6758	6745	6803	6944	7063	7152	7828

Table B:15: National total emission trends of coarse particulate matter (2000-2009), as used for modelling at the MSC-W (Gg of PM_{coarse} per year).

Area/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Albania	2	2	2	2	2	2	2	2	2	2
Armenia	1	1	1	1	1	1	1	1	1	1
Austria	14	13	13	13	13	13	13	12	13	12
Azerbaijan	5	5	5	5	5	5	5	5	6	6
Belarus	23	22	22	21	20	19	19	19	19	19
Belgium	15	14	13	14	13	12	11	10	10	9
Bosnia and Herzegovina	15	16	17	17	18	19	18	18	18	17
Bulgaria	21	21	19	22	23	26	27	31	27	22
Croatia	9	9	12	15	16	15	15	15	17	15
Cyprus	2	2	2	2	2	2	2	2	2	2
Czechia	17	16	15	14	14	15	15	15	14	13
Denmark	12	11	12	11	11	12	11	11	16	11
Estonia	17	16	11	10	9	8	7	10	7	6
Finland	17	17	17	18	17	16	17	16	16	15
France	104	102	99	100	100	94	92	89	87	82
Georgia	3	3	3	3	3	3	3	3	3	3
Germany	134	125	124	117	114	110	110	107	108	102
Greece	62	63	65	61	65	57	61	57	67	59
Hungary	24	27	24	27	32	32	24	22	29	30
Iceland	1	1	1	2	2	1	2	2	2	2
Ireland	18	20	19	21	22	22	23	23	21	20
Italy	54	54	52	51	52	49	48	47	44	39
Kazakhstan	61	61	61	62	62	62	65	67	70	73
Kyrgyzstan	4	4	4	4	4	4	4	5	5	5
Latvia	5	5	5	5	12	8	9	10	10	8
Lithuania	6	6	6	6	6	6	6	6	5	5
Luxembourg	1	1	1	1	1	1	1	1	1	1
Malta	0	0	0	0	1	1	1	1	1	1
Moldova	2	3	3	2	3	4	4	4	4	3
Montenegro	1	1	2	2	3	4	3	3	3	3
Netherlands	15	14	15	13	13	13	13	13	13	13
North Macedonia	14	9	9	13	14	13	12	10	10	9
Norway	9	9	9	9	8	9	9	10	9	9
Poland	124	124	125	123	121	124	131	124	122	116
Portugal	36	50	54	42	42	42	46	36	39	40
Romania	33	34	34	38	43	38	39	43	39	36
Russian Federation	507	507	506	506	505	505	491	478	464	450
Serbia	14	14	15	14	15	15	15	15	15	14
Slovakia	9	9	9	9	8	8	8	7	7	7
Slovenia	3	4	4	4	4	4	4	4	4	3
Spain	85	85	88	91	91	91	93	93	77	69
Sweden	19	19	19	19	19	19	19	20	19	18
Switzerland	7	7	7	7	7	8	8	8	8	8
Tajikistan	2	2	2	3	3	3	3	4	4	4
Turkey	124	120	117	113	110	106	113	119	125	132
Turkmenistan	6	6	6	7	7	7	7	6	6	6
Ukraine	190	191	193	195	197	198	190	183	175	167
United Kingdom	89	96	83	96	83	79	75	70	63	59
Uzbekistan	20	20	19	18	18	17	17	18	18	19
Asian areas	496	509	522	535	549	562	575	587	600	613
North Africa	83	87	92	96	100	104	105	106	106	107
Baltic Sea	0	0	0	0	0	0	0	0	0	0
Black Sea	0	0	0	0	0	0	0	0	0	0
Mediterranean Sea	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0
North-East Atlantic Ocean	0	0	0	0	0	0	0	0	0	0
Natural marine emissions	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	0	0	0	0	0	0	0	0	0	0
TOTAL	2534	2558	2559	2581	2605	2591	2593	2567	2549	2483

Table B:16: National total emission trends of coarse particulate matter (2010-2019), as used for modelling at the MSC-W (Gg of PM_{coarse} per year).

Area/Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019 EMEP	2019 EMEPwREf2.1C
Albania	2	2	2	2	2	2	2	2	3	3	2
Armenia	2	2	2	2	2	2	2	2	2	2	2
Austria	12	12	12	12	12	12	12	12	12	12	12
Azerbaijan	6	6	6	7	7	7	8	8	9	10	10
Belarus	19	18	18	18	18	18	18	18	18	18	17
Belgium	9	8	9	9	9	9	9	9	9	9	9
Bosnia and Herzegovina	17	18	18	19	19	20	17	15	13	10	9
Bulgaria	22	24	22	20	21	24	16	15	17	17	17
Croatia	11	12	12	12	11	11	11	11	12	12	12
Cyprus	2	1	1	1	1	1	1	1	1	1	1
Czechia	12	12	12	12	12	11	11	11	11	11	11
Denmark	11	11	11	11	12	10	10	10	11	10	10
Estonia	9	16	5	8	6	5	4	5	4	3	4
Finland	15	15	14	15	14	14	14	13	13	13	13
France	83	83	83	82	79	80	80	83	81	81	84
Georgia	4	4	4	4	4	4	4	4	4	4	4
Germany	108	112	111	114	114	112	103	107	112	112	111
Greece	43	31	27	28	31	27	30	28	23	24	24
Hungary	22	19	16	19	23	22	21	19	21	22	22
Iceland	2	1	1	1	1	1	1	1	1	1	1
Ireland	19	14	14	14	14	15	15	16	15	16	16
Italy	38	37	35	34	34	33	33	33	33	33	33
Kazakhstan	75	74	73	71	70	69	69	70	71	71	71
Kyrgyzstan	5	5	5	5	5	5	5	5	5	5	5
Latvia	8	10	10	9	9	11	9	9	9	9	9
Lithuania	6	5	6	6	6	6	6	6	6	6	6
Luxembourg	1	1	1	1	1	1	1	1	1	1	1
Malta	1	1	1	1	1	0	0	0	1	1	1
Moldova	3	3	3	3	4	3	3	4	4	5	5
Montenegro	3	3	3	3	3	2	2	2	2	1	1
Netherlands	13	13	13	13	13	13	13	13	13	12	12
North Macedonia	12	14	13	13	10	7	7	5	6	5	5
Norway	9	9	10	9	9	8	9	9	9	9	9
Poland	120	114	110	104	99	100	102	103	102	97	70
Portugal	33	38	32	23	18	19	21	22	20	20	20
Romania	37	39	41	38	38	37	35	32	36	41	41
Russian Federation	437	439	444	437	440	434	429	430	428	425	436
Serbia	14	15	14	14	14	15	15	15	15	16	16
Slovakia	6	6	6	6	5	7	5	6	5	5	6
Slovenia	2	2	2	2	2	2	2	2	2	3	3
Spain	65	62	57	56	55	59	62	59	62	60	60
Sweden	18	20	18	20	18	18	19	19	19	19	19
Switzerland	8	8	8	8	8	8	8	8	8	8	8
Tajikistan	4	4	5	5	7	8	8	8	9	9	9
Turkey	138	144	151	157	163	170	170	169	169	169	141
Turkmenistan	6	6	6	7	6	6	7	7	7	8	8
Ukraine	159	154	149	144	140	135	134	133	133	132	132
United Kingdom	67	62	57	63	61	60	63	69	64	62	62
Uzbekistan	19	19	18	17	16	16	16	17	18	19	19
Asian areas	626	640	655	670	684	699	747	799	853	904	904
North Africa	107	109	111	112	114	115	116	121	125	128	128
Baltic Sea	0	0	0	0	0	0	0	0	0	0	0
Black Sea	0	0	0	0	0	0	0	0	0	0	0
Mediterranean Sea	0	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0	0
North-East Atlantic Ocean	0	0	0	0	0	0	0	0	0	0	0
Natural marine emissions	0	0	0	0	0	0	0	0	0	0	0
Volcanic emissions	4297	33854	0	0	0	0	0	0	0	0	0
TOTAL	6768	36331	2453	2459	2462	2473	2508	2570	2629	2675	2632

APPENDIX C

Sites used for the trends calculations

This appendix contains information of which EMEP sites have been used in the trend analysis for the different components and time periods presented in chapter 4.

Table C:1: The sites used in the trend calculations for the different components and periods, x: 2000–2019, a: 2005–2019, b: 2000–2010, c: 2010–2019

Code	O_3	SO_2	SO_4pm	SO_4dep	NO_2	totNO_3	NO_3pm	HNO_3	NO_3dep	totNH_4	NH_4pm	NH_3	NH_4dep	PM_{10}	$PM_{2.5}$	EC/OC
AT0002R	x	x	b	b	x	-	-	b	b	b	b	b	-	x	x	-
AT0005R	x	x	-	b	x	-	-	-	b	-	-	-	-	b	-	-
AT0030R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0032R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0040R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0041R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0042R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0043R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0045R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0046R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0047R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AT0048R	x	x	-	-	x	-	-	-	-	-	-	-	-	b	-	-
BE0001R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE0011R	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
BE0013R	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
BE0032R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BE0035R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH0002R	x	x	x	x	x	x	x	a	x	x	x	-	x	x	b	c
CH0003R	x	-	-	-	x	-	-	-	-	-	-	-	-	x	-	-
CH0004R	x	b	-	x	x	-	-	-	x	-	-	-	x	x	b	-
CH0005R	x	x	x	x	x	x	a	a	x	x	a	a	x	x	-	c
CY0002R	x	a	c	-	-	-	-	-	-	-	c	-	-	x	a	-
CZ0001R	x	b	b	c	b	b	-	-	c	b	-	-	-	-	-	-
CZ0003R	x	x	x	x	-	x	-	-	x	x	-	-	x	x	a	c
CZ0005R	x	-	-	c	-	-	-	-	c	-	-	-	-	x	-	-
DE0001R	x	x	b	-	x	b	-	-	-	b	-	-	-	x	-	-
DE0002R	x	x	a	c	x	a	a	a	c	-	-	a	-	x	x	c
DE0003R	-	x	x	c	x	b	-	-	c	b	-	a	-	x	x	c
DE0004R	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-
DE0007R	x	x	x	x	x	x	a	a	x	b	-	a	-	x	a	c
DE0008R	x	x	-	-	x	-	-	-	-	-	-	-	-	x	c	c
DE0009R	x	x	b	c	x	b	-	-	c	b	-	a	-	x	-	-
DE0043G	x	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-
DE0044R	-	-	-	-	-	-	-	-	-	-	x	-	-	x	x	-
DK0003R	-	x	x	-	-	x	-	-	-	x	x	x	-	-	-	-
DK0005R	x	b	b	x	x	b	-	-	x	b	-	-	x	b	-	-
DK0008R	-	x	x	a	x	x	-	-	a	x	x	x	-	-	-	-
DK0012R	-	a	a	-	a	a	-	-	-	-	a	a	-	-	-	-
DK0031R	-	a	a	-	-	a	-	-	-	b	-	a	-	-	-	-
EE0009R	x	-	-	x	-	-	-	-	x	-	-	-	-	a	a	-
EE0011R	x	-	-	x	-	-	-	-	x	-	-	-	-	-	a	-
ES0001R	-	a	a	a	a	a	-	-	a	a	-	c	-	a	a	-
ES0005R	-	a	c	-	c	a	c	-	a	a	-	-	-	a	-	-
ES0006R	-	c	c	-	c	c	c	-	c	c	-	-	-	a	c	-
ES0008R	x	x	x	x	x	-	x	-	-	-	-	-	x	x	x	-
ES0010R	x	x	x	-	x	-	x	-	-	x	-	-	-	x	x	-
ES0011R	x	x	x	x	x	-	x	-	x	-	-	-	x	x	x	-
ES0012R	x	x	x	x	x	x	x	-	x	x	-	-	x	x	x	-
ES0013R	x	x	x	x	x	-	x	-	x	x	-	-	x	x	x	-
ES0014R	x	x	x	x	x	x	x	-	x	-	-	-	x	x	x	-
ES0016R	x	x	x	x	x	x	x	-	-	-	-	-	-	x	x	-
ES0017R	-	a	a	a	a	a	a	-	-	-	-	-	-	a	-	-
ES1778R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	c
FI0004R	-	-	-	x	-	-	-	-	x	-	-	-	x	-	-	-
FI0009R	x	x	x	b	x	x	c	c	b	x	x	c	-	-	c	-
FI0018R	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
FI0017(18)R	x	x	x	x	x	x	c	c	x	x	x	c	-	a	x	-
FI0022R	x	x	x	x	-	x	-	c	x	x	a	c	x	-	-	-
FI0036R	-	x	x	x	-	x	c	c	x	x	x	c	x	-	c	-
FI0037R	x	x	x	-	x	x	-	-	-	x	c	-	-	-	-	-
FI0096G	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-

Table : C:1 Cont. The sites used in the trend calculations for the different components and periods, x: 2000–2019, a: 2005–2019, b: 2000–2010, c: 2010–2019

Code	O_3	SO_2	SO_4pm	SO_4dep	NO_2	totNO_3	NO_3pm	HNO_3	NO_3dep	totNH_4	NH_4pm	NH_3	NH_4dep	PM_{10}	$PM_{2.5}$	EC/OC
FR0008R	x	b	-	x	-	-	-	-	x	-	-	-	x	-	-	-
FR0009R	x	b	-	x	-	-	-	-	x	-	-	-	x	x	a	-
FR0010R	x	b	-	x	-	-	-	-	x	-	-	-	x	c	-	-
FR0013R	x	b	-	x	-	-	-	-	x	-	-	-	x	x	a	-
FR0014R	x	b	-	x	-	-	-	-	-	-	-	-	x	c	-	-
FR0015R	x	b	b	x	-	-	-	-	x	-	-	-	x	a	a	-
FR0017R	x	-	-	x	-	-	-	-	x	-	-	-	x	-	-	-
FR0018R	-	-	-	a	-	-	-	-	a	-	-	-	-	a	c	-
FR0022R	-	-	-	-	-	-	-	-	-	-	-	-	-	c	c	c
GB0002R	x	-	b	x	x	-	-	-	x	-	-	-	x	-	-	-
GB0006R	x	-	b	x	-	-	-	a	x	b	-	a	x	x	-	-
GB0007R	-	-	b	-	-	-	-	-	-	-	-	-	-	-	-	-
GB0013R	x	b	b	x	x	-	-	b	-	b	b	b	-	-	-	-
GB0014R	x	-	b	b	x	b	-	b	x	b	b	b	x	-	-	-
GB0015R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GB0031R	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0033R	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0036R	-	x	-	-	x	-	-	-	-	-	-	-	-	x	x	-
GB0037R	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0038R	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0039R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GB0043R	x	x	-	-	x	-	-	-	-	-	-	-	-	x	-	-
GB0045R	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0048R	-	a	x	x	-	-	a	a	x	-	a	a	x	a	x	-
GB0049R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GB0050R	x	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0051R	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
GB0053R	-	-	-	-	a	-	-	-	-	-	-	-	-	-	-	-
GR0002R	-	-	-	-	-	-	-	-	-	-	-	-	-	b	-	-
HR0002R	-	-	-	c	-	-	-	-	c	-	-	-	-	-	-	-
HU0002R	x	x	x	x	x	b	x	x	x	b	x	x	x	a	c	-
IE0001R	x	x	x	x	x	x	-	-	-	x	-	-	x	-	-	-
IE0005R	-	-	x	a	-	-	x	-	a	-	x	-	-	-	-	-
IE0006R	-	-	x	-	-	-	x	-	-	-	x	-	-	-	-	-
IE0008R	-	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-
IE0009R	-	-	-	x	-	-	-	-	x	-	-	-	x	-	-	-
IE0031R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS0091R	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-
IT0001R	-	b	b	-	x	-	b	-	x	-	b	-	-	x	-	-
IT0004R	x	x	x	x	-	-	x	-	x	-	x	-	x	-	x	c
LT0015R	x	x	x	x	x	x	-	-	x	x	-	-	x	-	-	-
LV0010R	x	x	x	x	x	x	-	-	-	x	x	-	-	a	a	-
LV0016R	-	b	-	-	b	b	-	-	-	b	b	-	-	-	-	-
MD0013R	-	c	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NL0007R	-	a	-	-	a	-	-	-	-	-	-	-	-	x	-	-
NL0009R	x	x	b	-	x	-	-	-	-	-	b	-	-	x	a	-
NL0010R	x	b	b	-	x	-	-	-	-	-	b	-	-	x	a	-
NL0091R	-	a	-	c	x	-	-	-	c	-	b	x	-	a	a	-
NL0644R	-	c	-	-	c	-	-	-	-	-	-	-	-	c	-	-
NO0001R	-	-	-	x	-	-	-	-	x	-	-	-	x	-	-	-
NO0002R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	c
NO0001(2)R	x	x	x	-	x	x	x	x	-	x	x	x	-	x	x	-
NO0015R	x	x	x	x	x	-	-	-	x	-	-	-	x	-	-	-
NO0039R	x	x	x	x	x	-	-	-	x	-	-	-	x	a	a	c
NO0043R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO0052R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO0055R	-	b	b	-	-	-	-	-	-	-	-	-	-	-	-	-
NO0056R	x	x	x	x	x	x	x	x	x	x	x	-	x	a	a	c
PL0002R	x	x	x	x	x	x	x	-	x	x	x	-	x	-	-	-
PL0004R	x	x	x	c	x	x	x	-	c	x	x	-	-	-	-	-
PL0005R	x	x	x	x	x	-	-	-	x	x	a	a	x	x	a	c
PT0003R	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-	-
PT0004R	-	-	-	b	-	-	-	-	-	-	-	-	-	-	-	-
RU0001R	-	b	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RU0018R	-	-	-	x	-	-	-	-	x	-	x	-	x	-	-	-
RU0020R	-	c	-	-	-	-	-	-	x	-	c	-	x	-	-	-

Table : C:1 Cont. The sites used in the trend calculations for the different components and periods, x: 2000–2019, a: 2005–2019, b: 2000–2010, c: 2010–2019

Code	O_3	SO_2	SO_4pm	SO_4dep	NO_2	totNO_3	NO_3pm	HNO_3	NO_3dep	totNH_4	NH_4pm	NH_3	NH_4dep	PM_{10}	$PM_{2.5}$	EC/OC
SE0002R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SE0005R	x	x	x	x	x	x	x	x	x	x	x	x	-	c	c	-
SE0008R	-	b	b	-	b	-	-	-	-	-	-	-	-	-	-	-
SE0011R	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	-
SE0012R	x	c	c	c	c	c	c	c	c	c	c	c	-	x	x	-
SE0013R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SE0014R	-	-	-	-	-	-	-	-	-	-	-	-	-	a	a	-
SE0002(14)R	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-
SE0011(20)R	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-	-
SE0032R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SE0035R	x	-	-	-	-	-	-	-	-	-	-	-	-	b	-	-
SE0039R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI0008R	x	x	x	x	x	x	-	-	x	x	-	-	x	x	x	c
SI0031R	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SK0004R	x	b	b	-	-	-	b	-	-	-	-	-	x	x	-	-
SK0005R	-	b	b	b	b	-	b	-	b	-	-	-	-	-	-	-
SK0006R	x	x	x	x	x	-	-	-	x	-	a	-	x	a	-	-
SK0007R	x	-	-	x	-	-	-	-	x	-	-	-	x	a	-	-

APPENDIX D

Source-receptor tables for 2019

The source-receptor tables in this appendix are calculated for the meteorological and chemical conditions of 2019, using the EMEP MSC-W model version rv4.42. The tables are calculated for the EMEP domain covering the geographic area between 30°N–82°N latitude and 30°W–90°E longitude, and are based on model runs driven by ECMWF-IFS(cy46r1) meteorology in $0.3° \times 0.2°$ longitude-latitude projection.

The source-receptor (SR) relationships give the change in air concentrations or depositions resulting from a change in emissions from each emitter country.

The tables in this appendix are based on model calculations using the EMEPwREF2.1C dataset as described in Chapter 3 and summarized in Appendix A.

For each country, reductions in five different pollutants have been calculated separately, with an emission reduction of 15% for SO_x, NO_x, NH_3, NMVOC or PPM, respectively. Here, a reduction in PPM means that $PPM_{2.5}$ and PPM_{coarse} are reduced together in one simulation. For year 2019, reductions in volcanic emissions are done for passive SO_2 degassing of Italian volcanoes (Etna, Stromboli and Vulcano).

The boundary conditions for all gaseous and aerosol species were given as 5-year monthly average concentrations, derived from EMEP MSC-W global runs, kept invariable over the calculation period.

The deposition tables show the contribution from one country to another. They have been calculated adding the differences obtained by a 15% reduction for all emissions in one country multiplied by a factor of 100/15, in order to arrive at total estimates.

For the concentrations and indicator tables, the differences obtained by the 15% emission reduction of the relevant pollutants are given directly. Thus, the tables should be interpreted as estimates of this reduction scenario from the chemical conditions in 2019.

The SR tables in the following aim to respond to two fundamental questions about transboundary air pollution:

1. Where do the pollutants emitted by a country or region end up?
2. Where do the pollutants in a given country or region come from?

Each column answers the first question. The numbers within a column give the change in the value of each pollutant (or indicator) for each receiver country caused by the emissions in the country given at the top of the column.

Each row answers the second question. The numbers given in each row show which emitter countries were responsible for the change in pollutants in the country given at the beginning of each row.

A list of abbreviations of countries and regions is given in Table 1.1.

More information on aerosol components and SR tables in electronic format are available from the EMEP website www.emep.int.

Acidification and eutrophication

- Deposition of OXS (oxidised sulphur). The contribution from SO_x, NO_x, NH_3, PPM and VOC emissions have been summed up and scaled to a 100% reduction. Units: 100 Mg of S.
- Deposition of OXN (oxidised nitrogen). The contribution from SO_x, NO_x, NH_3, PPM and VOC emissions have been summed up and scaled to a 100% reduction. Units: 100 Mg of N.
- Deposition of RDN (reduced nitrogen). The contribution from SO_x, NO_x, NH_3, PPM and VOC emissions have been summed up and scaled to a 100% reduction. Units: 100 Mg of N.

Ground Level Ozone

- $AOT40_f^{uc}$. Effect of a 15% reduction in NO_x emissions. Units: ppb.h
- $AOT40_f^{uc}$. Effect of a 15% reduction in VOC emissions. Units: ppb.h
- SOMO35. Effect of a 15% reduction in NO_x emissions. Units: ppb.d
- SOMO35. Effect of a 15% reduction in VOC emissions. Units: ppb.d

For ozone, we do not include the contributions from areas that are outside the EMEP domain. Until last year these had been included in the tables as BIC (Boundary and Initial Conditions) and were calculated by reducing NOx and NMVOC at the model boundary. However, the most important contributor to ozone from areas outside the EMEP domain is ozone itself, transported hemispherically accross the model boundary. Including the BIC contribution that is due (only) to NOx and NMVOC only would be misleading.

Particulate Matter

- $PM_{2.5}$. Effect of a 15% reduction in PPM emissions. Units: ng/m^3
- $PM_{2.5}$. Effect of a 15% reduction in SO_x emissions. Units: ng/m^3
- $PM_{2.5}$. Effect of a 15% reduction in NO_x emissions. Units: ng/m^3
- $PM_{2.5}$. Effect of a 15% reduction in NH_3 emissions. Units: ng/m^3
- $PM_{2.5}$. Effect of a 15% reduction in VOC emissions. Units: ng/m^3
- $PM_{2.5}$. Effect of a 15% reduction in all emissions. The contribution from a 15% reduction in PPM, SO_x, NO_x, NH_3 and VOC emissions have been summed up. Units: ng/m^3

Fine Elemental Carbon

- Fine EC. Effect of a 15% reduction in PPM emissions. Units: 0.1 ng/m^3

Coarse Elemental Carbon

- Coarse EC. Effect of a 15% reduction in PPM emissions. Units: 0.1 ng/m^3

Primary Particulate Matter

- $PPM_{2.5}$. Effect of a 15% reduction in PPM emissions. Units: ng/m^3

Table D.1: 2019 country-to-country blame matrices for **oxidised sulphur** deposition.
Units: 100 Mg of S. **Emitters** →, **Receptors** ↓.

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	
AL	14	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0	3	-0	0	0	0	0	0	2	AL
AM	0	11	0	16	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	2	0	0	0	-0	0	0	0	1	0	0	0	0	0	AM
AT	0	0	21	0	4	1	1	0	1	0	11	28	0	0	1	0	3	1	0	0	1	1	0	0	3	0	0	0	0	0	0	1	AT
AZ	0	3	0	120	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	8	0	-0	0	0	0	0	0	7	0	0	0	0	0	AZ
BA	0	0	1	0	117	0	1	0	0	0	3	3	0	0	1	0	1	0	0	1	2	2	0	0	4	0	0	0	0	0	0	7	BA
BE	0	-0	0	-0	0	28	0	0	0	0	1	11	0	0	1	0	12	5	-0	0	0	0	0	0	0	-0	0	0	1	0	0	0	BE
BG	1	0	0	0	5	0	139	0	0	0	1	2	0	0	1	0	1	0	0	10	0	1	0	0	2	0	1	0	0	0	1	2	BG
BY	0	0	0	0	5	1	4	86	0	0	8	16	1	2	1	1	1	2	0	1	0	1	0	0	1	0	1	3	0	1	1	1	BY
CH	0	0	0	0	0	0	0	0	9	0	0	5	0	0	2	0	6	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CY
CZ	0	0	2	0	4	1	1	0	0	0	106	37	0	0	1	0	2	2	0	0	0	1	0	0	1	0	0	0	0	0	0	1	CZ
DE	0	0	6	0	4	21	1	0	4	0	37	500	2	0	7	0	35	24	0	0	0	1	1	0	3	0	0	0	1	0	0	1	DE
DK	0	0	0	0	1	2	0	0	0	0	2	16	10	0	0	0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	DK
EE	0	0	0	0	1	0	0	2	0	0	1	4	0	11	0	3	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	EE
ES	0	0	0	0	2	0	0	0	0	0	0	2	0	0	248	0	5	2	0	0	0	0	0	0	4	0	0	0	0	0	0	0	ES
FI	0	0	0	0	2	1	1	4	0	0	4	12	1	10	1	54	1	3	0	0	0	0	0	0	0	0	2	2	0	1	0	0	FI
FR	0	0	1	0	1	11	0	0	2	0	3	34	0	0	68	0	199	26	0	0	0	0	1	0	10	0	0	0	1	0	0	0	FR
GB	0	-0	0	-0	0	4	0	0	0	0	2	13	0	0	5	0	12	280	-0	0	0	0	6	1	0	0	0	0	0	0	0	0	GB
GE	0	3	0	26	0	0	1	0	-0	0	0	0	0	0	0	0	0	0	54	1	0	0	0	0	0	0	3	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	1	0	0	0	4	0	19	0	0	0	1	2	0	0	1	0	1	0	0	84	0	0	0	0	5	0	0	0	0	0	0	2	GR
HR	0	0	1	0	25	0	2	0	0	0	4	4	0	0	2	0	1	0	0	1	14	2	0	0	9	-0	0	0	0	0	0	2	HR
HU	0	0	2	0	22	0	6	0	0	0	8	8	0	0	1	0	1	1	0	1	2	35	0	0	3	0	0	0	0	0	0	4	HU
IE	0	0	0	-0	0	1	0	0	0	0	0	2	0	0	1	0	2	10	0	0	0	0	19	0	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0	0	0	54	0	0	0	0	0	0	0	0	IS
IT	1	0	2	0	16	0	2	0	1	0	5	7	0	0	14	0	14	1	0	3	4	1	0	0	189	0	0	0	0	0	0	3	IT
KG	-0	0	0	1	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	86	120	0	0	0	0	0	KG
KZ	0	3	0	34	5	0	4	3	0	1	2	6	0	1	1	1	1	2	5	2	0	0	0	0	1	63	4392	0	0	0	0	2	KZ
LT	0	0	0	0	1	0	0	5	0	0	3	9	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	15	0	1	0	0	LT
LU	0	-0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	-0	0	0	0	0	0	0	-0	0	0	1	0	0	0	LU
LV	0	0	0	0	1	0	0	3	0	0	2	7	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	8	0	7	0	0	LV
MD	0	0	0	0	1	0	3	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	10	0	MD
ME	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	13	ME
MK	1	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	1	0	0	0	0	0	0	0	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	MT
NL	0	-0	0	-0	0	18	0	0	0	0	1	23	0	0	1	0	9	8	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	NL
NO	0	-0	0	0	1	1	0	1	0	0	3	12	2	1	1	1	2	11	0	0	0	0	0	2	0	0	0	1	0	0	0	0	NO
PL	0	0	2	0	10	2	3	6	0	0	50	104	3	1	2	1	5	7	0	1	1	3	0	0	2	0	1	2	0	0	0	2	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	PT
RO	1	0	1	1	21	0	45	1	0	0	6	9	0	0	1	0	1	1	1	7	1	6	0	0	3	0	2	0	0	0	3	7	RO
RS	1	0	1	0	38	0	11	0	0	0	4	4	0	0	1	0	1	0	0	5	1	4	0	0	3	0	0	0	0	0	0	17	RS
RU	0	4	3	59	30	5	34	63	1	1	32	81	3	45	6	36	10	19	14	15	1	5	1	2	6	8	3534	10	0	4	4	10	RU
SE	0	0	0	0	4	2	1	4	0	0	8	34	6	2	1	9	3	9	0	1	0	1	0	1	1	0	1	3	0	0	0	1	SE
SI	0	0	1	0	3	0	0	0	0	0	1	2	0	0	1	0	1	0	0	0	3	0	0	0	7	-0	0	0	0	0	0	0	SI
SK	0	0	1	0	8	0	2	0	0	0	10	7	0	0	1	0	1	1	0	1	1	6	0	0	2	0	0	0	0	0	0	1	SK
TJ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	17	0	0	0	0	0	TJ
TM	0	1	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	55	0	0	0	0	0	TM
TR	0	3	0	6	4	0	16	1	0	10	1	3	0	0	2	0	1	0	3	21	0	0	0	0	4	0	4	0	0	0	1	2	TR
UA	0	0	1	3	17	1	23	21	0	0	12	23	1	1	2	1	2	3	2	8	1	4	0	0	3	0	11	2	0	0	7	5	UA
UZ	0	1	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	14	116	0	0	0	0	0	UZ
ATL	0	0	1	0	4	11	2	3	0	0	10	56	2	4	139	8	37	169	0	1	0	1	19	190	3	0	59	1	0	0	0	1	ATL
BAS	0	0	1	0	6	4	2	6	0	0	19	74	10	11	2	22	6	13	0	1	0	1	0	0	1	0	1	7	0	2	0	1	BAS
BLS	0	1	0	7	8	0	29	3	0	1	3	7	0	0	1	0	1	1	14	9	0	1	0	0	2	0	6	0	0	0	3	3	BLS
MED	7	0	3	1	70	2	47	1	1	30	15	26	0	0	137	0	55	7	0	146	7	3	0	0	218	0	2	0	0	0	1	22	MED
NOS	0	-0	1	0	4	25	1	1	0	0	15	105	8	0	9	1	55	194	0	0	0	1	4	4	1	0	0	0	0	0	0	1	NOS
AST	0	4	0	117	1	0	3	1	0	8	1	2	0	0	1	0	0	0	6	5	0	0	0	0	1	24	537	0	0	0	0	1	AST
NOA	0	0	0	0	3	0	2	0	0	0	1	2	0	0	31	0	5	1	0	4	0	0	0	0	10	0	0	0	0	0	0	1	NOA
SUM	30	33	56	411	462	148	411	219	23	62	399	1307	52	92	704	143	499	815	111	344	43	86	54	256	515	199	8880	58	5	18	33	117	SUM
EXC	23	29	49	285	365	104	326	205	21	22	335	1034	30	76	386	111	340	430	91	178	35	78	30	61	278	176	8273	48	4	16	29	87	EXC
EU	4	0	43	1	138	95	225	29	10	8	267	876	24	27	366	70	313	389	1	110	28	60	28	4	247	0	9	32	4	10	5	29	EU
emis	31	30	55	394	466	148	441	223	22	79	399	1318	52	94	747	145	499	817	107	402	41	86	54	292	525	194	11048	58	5	19	34	125	emis
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	

Table D.1 Cont.: 2019 country-to-country blame matrices for **oxidised sulphur** deposition.
Units: 100 Mg of S. **Emitters →, Receptors ↓.**

	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	
AL	20	0	0	0	1	0	1	13	0	0	0	0	-0	0	2	1	0	0	0	0	10	0	0	5	5	3	42	131	65	11	AL
AM	0	0	0	0	0	0	0	0	1	0	0	0	0	0	42	0	0	0	0	0	1	0	55	2	12	0	2	147	74	1	AM
AT	1	-0	0	0	13	0	1	13	1	0	2	2	0	0	1	1	0	1	0	0	4	0	0	4	6	2	10	140	112	89	AT
AZ	0	-0	0	0	0	0	0	0	9	0	0	0	0	2	49	2	1	0	0	0	1	0	132	2	21	1	4	362	202	1	AZ
BA	4	0	0	0	7	0	3	54	1	0	0	1	0	0	4	2	0	1	-0	0	9	0	0	7	6	3	25	270	219	31	BA
BE	0	-0	4	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	2	0	0	1	2	0	1	2	3	0	75	64	64	BE
BG	30	0	0	0	7	0	25	69	6	0	0	1	0	0	119	13	0	0	0	3	11	0	11	9	11	5	44	535	440	190	BG
BY	4	-0	1	0	88	0	7	28	23	1	0	2	0	0	44	62	0	1	1	1	4	1	5	3	9	5	8	436	399	143	BY
CH	0	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	0	2	4	2	2	43	29	20	CH
CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	3	0	8	3	5	1	2	53	31	8	CY
CZ	1	0	1	0	30	0	2	18	1	0	0	3	0	0	1	1	0	1	0	0	2	0	0	2	4	2	6	236	217	190	CZ
DE	1	-0	17	1	55	1	1	13	2	0	0	1	0	0	1	1	-0	9	1	0	7	7	0	8	19	23	9	825	741	714	DE
DK	0	-0	2	0	10	0	0	3	1	0	0	0	0	0	0	1	0	1	1	0	1	1	0	1	2	7	1	73	58	51	DK
EE	0	0	0	0	12	0	1	3	5	1	0	0	0	0	3	5	0	0	1	0	0	0	0	0	2	2	1	66	59	38	EE
ES	1	0	0	0	1	16	0	4	0	0	0	0	-0	0	0	0	0	55	0	0	68	0	0	71	50	37	14	583	288	280	ES
FI	1	-0	1	2	32	0	1	10	75	6	0	1	0	0	9	16	0	3	3	0	1	1	2	1	8	13	4	291	253	132	FI
FR	0	0	4	0	4	4	0	3	0	0	0	0	0	0	0	0	0	54	0	0	56	9	0	43	53	61	16	667	375	366	FR
GB	0	0	3	0	4	1	0	1	1	0	0	0	-0	-0	0	0	-0	37	0	0	2	7	0	4	17	57	1	458	334	330	GB
GE	1	-0	0	0	1	0	1	3	7	0	0	0	0	1	176	5	0	0	0	2	2	0	91	4	24	3	9	420	284	5	GE
GL	0	-0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	6	2	0	13	4	2	GL
GR	39	0	0	0	4	0	5	36	3	0	0	0	0	0	122	7	0	1	0	2	56	0	15	22	31	15	97	576	338	124	GR
HR	3	0	0	0	9	0	3	43	1	0	1	1	-0	0	5	2	0	1	0	0	19	0	0	8	7	4	29	205	137	55	HR
HU	11	-0	0	0	24	0	20	132	2	0	1	8	0	0	12	5	0	0	0	0	6	0	1	4	5	2	13	343	312	122	HU
IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	1	1	0	1	7	22	0	78	36	35	IE
IS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	6	19	0	89	61	6	IS
IT	8	0	0	0	10	1	2	24	1	0	2	1	0	0	6	2	0	6	0	0	143	0	1	68	51	35	377	1004	321	260	IT
KG	0	-0	0	0	0	0	0	0	4	0	0	0	30	10	14	1	277	0	0	0	0	0	102	1	44	0	3	695	545	1	KG
KZ	8	-0	0	0	17	0	4	22	415	0	0	0	24	92	270	119	470	1	0	3	8	0	786	13	236	6	56	7087	5978	48	KZ
LT	1	-0	0	0	35	0	2	8	6	1	0	0	0	0	5	7	0	1	1	0	1	0	1	1	2	3	2	116	105	70	LT
LU	0	-0	0	0	0	0	0	0	0	0	0	0	-0	-0	0	0	-0	0	0	0	0	0	0	0	0	0	0	4	3	3	LU
LV	1	-0	0	0	21	0	1	6	5	1	0	0	0	0	5	7	0	1	1	0	1	0	1	1	2	3	1	98	86	56	LV
MD	2	-0	0	0	5	0	5	4	3	0	0	0	0	0	27	17	0	0	0	1	2	0	3	1	2	1	6	96	81	16	MD
ME	3	0	0	0	1	0	1	12	0	0	0	0	0	0	1	0	0	0	0	0	5	0	0	2	2	1	15	68	41	5	ME
MK	81	0	0	0	1	0	1	16	0	0	0	0	0	0	9	1	0	0	0	0	3	0	1	2	3	1	13	148	124	14	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	MT
NL	0	-0	26	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	5	0	1	2	6	0	105	89	88	NL
NO	1	-0	1	27	18	0	1	6	22	3	0	0	0	0	3	5	0	19	1	0	1	6	1	2	17	53	5	231	127	59	NO
PL	6	-0	2	1	824	0	11	60	9	1	1	7	-0	0	12	21	0	3	1	0	4	0	2	6	12	11	15	1220	1164	1036	PL
PT	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	29	0	0	3	0	0	6	10	12	0	121	61	60	PT
RO	30	-0	0	0	35	0	211	168	12	0	0	3	0	0	142	40	0	1	0	6	13	0	19	11	17	7	43	880	763	334	RO
RS	50	0	0	0	9	0	16	430	1	0	0	2	0	0	15	3	0	0	-0	0	7	-0	1	6	6	2	30	671	618	62	RS
RU	43	-0	4	5	251	1	42	165	4771	10	1	6	5	37	1102	992	74	26	6	25	39	4	513	38	1264	129	171	13768	11553	630	RU
SE	3	-0	2	7	64	0	3	19	27	31	0	1	0	0	11	18	0	6	5	0	3	3	2	3	13	27	10	353	280	184	SE
SI	1	0	0	0	3	0	1	7	0	0	7	0	-0	0	1	0	0	0	0	0	6	0	0	2	2	1	6	58	41	28	SI
SK	3	0	0	0	31	0	7	46	1	0	0	21	0	0	6	3	0	0	0	0	3	0	1	3	4	1	6	178	160	92	SK
TJ	0	-0	0	0	0	0	0	0	2	0	0	0	86	11	10	0	74	0	0	0	0	0	78	0	46	0	3	332	204	0	TJ
TM	0	-0	0	0	1	0	0	1	13	0	0	0	7	157	37	6	52	0	0	0	1	0	444	3	146	1	6	946	345	3	TM
TR	17	0	0	0	8	0	8	32	20	0	0	0	0	1	4522	33	0	1	0	19	91	0	1204	92	321	37	144	6637	4727	79	TR
UA	19	0	1	0	128	0	42	101	99	1	0	4	0	1	379	710	0	2	1	17	20	1	47	15	34	14	56	1847	1641	265	UA
UZ	1	0	0	0	1	0	0	2	14	0	0	0	37	55	34	6	492	0	0	0	1	0	262	2	111	1	7	1167	783	3	UZ
ATL	3	-0	9	22	46	80	2	17	438	6	0	1	0	0	17	22	1	1682	2	0	61	31	7	152	2247	4488	18	10077	1388	608	ATL
BAS	4	0	4	3	154	0	4	33	32	17	0	2	0	0	16	25	0	5	27	1	4	4	3	5	13	50	9	609	489	359	BAS
BLS	19	0	0	0	29	0	29	64	68	0	0	1	0	1	1166	177	0	1	0	136	28	0	150	16	51	105	57	2204	1658	117	BLS
MED	92	1	1	0	42	7	20	177	11	0	2	3	0	0	1693	36	0	44	1	13	2434	2	502	985	609	801	1472	9750	2887	773	MED
NOS	2	-0	31	12	53	1	2	17	4	2	0	1	0	0	3	4	0	56	3	0	6	92	1	8	40	357	7	1132	565	513	NOS
AST	5	0	0	0	6	0	2	8	68	0	0	0	34	118	658	38	149	0	0	2	36	0	10419	128	5221	17	77	17699	1797	30	AST
NOA	5	0	0	0	3	7	2	9	1	0	0	0	0	0	40	3	0	39	0	0	116	0	8	991	314	48	64	1714	135	71	NOA
SUM	532	1	116	82	2100	174	489	1900	6185	82	22	78	223	487	10819	2423	1591	2109	55	236	3307	179	14879	2773	11165	6516	3018	88127			SUM
EXC	402	0	71	45	1769	79	428	1574	5563	57	19	70	190	368	7225	2117	1441	282	23	84	621	51	3789	488	2671	649	1314		34972	6403	EXC
EU	145	0	64	12	1229	76	296	686	157	42	17	52	0	0	485	151	0	226	15	13	414	39	65	285	345	365	707		6868	4999	EU
emis	579	1	115	81	2135	221	495	1977	6839	82	21	79	209	564	12273	2539	1625	2465	56	248	3752	180	26445	6150	0	14630	4717	107425	48783	9132	emis
	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	

Table D.2: 2019 country-to-country blame matrices for **oxidised nitrogen** deposition.
Units: 100 Mg of N. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	
AL	19	0	1	0	1	0	1	0	0	0	0	1	0	0	2	0	2	0	0	5	1	1	0	0	10	0	0	0	0	0	0	1	AL
AM	0	27	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	104	0	2	3	0	0	10	0	16	86	1	0	3	0	17	5	0	0	3	5	0	0	23	0	0	0	1	0	0	0	AT
AZ	0	12	0	243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	3	0	0	0	0	0	AZ
BA	1	0	6	0	35	1	1	0	1	0	6	12	0	0	3	0	4	1	0	1	9	9	0	0	20	0	0	0	0	0	0	2	BA
BE	0	0	1	0	0	41	0	0	1	0	1	21	0	0	3	0	35	20	0	0	0	0	1	0	1	0	0	0	4	0	0	0	BE
BG	2	0	2	1	2	1	79	1	0	0	3	8	0	0	2	0	3	1	0	20	1	5	0	0	7	0	1	0	0	0	3	1	BG
BY	0	0	5	1	1	4	2	73	1	0	12	48	5	2	3	4	10	11	0	2	1	6	1	0	6	0	0	13	1	5	4	0	BY
CH	0	0	2	0	0	2	0	0	45	0	1	21	0	0	4	0	30	3	0	0	0	0	0	0	17	0	0	0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	CY
CZ	0	0	20	0	1	5	1	0	3	0	87	99	1	0	2	0	16	9	0	0	2	7	0	0	7	0	0	0	1	0	0	0	CZ
DE	0	0	41	0	1	72	0	1	30	0	47	918	10	0	17	1	191	108	0	0	2	5	6	0	23	0	0	1	13	1	0	0	DE
DK	0	0	1	0	0	6	0	0	1	0	3	41	21	0	1	0	10	23	0	0	0	1	1	0	1	0	0	0	1	0	0	0	DK
EE	0	0	1	0	0	2	0	4	0	0	2	14	3	7	0	6	3	5	0	0	0	1	0	0	1	0	0	4	0	4	0	0	EE
ES	0	0	1	0	1	2	0	0	1	0	1	7	0	0	554	0	37	8	0	0	1	1	1	0	14	0	0	0	0	0	0	0	ES
FI	0	0	2	0	0	4	0	10	1	0	5	35	7	9	2	95	8	17	0	0	0	2	1	0	2	0	0	7	0	6	1	0	FI
FR	0	0	6	0	0	39	0	0	20	0	4	108	2	0	166	0	743	107	0	0	1	1	10	0	47	0	0	0	6	0	0	0	FR
GB	0	0	1	0	0	13	0	0	1	0	2	41	3	0	12	0	49	421	0	0	0	0	34	0	2	0	0	0	1	0	0	0	GB
GE	0	12	0	67	0	0	0	0	0	0	0	1	0	0	0	0	0	0	51	1	0	0	0	0	0	0	1	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	4	0	1	0	1	0	15	0	0	0	2	5	0	0	4	0	4	1	0	131	1	2	0	0	14	0	0	0	0	0	1	1	GR
HR	1	0	13	0	12	1	1	0	1	0	7	16	0	0	5	0	7	1	0	1	30	13	0	0	46	0	0	0	0	0	0	1	HR
HU	1	0	21	0	8	2	4	1	2	0	14	31	1	0	3	0	7	3	0	2	10	68	0	0	20	0	0	0	0	0	1	1	HU
IE	0	0	0	0	0	2	0	0	0	0	0	5	0	0	3	0	9	25	0	0	0	0	40	0	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	1	0	0	0	0	0	4	1	0	0	0	3	10	0	0	0	0	1	8	0	0	0	0	0	0	0	0	IS
IT	2	0	22	0	7	2	1	0	12	0	8	31	1	0	44	0	64	5	0	4	14	7	0	0	700	0	0	0	0	0	0	1	IT
KG	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	42	0	0	0	0	0	KG
KZ	1	15	3	85	1	2	2	8	1	0	4	22	2	1	6	4	9	9	8	4	1	3	1	0	8	61	1098	2	0	1	2	0	KZ
LT	0	0	2	0	0	3	0	7	0	0	4	28	4	1	1	2	5	7	0	0	0	2	0	0	2	0	0	20	0	3	1	0	LT
LU	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	3	1	0	0	0	0	0	0	0	-0	0	0	3	0	0	0	LU
LV	0	0	2	0	0	2	0	6	0	0	4	26	4	2	1	4	5	7	0	0	0	2	0	0	2	0	0	10	0	13	0	0	LV
MD	0	0	1	0	0	0	2	1	0	0	1	3	0	0	0	0	1	1	0	1	0	1	0	0	1	0	0	0	0	0	16	0	MD
ME	2	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	1	0	0	5	0	0	0	0	0	0	6	ME
MK	2	0	0	0	0	0	3	0	0	0	1	1	0	0	1	0	1	0	0	11	0	1	0	0	2	0	0	0	0	0	0	0	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	MT
NL	0	0	1	0	0	19	0	0	1	0	1	32	1	0	2	0	25	32	0	0	0	0	2	0	1	0	0	0	1	0	0	0	NL
NO	0	0	2	0	0	6	0	2	1	0	4	36	13	1	3	5	13	53	0	0	0	1	4	0	1	0	0	2	0	1	0	0	NO
PL	1	0	21	0	4	17	2	10	4	0	65	257	17	1	5	3	36	40	0	2	5	21	2	0	16	0	0	5	2	2	2	0	PL
PT	0	0	0	0	0	0	0	0	0	0	0	1	0	0	27	0	3	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	PT
RO	2	0	9	1	7	2	31	3	1	0	11	32	1	0	5	1	8	5	1	12	4	24	0	0	17	0	1	1	0	0	12	2	RO
RS	5	0	6	0	10	1	9	0	1	0	8	16	0	0	3	0	5	2	0	9	4	15	0	0	13	0	0	0	0	0	1	4	RS
RU	3	18	25	133	7	28	19	144	8	1	43	257	30	31	23	113	69	101	24	24	7	27	8	1	40	6	779	44	3	33	18	2	RU
SE	0	0	4	0	1	13	1	8	1	0	10	104	34	3	4	24	22	51	0	1	1	4	4	0	4	0	0	7	1	4	1	0	SE
SI	0	0	13	0	1	0	0	0	1	0	3	8	0	0	2	0	3	1	0	0	5	3	0	0	24	0	0	0	0	0	0	0	SI
SK	0	0	10	0	3	1	2	0	1	0	14	24	1	0	2	0	5	3	0	1	3	19	0	0	8	0	0	0	0	0	0	0	SK
TJ	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	0	0	0	0	0	TJ
TM	0	4	0	33	0	0	0	0	0	0	0	2	0	0	0	0	1	1	2	0	0	0	0	0	1	1	22	0	0	0	0	0	TM
TR	1	13	2	17	1	1	12	2	1	5	2	11	1	0	7	0	6	2	6	45	1	3	0	0	10	0	2	0	0	0	2	0	TR
UA	1	1	11	6	5	6	15	32	2	0	20	73	6	1	7	4	14	16	3	16	4	22	1	0	18	0	4	7	1	3	25	1	UA
UZ	0	3	0	17	0	0	0	1	0	0	0	2	0	0	1	0	1	1	2	0	0	0	0	0	1	14	47	0	0	0	0	0	UZ
ATL	0	0	8	1	1	54	1	8	4	0	12	189	26	4	256	32	237	575	0	1	1	4	119	36	15	0	10	5	5	4	1	0	ATL
BAS	0	0	10	0	2	22	1	13	3	0	25	202	36	8	6	35	38	66	0	1	2	9	4	0	7	0	0	13	2	10	2	0	BAS
BLS	1	3	4	18	2	3	19	7	1	0	5	25	2	0	3	1	6	6	22	18	1	6	0	0	8	0	3	2	0	1	13	1	BLS
MED	25	1	39	3	27	15	35	3	15	16	27	118	4	0	396	1	275	40	1	273	35	24	3	0	622	0	1	1	2	1	4	9	MED
NOS	0	0	10	0	1	64	1	1	5	0	20	263	44	1	24	3	160	632	0	0	1	5	37	1	8	0	0	1	5	1	0	0	NOS
AST	0	19	1	235	1	1	2	2	1	6	1	7	1	0	4	1	5	2	11	13	0	1	0	0	5	25	175	0	0	0	1	0	AST
NOA	1	0	3	0	2	2	3	0	2	0	2	11	0	0	103	0	30	6	0	16	2	1	1	0	34	0	0	0	0	0	0	1	NOA
SUM	79	132	440	897	150	469	268	350	183	34	508	3313	285	72	1729	341	2238	2449	147	621	159	334	289	48	1836	183	2198	151	57	94	112	38	SUM
EXC	51	108	365	640	116	309	207	316	153	12	415	2496	172	60	937	268	1488	1122	113	300	116	284	124	10	1136	158	2008	127	43	78	91	26	EXC
EU	15	1	300	4	51	255	139	52	92	5	314	1981	113	24	871	137	1317	908	2	178	86	194	108	1	980	0	3	57	36	35	23	8	EU
emis	87	128	439	895	157	488	294	390	187	43	525	3460	300	77	1966	365	2355	2565	144	760	164	348	307	63	1907	190	2644	160	59	101	124	39	emis
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	

Table D.2 Cont.: 2019 country-to-country blame matrices for **oxidised nitrogen** deposition.
Units: 100 Mg of N. **Emitters →, Receptors ↓.**

	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	
AL	2	0	0	0	1	0	1	5	1	0	0	0	0	0	1	1	0	0	0	0	16	0	0	4	13	-0	0	91	57	27	AL
AM	0	0	0	0	0	0	0	0	1	0	0	0	0	1	10	0	0	0	0	0	1	0	36	1	14	-0	0	125	73	1	AM
AT	0	0	5	1	14	0	1	3	1	0	6	3	0	0	0	1	0	1	2	0	7	8	0	3	21	-0	0	360	317	300	AT
AZ	0	0	0	0	0	0	0	0	13	0	0	0	0	5	12	1	1	0	0	0	1	0	103	1	26	-0	0	436	304	2	AZ
BA	0	0	1	0	8	0	3	12	1	0	1	3	0	0	0	2	0	1	1	0	15	2	0	6	18	-0	-0	188	145	90	BA
BE	0	0	11	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	28	0	1	12	0	-0	188	142	141	BE
BG	3	0	1	0	11	0	33	17	10	0	0	2	0	0	34	14	0	1	1	8	21	2	5	5	30	-0	0	344	271	181	BG
BY	0	0	6	2	98	0	13	5	55	5	1	5	0	0	9	69	0	2	22	3	6	15	2	2	45	-0	0	588	491	269	BY
CH	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	5	5	0	2	12	-0	-0	156	131	85	CH
CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	6	0	5	1	6	-0	-0	30	13	6	CY
CZ	0	0	7	1	32	0	2	4	1	1	2	7	0	0	0	1	0	2	3	0	3	13	0	2	19	-0	0	367	325	312	CZ
DE	0	0	100	6	53	2	2	2	3	4	2	4	0	0	0	2	0	20	26	0	12	163	0	7	105	0	0	2003	1669	1623	DE
DK	0	0	13	2	10	0	1	1	1	3	0	1	0	0	0	1	0	3	20	0	1	37	0	1	11	-0	0	218	145	140	DK
EE	0	0	3	1	15	0	1	0	13	5	0	1	0	0	1	5	0	1	23	0	1	7	0	0	10	-0	0	145	103	78	EE
ES	0	0	2	0	1	59	0	0	1	0	0	0	0	0	0	0	0	93	0	0	131	7	0	53	183	-0	-0	1160	693	689	ES
FI	0	0	9	11	34	0	2	1	86	26	0	1	0	0	1	11	0	9	72	0	2	25	1	1	55	-0	-0	564	400	277	FI
FR	0	0	28	1	5	14	0	0	1	1	1	1	0	0	0	1	0	97	3	0	100	134	0	37	217	0	-0	1905	1316	1292	FR
GB	0	0	20	4	5	2	0	0	1	1	0	0	0	0	0	0	0	60	4	0	3	128	0	3	83	0	-0	899	616	609	GB
GE	0	0	0	0	1	0	1	0	9	0	0	0	0	2	37	2	0	0	0	3	3	0	47	2	32	-0	0	278	190	7	GE
GL	0	0	0	0	1	0	0	0	1	0	0	0	-0	0	0	0	0	1	0	0	0	1	0	0	17	-0	-0	27	8	6	GL
GR	5	0	1	0	5	0	7	9	5	0	0	1	0	0	35	7	0	1	1	4	93	1	8	16	61	-0	0	452	267	198	GR
HR	0	0	1	0	11	0	3	9	1	0	5	4	0	0	1	2	0	1	1	0	32	2	0	7	21	-0	0	262	198	169	HR
HU	1	0	2	0	33	0	23	25	3	0	4	15	0	0	2	8	0	1	2	1	11	4	0	3	21	-0	0	361	318	265	HU
IE	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	17	1	0	1	13	0	1	26	-0	0	148	90	89	IE
IS	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	6	0	0	18	-0	-0	65	34	25	IS
IT	1	1	3	0	11	3	2	6	2	0	13	3	0	0	1	2	0	9	1	0	253	6	1	62	138	-0	0	1447	976	941	IT
KG	0	0	0	0	0	0	0	0	5	0	0	0	18	7	2	0	162	0	0	0	0	0	90	0	56	-0	0	463	316	2	KG
KZ	1	0	4	3	20	1	7	3	689	3	1	2	17	118	54	62	268	4	9	6	12	9	737	7	529	-0	0	3929	2617	121	KZ
LT	0	0	4	2	38	0	2	1	11	4	0	1	0	0	1	8	0	1	20	0	1	11	0	0	14	0	0	217	168	136	LT
LU	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	13	11	10	LU
LV	0	0	4	2	28	0	2	1	13	5	0	1	0	0	1	8	0	2	26	0	1	11	0	0	15	-0	0	213	158	125	LV
MD	0	0	0	0	7	0	8	1	6	0	0	1	0	0	6	19	0	0	1	3	3	1	1	1	7	-0	0	95	79	28	MD
ME	0	0	0	0	1	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	2	6	-0	0	45	29	14	ME
MK	11	0	0	0	1	0	1	6	1	0	0	0	0	0	2	1	0	0	0	0	5	0	0	2	7	-0	0	63	49	25	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	MT
NL	0	0	61	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	1	51	0	0	14	0	0	253	180	178	NL
NO	0	0	12	81	18	1	1	1	11	18	0	1	0	0	0	4	0	28	27	0	2	80	0	1	61	-0	-0	495	295	195	NO
PL	1	0	30	7	545	1	16	12	17	10	3	21	0	0	2	30	0	7	58	1	9	63	1	5	74	-0	0	1449	1233	1144	PL
PT	0	0	0	0	0	84	0	0	0	0	0	0	0	0	0	0	0	49	0	0	7	1	0	4	36	-0	-0	214	117	117	PT
RO	3	0	3	1	46	0	224	32	23	1	1	8	0	0	32	52	0	1	4	11	22	7	8	7	56	-0	0	742	625	451	RO
RS	6	0	1	0	14	0	18	82	3	0	1	5	0	0	3	4	0	1	1	1	12	3	1	5	22	-0	0	297	252	132	RS
RU	3	0	47	37	285	3	64	24	6134	58	4	17	3	55	204	585	52	58	197	47	58	121	376	20	1478	-1	0	11997	9643	1403	RU
SE	0	0	26	36	67	1	4	3	30	98	1	3	0	0	1	14	0	16	117	0	4	88	1	2	82	-0	-0	903	592	495	SE
SI	0	0	0	0	4	0	1	1	0	0	17	1	0	0	0	0	0	0	0	0	9	1	0	2	7	-0	0	108	88	84	SI
SK	0	0	2	0	35	0	9	9	2	0	2	25	0	0	1	4	0	1	2	0	5	4	0	2	13	-0	0	215	189	166	SK
TJ	0	0	0	0	0	0	0	0	2	0	0	0	43	9	2	0	44	0	0	0	0	0	72	0	42	-0	0	228	113	1	TJ
TM	0	0	0	0	1	0	0	0	25	0	0	0	4	226	9	3	59	0	0	1	2	1	506	1	148	-0	0	1056	398	8	TM
TR	2	0	1	0	10	1	13	6	37	0	0	1	0	2	899	26	0	2	2	38	154	2	511	43	397	-0	0	2304	1156	138	TR
UA	2	0	11	3	161	1	69	19	201	5	2	12	0	2	85	577	1	4	22	36	34	21	19	9	134	-0	0	1753	1475	505	UA
UZ	0	0	0	0	1	0	1	0	27	0	0	0	23	60	8	3	271	0	0	1	2	1	262	1	121	-0	0	875	487	10	UZ
ATL	0	0	79	132	47	126	3	2	295	32	1	2	0	0	2	14	1	1403	61	1	101	397	3	74	3613	4	-0	8001	2344	1836	ATL
BAS	0	0	41	18	140	1	7	5	46	55	2	7	0	0	2	22	0	13	217	1	6	108	1	3	68	1	0	1280	862	748	BAS
BLS	2	0	4	1	38	0	46	12	131	2	1	3	0	2	248	144	0	2	7	125	46	8	61	8	93	0	0	1165	815	204	BLS
MED	10	11	17	3	50	26	33	42	25	3	13	9	0	0	373	33	0	80	10	24	2365	45	243	704	1160	1	2	7298	2664	2088	MED
NOS	0	0	119	73	54	4	3	3	6	20	1	3	0	0	0	4	0	109	64	0	10	601	0	6	197	3	0	2568	1578	1484	NOS
AST	0	0	1	1	7	0	3	2	115	1	0	1	27	184	175	19	101	2	2	5	77	2	8684	62	4629	-0	0	14621	1158	65	AST
NOA	1	1	2	0	4	20	3	3	3	0	1	1	0	0	14	3	0	89	1	1	281	6	13	835	805	-0	0	2311	279	249	NOA
SUM	58	14	693	434	1973	355	635	373	8067	364	88	177	137	674	2282	1771	962	2208	1036	322	3957	2253	11801	2027	15103	7	4	77978			SUM
EXC	45	2	430	207	1635	177	537	306	7446	252	70	151	109	487	1466	1531	860	511	674	166	1072	1085	2795	335	4538	-2	1		29561	13312	EXC
EU	16	1	341	78	1005	170	336	138	226	161	60	104	0	1	122	171	0	402	390	28	735	816	31	225	1336	-0	0		11220	10216	EU
emis	64	17	726	458	2074	449	662	392	9534	387	89	185	150	805	2623	1870	1052	2829	1063	341	4622	2308	20243	3854	0			78524	43264	21270	emis
	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	

Table D.3: 2019 country-to-country blame matrices for **reduced nitrogen** deposition.
Units: 100 Mg of N. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	
AL	68	0	0	0	0	0	1	0	0	0	0	1	0	0	4	0	1	0	0	5	1	1	0	0	10	0	0	0	0	0	0	1	AL
AM	0	44	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	252	0	1	2	0	1	19	0	34	124	2	0	6	0	19	2	0	0	5	9	0	0	33	0	0	0	0	0	0	0	AT
AZ	0	16	0	279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	AZ
BA	2	0	4	0	76	0	1	1	1	0	6	8	0	0	6	0	3	0	0	1	23	13	0	0	23	0	0	0	0	0	0	2	BA
BE	0	-0	1	-0	0	154	0	0	1	-0	1	24	0	0	6	0	85	12	-0	0	0	0	2	0	1	0	-0	0	4	0	0	0	BE
BG	3	0	1	1	1	0	154	2	0	0	3	6	0	0	5	0	2	0	1	24	1	7	0	0	7	0	0	0	0	0	3	0	BG
BY	0	0	4	0	1	2	3	467	2	0	9	37	6	1	4	2	9	5	0	1	2	8	1	0	6	0	0	24	0	6	5	0	BY
CH	0	0	2	0	0	2	0	0	234	0	1	33	0	0	8	0	39	2	0	0	0	0	1	0	25	0	0	0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CY
CZ	0	0	22	0	1	4	1	1	5	0	274	108	2	0	4	0	19	5	0	0	4	11	1	0	9	0	0	0	0	0	0	0	CZ
DE	0	0	52	0	1	71	0	2	62	0	54	2407	20	0	33	0	284	57	0	0	4	8	10	0	27	-0	0	2	13	1	0	0	DE
DK	0	0	1	0	0	4	0	0	1	0	3	64	173	0	2	0	12	12	0	0	0	1	2	0	1	0	0	0	0	0	0	0	DK
EE	0	0	1	0	0	1	0	9	0	0	2	12	3	34	0	3	3	2	0	0	0	1	1	0	1	0	0	5	0	7	0	0	EE
ES	0	0	1	0	1	1	0	0	2	0	1	7	0	0	1673	0	59	3	0	0	1	1	2	0	18	0	0	0	0	0	0	0	ES
FI	0	0	1	0	0	3	0	18	1	0	4	29	7	7	3	142	10	8	0	0	0	2	2	0	1	0	0	7	0	5	1	0	FI
FR	0	0	5	0	1	46	0	0	41	0	4	97	2	0	314	0	2662	61	0	0	2	2	19	0	65	0	0	0	5	0	0	0	FR
GB	0	0	1	-0	0	13	0	1	2	0	2	43	3	0	18	0	91	914	0	0	0	0	103	0	2	-0	0	0	1	0	0	0	GB
GE	0	13	0	54	0	0	0	0	0	0	0	1	0	0	1	0	0	0	144	1	0	0	0	0	0	0	1	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	8	0	1	0	1	0	13	1	0	0	1	4	0	0	8	0	3	0	0	195	1	3	0	0	13	0	0	0	0	0	1	0	GR
HR	1	0	10	0	14	0	1	1	1	0	9	13	0	0	9	0	5	1	0	1	117	27	0	0	57	-0	0	0	0	0	0	0	HR
HU	1	0	17	0	7	1	5	2	2	0	15	24	1	0	5	0	6	1	0	2	26	253	0	0	24	0	0	0	0	0	1	1	HU
IE	0	-0	0	-0	0	2	0	0	0	0	0	9	1	0	4	0	19	31	-0	0	0	0	420	-0	1	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	1	0	0	0	0	0	5	1	0	1	0	9	8	0	0	0	0	3	14	0	0	0	0	0	0	0	0	IS
IT	3	0	17	0	5	2	2	1	16	0	9	27	1	0	75	0	48	2	0	3	13	9	1	0	1787	0	0	0	0	0	0	1	IT
KG	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	156	14	0	0	0	0	0	KG
KZ	1	11	2	58	1	1	2	13	1	0	3	16	2	1	7	2	7	4	11	2	1	3	1	0	5	49	439	2	0	1	2	0	KZ
LT	0	0	1	0	0	1	0	27	1	0	3	22	5	1	1	1	5	4	0	0	0	2	1	0	2	0	0	99	0	6	1	0	LT
LU	0	-0	0	-0	0	3	0	0	0	0	0	3	0	0	0	0	9	0	-0	0	0	0	0	0	0	-0	0	0	8	0	0	0	LU
LV	0	0	1	0	0	1	0	20	1	0	2	20	5	3	1	2	5	4	0	0	0	2	1	0	2	0	0	22	0	56	0	0	LV
MD	0	0	0	0	0	0	2	2	0	0	1	2	0	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	39	0	MD
ME	4	0	0	0	1	0	0	0	0	0	0	1	0	0	2	0	1	0	0	1	1	1	0	0	5	0	0	0	0	0	0	11	ME
MK	5	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0	0	0	0	12	0	1	0	0	2	0	0	0	0	0	0	0	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	MT
NL	0	-0	1	-0	0	47	0	0	1	-0	1	78	0	0	4	0	41	20	-0	0	0	0	3	-0	0	-0	-0	0	1	0	0	0	NL
NO	0	0	1	0	0	4	0	4	1	0	3	32	16	1	5	2	19	27	0	0	0	1	8	0	1	0	0	2	0	1	0	0	NO
PL	1	0	17	0	3	10	2	32	5	0	69	232	24	1	9	1	38	20	0	1	7	31	4	0	18	0	0	10	1	2	2	0	PL
PT	0	-0	0	0	0	0	0	0	0	0	0	1	0	0	49	0	4	0	0	0	0	0	0	0	1	-0	0	0	0	0	0	0	PT
RO	3	0	7	1	6	1	35	6	1	0	10	26	2	0	10	0	7	2	1	13	7	50	0	0	20	0	1	1	0	0	17	1	RO
RS	7	0	4	0	10	0	11	1	1	0	7	11	0	0	6	0	3	1	0	9	11	28	0	0	15	0	0	0	0	0	1	4	RS
RU	3	14	17	95	8	15	20	294	9	1	33	192	30	21	33	48	63	47	36	15	8	29	11	0	37	5	232	49	1	31	20	1	RU
SE	0	0	3	0	1	7	1	18	2	0	10	94	51	3	7	12	24	25	0	0	1	6	6	0	4	0	0	12	0	5	1	0	SE
SI	0	0	14	0	1	0	0	0	1	0	4	8	0	0	3	0	2	0	0	0	8	5	0	0	33	0	0	0	0	0	0	0	SI
SK	0	0	10	0	3	1	2	1	1	0	19	22	1	0	3	0	4	1	0	1	7	37	0	0	10	0	0	0	0	0	0	0	SK
TJ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	TJ
TM	0	3	0	17	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	1	3	0	0	0	0	0	TM
TR	2	10	1	11	1	1	11	3	1	6	2	7	0	0	15	0	6	1	9	23	1	3	0	0	10	0	1	0	0	0	2	0	TR
UA	2	1	9	4	5	4	16	86	2	0	18	64	6	1	12	1	11	8	4	12	7	38	1	0	20	0	3	9	0	3	36	1	UA
UZ	0	2	0	11	0	0	0	1	0	0	0	1	0	0	1	0	1	0	2	0	0	0	0	0	0	22	11	0	0	0	0	0	UZ
ATL	0	0	7	0	1	44	1	13	6	0	14	213	30	3	426	12	584	446	0	1	2	5	350	19	21	0	5	6	3	3	1	0	ATL
BAS	0	0	8	0	1	12	1	29	4	0	20	234	112	10	8	27	36	30	0	1	3	10	7	-0	8	0	0	22	1	14	2	0	BAS
BLS	2	3	2	13	2	1	20	14	1	1	4	17	2	0	5	1	5	2	38	11	2	7	0	0	8	0	1	2	0	1	16	1	BLS
MED	34	1	23	2	16	8	25	5	16	16	21	66	3	0	606	0	245	15	1	125	32	24	3	0	595	0	0	1	1	0	4	5	MED
NOS	0	0	8	0	1	73	1	3	6	0	19	368	106	1	38	1	318	456	0	0	2	6	66	0	7	0	0	2	3	1	0	0	NOS
AST	0	12	0	127	0	0	2	3	0	5	1	4	1	0	5	0	2	1	12	4	0	1	0	0	3	33	27	0	0	0	1	0	AST
NOA	1	0	1	0	1	1	2	1	1	0	1	5	0	0	120	0	27	2	0	5	1	2	1	0	25	0	0	0	0	0	0	0	NOA
SUM	154	130	535	701	175	549	341	1085	453	44	699	4827	620	86	3568	258	4856	2249	283	473	304	651	1031	34	2964	270	742	284	46	145	157	32	SUM
EXC	115	114	486	559	152	409	289	1018	420	22	619	3921	367	72	2360	217	3639	1296	230	327	262	597	604	15	2298	237	708	250	38	126	134	26	EXC
EU	22	1	439	2	48	378	219	144	167	14	534	3505	305	48	2254	162	3464	1190	3	243	208	468	578	0	2135	0	2	162	35	84	29	5	EU
emis	163	124	526	651	179	548	361	1103	443	56	699	4832	620	87	3881	260	4881	2240	268	526	303	654	1033	37	2921	266	898	286	46	146	162	33	emis
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	ME	

Table D.3 Cont.: 2019 country-to-country blame matrices for **reduced nitrogen** deposition.
Units: 100 Mg of N. **Emitters →, Receptors ↓.**

	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	
AL	-0	0	0	0	1	0	2	6	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	3	0	-1	110	105	28	AL
AM	0	0	0	0	0	0	0	0	1	0	0	0	0	1	53	0	0	0	0	0	0	0	20	2	5	0	-0	154	127	1	AM
AT	0	0	4	0	15	0	2	4	1	0	11	4	-0	0	0	1	0	0	-0	0	0	0	0	1	4	0	-0	563	557	529	AT
AZ	0	0	0	0	0	0	0	0	22	0	0	0	0	4	42	1	2	0	0	0	0	0	53	3	8	0	-0	446	382	2	AZ
BA	0	0	1	0	6	0	6	19	1	0	1	3	0	0	2	2	0	0	0	0	1	0	0	2	3	0	-0	221	214	109	BA
BE	0	0	23	0	1	0	0	0	0	0	0	0	0	-0	0	0	-0	0	0	0	0	-1	-0	0	0	-0	0	316	316	315	BE
BG	5	0	1	0	6	0	74	21	14	0	0	2	0	0	47	12	0	0	0	0	1	0	3	7	6	0	0	425	407	296	BG
BY	0	0	4	1	107	0	23	5	51	3	1	4	0	0	16	85	0	0	-0	0	1	0	1	2	5	1	0	918	909	274	BY
CH	0	0	1	0	1	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	1	0	0	1	2	0	0	356	352	118	CH
CY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	-0	0	2	1	2	-0	-0	26	22	14	CY
CZ	0	0	6	0	30	0	3	5	1	1	3	11	0	0	0	1	0	0	0	0	0	0	0	1	3	0	-0	538	533	517	CZ
DE	0	0	176	1	54	2	3	4	2	3	3	4	-0	-0	0	2	0	1	-1	0	1	-6	0	3	8	0	0	3371	3364	3289	DE
DK	0	0	12	0	11	0	1	1	1	3	0	1	0	0	0	1	0	0	-1	0	0	-2	0	0	1	-0	0	307	309	305	DK
EE	0	0	2	1	12	0	1	0	8	4	0	1	0	0	1	5	0	0	-0	0	0	0	0	0	1	0	0	122	120	95	EE
ES	-0	0	1	0	1	54	0	1	0	0	0	0	0	0	0	0	0	-4	0	0	-5	0	0	29	25	-2	-1	1872	1830	1825	ES
FI	0	0	6	4	30	0	3	1	40	16	0	1	0	0	3	12	0	0	1	0	0	1	1	1	4	0	0	376	369	288	FI
FR	0	0	25	0	4	15	1	1	1	1	1	1	-0	0	0	1	0	-2	0	0	2	-5	0	14	24	-2	-0	3408	3377	3332	FR
GB	0	0	19	1	5	2	1	0	1	1	0	0	-0	0	0	0	0	-3	0	0	0	-4	-0	1	5	-3	0	1222	1226	1221	GB
GE	0	0	0	0	1	0	1	1	12	0	0	0	0	2	118	3	1	0	0	0	0	0	25	4	10	0	0	397	356	7	GE
GL	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	0	0	12	10	8	GL
GR	6	0	0	0	3	0	11	9	6	0	0	1	0	0	41	5	0	0	0	0	-1	0	4	11	15	-0	-2	366	339	260	GR
HR	0	0	1	0	10	0	7	15	1	0	11	5	0	0	2	3	0	0	0	0	1	0	0	3	4	0	0	335	326	287	HR
HU	1	0	2	0	22	0	54	42	3	0	7	30	0	0	4	10	0	0	0	0	0	0	0	1	3	0	-0	577	572	498	HU
IE	0	0	4	0	1	0	0	0	0	0	0	0	0	-0	0	0	-0	-2	0	0	0	-1	-0	0	1	-3	0	490	494	493	IE
IS	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	51	47	32	IS
IT	1	0	2	0	8	4	4	7	2	0	11	3	0	0	2	2	0	1	0	0	-2	0	0	30	28	1	-3	2124	2069	2029	IT
KG	0	0	0	0	0	0	0	0	7	0	0	0	37	6	10	0	179	0	0	0	0	0	106	0	19	0	-0	539	413	1	KG
KZ	1	0	2	1	18	1	10	4	657	2	0	1	29	87	140	41	364	0	0	1	1	1	770	9	86	1	1	2875	2006	96	KZ
LT	0	0	3	1	47	0	3	1	13	3	0	1	0	0	2	9	0	0	-0	0	0	0	0	0	1	0	0	268	266	212	LT
LU	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	0	0	-0	0	0	0	0	-0	-0	0	0	0	0	25	24	24	LU
LV	0	0	3	1	25	0	3	1	10	5	0	1	0	0	2	7	0	0	-0	0	0	0	0	0	1	0	0	208	206	163	LV
MD	0	0	0	0	4	0	22	1	8	0	0	1	0	0	11	24	0	0	-0	-0	0	0	1	1	1	0	0	126	123	38	MD
ME	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	-0	40	37	14	ME
MK	20	0	0	0	1	0	2	8	1	0	0	0	0	0	3	1	0	0	0	0	0	0	0	1	1	0	-0	66	63	25	MK
MT	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	-0	-0	1	1	1	MT
NL	-0	0	328	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	-0	-0	-0	0	-3	-0	0	-0	-0	-0	527	530	529	NL
NO	0	0	9	119	20	1	2	1	6	13	0	1	0	0	1	5	0	1	1	0	0	1	0	1	6	0	0	317	307	169	NO
PL	1	0	24	2	1270	1	28	14	17	10	5	23	0	0	4	38	0	1	-0	0	1	2	0	3	7	1	0	1990	1976	1857	PL
PT	-0	0	0	0	0	147	0	0	0	0	0	0	-0	-0	-0	0	-0	-2	0	-0	-0	0	0	1	3	-1	-0	204	203	203	PT
RO	2	0	3	0	29	0	693	44	30	1	2	11	0	0	51	54	0	0	0	0	1	0	5	9	10	1	-0	1179	1153	933	RO
RS	4	0	1	0	7	0	37	245	3	0	1	6	0	0	5	4	0	0	0	0	1	0	0	3	4	0	-0	452	444	160	RS
RU	5	0	29	11	255	2	101	31	7636	34	4	14	6	44	412	448	100	3	3	2	5	6	357	18	219	6	4	11177	10552	1140	RU
SE	0	0	18	19	77	1	8	4	19	218	1	3	0	0	4	17	0	1	-1	0	1	2	1	1	7	1	0	695	683	596	SE
SI	0	0	0	0	3	0	1	2	0	0	62	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	-0	154	152	146	SI
SK	0	0	2	0	27	0	17	13	2	0	3	87	0	0	2	6	0	0	0	0	0	0	0	1	2	0	-0	286	282	253	SK
TJ	0	0	0	0	0	0	0	0	3	0	0	0	129	5	6	0	61	0	0	0	0	0	90	0	17	0	-0	321	214	1	TJ
TM	0	0	0	0	1	0	0	0	28	0	0	0	6	212	23	2	104	0	0	0	0	0	283	3	48	0	-0	739	406	5	TM
TR	1	0	1	0	7	1	18	6	53	0	0	1	0	1	3204	18	1	0	0	-1	-3	0	189	81	116	-1	-4	3816	3439	115	TR
UA	2	0	9	1	141	1	150	21	238	3	2	12	0	1	142	943	1	0	0	0	3	1	10	13	18	1	1	2097	2050	559	UA
UZ	0	0	0	0	1	0	1	0	28	0	0	0	39	39	20	2	609	0	0	0	0	0	160	2	37	0	-0	995	795	7	UZ
ATL	0	0	65	45	51	135	5	4	103	18	1	3	0	0	5	15	1	-24	4	0	-0	10	4	33	426	-12	-0	3110	2669	2449	ATL
BAS	0	0	32	7	152	1	10	5	37	80	2	6	0	0	5	23	0	1	-6	0	1	-1	1	2	6	-2	0	959	958	844	BAS
BLS	2	0	2	0	24	0	83	11	190	1	1	3	0	2	410	114	1	0	0	-6	1	0	29	15	20	-2	1	1082	1023	205	BLS
MED	6	7	9	1	25	23	43	33	26	1	11	8	0	0	427	24	0	2	0	-0	-41	3	101	411	268	-10	-3	3269	2538	1938	MED
NOS	0	0	186	24	51	3	4	3	3	17	1	3	0	0	1	5	0	-0	-2	0	1	-13	0	2	14	-4	0	1786	1786	1739	NOS
AST	0	0	0	0	5	0	4	2	169	0	0	0	44	126	295	13	149	0	0	0	-1	0	16221	106	1921	-0	-4	19298	1054	40	AST
NOA	0	0	1	0	2	17	3	2	3	0	1	1	0	0	15	2	0	-3	0	0	-7	0	3	964	166	-2	-2	1367	247	219	NOA
SUM	61	9	1023	241	2577	415	1447	602	9459	442	150	259	291	531	5538	1965	1575	-24	-0	-3	-33	-1	18443	1804	3599	-28	-14	79075			SUM
EXC	52	2	728	164	2265	236	1294	541	8929	325	134	235	247	403	4381	1769	1424	-1	2	3	13	-1	2085	270	777	5	-5		45056	23419	EXC
EU	18	1	667	31	1690	229	918	190	172	267	122	191	0	1	173	188	1	-7	-2	1	3	-12	18	121	163	-5	-6		21704	20508	EU
emis	70	11	1012	235	2612	486	1468	626	10036	440	149	259	280	604	6297	2027	1649	0	0	0	0	0	27187	3356	0			88039	57497	31343	emis
	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	SUM	EXC	EU	

Table D.4: 2019 country-to-country blame matrices for $\mathbf{AOT40}_f^{\mathbf{uc}}$.
Units: ppb.h per 15% emis. red. of NO_x. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	603	0	29	1	67	2	81	6	7	0	28	62	2	0	66	2	89	8	1	185	48	52	3	0	261	0	3	2	1	1	7	AL
AM	1	58	3	552	2	0	5	5	1	3	3	10	1	1	13	3	12	2	119	10	1	3	1	0	12	0	32	1	0	1	2	AM
AT	2	0	454	0	19	6	6	10	73	0	114	515	6	1	56	5	214	24	0	6	35	52	7	1	218	0	1	4	5	2	2	AT
AZ	1	40	2	637	1	1	4	7	1	1	2	11	1	1	10	5	10	4	81	6	1	2	1	0	7	0	83	2	0	1	2	AZ
BA	23	0	81	1	654	3	30	11	10	0	79	134	4	1	60	3	99	12	1	32	192	133	3	1	245	0	2	3	2	1	5	BA
BE	0	0	12	0	1	-423	1	4	7	0	26	52	5	1	47	5	282	39	0	1	1	5	25	3	11	0	1	2	2	2	0	BE
BG	17	1	28	3	23	2	647	17	5	0	31	73	4	1	33	4	52	9	4	116	16	66	2	1	61	0	10	5	1	2	32	BG
BY	1	0	8	1	3	3	5	246	2	0	16	77	16	11	15	23	32	30	1	4	4	13	7	1	13	0	4	57	1	30	8	BY
CH	1	0	51	0	3	6	2	4	532	0	16	245	3	1	99	3	574	23	0	5	6	5	10	1	300	0	1	2	3	1	1	CH
CY	7	2	8	8	7	1	22	7	4	336	6	20	1	0	32	2	35	4	6	228	5	8	1	0	59	0	6	2	0	1	5	CY
CZ	2	0	106	0	17	6	7	13	15	0	251	485	13	1	41	7	165	36	0	5	25	71	9	2	53	0	2	6	6	3	2	CZ
DE	1	0	46	0	4	-2	2	9	26	0	60	251	10	2	42	7	227	55	0	3	5	12	17	3	29	0	1	4	10	3	1	DE
DK	0	0	3	0	1	-3	2	15	1	0	9	74	-51	4	16	12	57	107	0	2	1	5	31	6	5	0	1	10	2	5	1	DK
EE	0	0	1	0	1	3	1	39	1	0	4	56	24	52	7	70	25	45	0	1	1	2	11	2	2	0	1	25	1	42	1	EE
ES	1	0	4	0	3	2	1	1	3	0	2	12	1	0	1021	1	158	15	0	1	3	3	8	1	44	0	0	0	1	0	0	ES
FI	0	0	0	0	0	1	0	12	0	0	2	24	9	9	4	86	14	24	0	0	0	0	6	1	1	0	0	9	0	8	0	FI
FR	1	0	13	0	3	0	1	3	28	0	8	89	2	1	155	3	846	44	0	2	5	4	21	2	74	0	0	2	5	1	1	FR
GB	0	0	2	0	0	-7	0	3	1	0	5	15	7	1	10	5	54	-124	0	0	0	1	52	5	2	0	0	2	1	1	0	GB
GE	2	55	3	483	2	1	9	10	1	1	4	13	1	1	15	5	13	3	561	14	2	4	1	0	14	0	33	2	0	1	4	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	61	1	21	4	26	2	258	11	6	1	18	50	2	1	56	3	71	8	3	622	18	32	2	0	160	0	7	3	1	1	17	GR
HR	13	0	138	1	220	4	18	13	12	0	95	184	4	1	54	4	113	15	1	18	451	182	4	1	284	0	2	4	2	2	4	HR
HU	6	0	117	1	56	3	32	22	12	0	110	216	6	1	33	6	92	18	1	12	101	413	4	1	104	0	3	7	2	3	8	HU
IE	0	0	2	0	0	-5	0	1	1	0	2	10	4	0	8	2	48	52	0	0	0	1	73	5	4	0	0	0	1	0	0	IE
IS	0	0	0	0	0	-1	0	1	0	0	0	6	5	1	3	4	19	24	0	0	0	0	8	17	0	0	0	1	0	1	0	IS
IT	8	0	91	0	38	3	10	6	39	0	34	111	3	0	124	2	262	14	0	17	61	39	5	0	898	0	1	2	2	1	2	IT
KG	0	5	3	20	1	1	2	3	1	0	2	9	0	1	20	2	12	2	5	3	1	1	0	0	7	503	261	1	0	1	1	KG
KZ	0	1	2	9	1	1	2	7	1	0	3	14	2	1	10	9	11	7	2	2	1	2	2	0	5	12	295	3	0	2	1	KZ
LT	1	0	4	1	2	4	3	106	1	0	10	89	30	10	12	36	32	45	1	3	2	7	11	2	7	0	3	133	1	45	4	LT
LU	0	0	17	0	2	2	1	5	16	0	29	184	5	1	59	4	465	63	0	2	2	7	17	3	18	0	1	2	-338	1	1	LU
LV	0	0	2	0	1	3	2	72	1	0	7	69	26	19	10	42	29	44	0	2	1	3	9	2	3	0	2	69	1	77	2	LV
MD	3	1	15	3	10	2	33	58	3	0	25	70	6	3	19	10	34	12	4	15	8	36	2	1	28	0	14	18	1	8	175	MD
ME	101	0	44	1	200	3	56	7	8	0	44	82	2	0	72	2	95	9	1	69	77	76	3	0	239	0	3	2	1	1	8	ME
MK	153	0	34	2	45	2	222	8	7	0	37	76	2	0	63	2	77	9	2	354	27	69	3	0	148	0	5	2	1	1	12	MK
MT	9	0	19	0	18	3	15	2	9	0	14	43	2	0	138	1	210	12	0	33	16	17	6	0	304	0	1	1	1	0	1	MT
NL	0	0	5	0	1	-51	1	6	3	0	19	14	6	1	28	6	107	31	0	1	1	4	28	4	7	0	1	3	4	2	0	NL
NO	0	0	1	0	0	2	1	6	0	0	2	28	11	2	7	17	21	58	0	1	0	1	14	2	2	0	0	3	1	2	0	NO
PL	2	0	25	1	9	3	8	37	4	0	64	226	21	3	23	16	72	42	1	5	13	45	11	3	28	0	2	19	3	9	6	PL
PT	0	0	2	0	1	1	0	0	1	0	1	5	0	0	455	0	68	14	0	0	1	1	8	1	15	0	0	0	0	0	0	PT
RO	8	0	29	2	24	2	92	29	4	0	39	90	5	1	24	6	44	11	2	26	18	101	2	1	51	0	10	9	1	3	49	RO
RS	47	0	60	1	114	3	131	12	8	0	73	124	4	1	43	3	76	13	1	56	64	161	3	1	124	0	4	4	1	1	13	RS
RU	0	1	1	7	0	1	1	12	0	0	2	12	2	3	4	12	7	7	3	1	0	1	2	0	3	0	37	4	0	3	1	RU
SE	0	0	1	0	0	2	1	13	1	0	4	51	21	4	8	35	25	51	0	1	0	2	12	3	2	0	1	10	1	7	1	SE
SI	4	0	349	0	49	4	9	12	19	0	85	264	5	1	53	4	127	18	0	10	226	103	4	1	361	0	1	4	3	2	3	SI
SK	4	0	80	1	34	4	22	22	9	0	162	245	9	2	34	7	85	23	1	11	52	251	5	2	75	0	4	9	3	3	6	SK
TJ	0	6	2	23	1	0	1	2	1	0	2	7	0	0	14	1	9	1	5	3	1	1	0	0	6	39	91	1	0	0	0	TJ
TM	1	7	2	54	1	1	2	5	1	0	2	12	1	1	13	4	11	4	9	4	1	2	1	0	6	1	139	2	0	1	1	TM
TR	4	15	7	39	5	1	28	11	3	8	6	21	1	1	27	4	27	4	26	54	4	9	1	0	36	0	12	3	0	2	9	TR
UA	2	0	12	3	7	2	16	76	2	0	18	64	7	5	18	16	31	15	3	10	7	26	3	1	21	0	14	20	1	10	28	UA
UZ	0	4	2	23	1	1	2	5	1	0	3	12	1	1	14	5	11	4	6	3	1	2	1	0	6	18	219	2	0	1	1	UZ
ATL	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	1	0	0	0	0	0	0	0	0	ATL
BAS	0	0	1	0	0	0	0	8	0	0	3	25	8	4	3	20	12	26	0	0	0	1	6	1	1	0	0	6	0	6	0	BAS
BLS	0	0	1	3	1	0	7	6	0	0	2	5	1	0	2	2	3	2	8	3	1	2	0	0	3	0	4	2	0	1	5	BLS
MED	3	0	5	1	6	0	13	2	1	1	3	9	0	0	21	0	31	2	0	24	8	5	1	0	36	0	1	0	0	0	2	MED
NOS	0	0	0	0	0	-2	0	1	0	0	1	2	1	0	2	1	9	6	0	0	0	0	6	1	0	0	0	0	0	0	0	NOS
AST	1	4	1	22	1	0	2	2	1	4	1	5	0	0	10	1	7	1	4	9	1	1	0	0	6	14	61	1	0	0	1	AST
NOA	3	0	4	0	4	1	8	1	2	1	3	9	0	0	111	0	50	4	0	26	3	3	2	0	46	0	1	0	0	0	1	NOA
EXC	3	2	11	14	6	0	12	15	5	1	10	39	4	2	47	12	57	12	6	11	6	12	5	1	32	8	73	6	1	3	4	EXC
EU	4	0	35	1	12	-2	33	14	12	1	31	107	8	3	170	16	198	24	0	27	19	33	14	2	105	0	2	9	2	5	5	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.4 Cont.: 2019 country-to-country blame matrices for $\mathbf{AOT40}_f^{\mathbf{uc}}$.
Units: ppb.h per 15% emis. red. of NO_x. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	
AL	84	97	1	2	5	58	6	70	218	50	5	6	21	0	1	20	49	1	25	6	6	361	9	6	79	0	0	2310	1091	AL
AM	1	1	0	0	2	11	2	10	3	136	2	1	1	0	41	309	36	12	6	3	24	31	2	752	28	0	0	1423	109	AM
AT	2	1	0	2	10	97	6	24	18	38	9	60	32	0	0	5	28	0	35	14	1	51	17	1	38	0	0	2171	1958	AT
AZ	0	1	0	1	3	13	1	8	2	358	4	0	1	0	88	106	48	26	7	5	19	14	3	444	14	0	0	1586	100	AZ
BA	45	9	0	2	7	110	5	87	124	52	8	15	46	0	1	15	52	0	25	11	3	162	13	4	58	0	0	2403	1391	BA
BE	0	0	0	-99	16	34	6	3	1	21	8	1	5	0	0	3	7	0	76	7	0	15	-149	1	7	0	0	121	55	BE
BG	8	20	0	2	7	124	3	333	108	190	9	4	28	0	2	69	198	1	17	13	66	78	10	8	32	0	0	2373	1658	BG
BY	1	1	0	4	18	169	2	25	5	325	29	2	9	0	0	8	174	0	28	70	4	11	29	1	6	0	0	1403	603	BY
CH	1	1	0	-2	8	23	10	6	3	19	4	8	4	0	0	4	10	0	48	7	1	63	12	1	40	0	0	1997	1410	CH
CY	3	7	1	1	3	21	3	21	15	90	3	2	4	0	2	753	48	1	11	4	40	781	4	159	70	0	0	1800	826	CY
CZ	2	1	0	4	16	219	6	35	22	48	16	14	63	0	0	3	31	0	45	23	1	26	30	1	19	0	0	1830	1653	CZ
DE	1	0	0	-22	22	94	6	10	5	34	13	3	10	0	0	3	14	0	65	9	1	17	0	1	12	0	0	1020	897	DE
DK	0	0	0	-21	61	88	2	7	2	64	36	1	4	0	0	2	22	0	92	-41	1	5	46	0	3	0	0	584	407	DK
EE	0	0	0	1	36	53	1	4	1	223	75	0	2	0	0	1	24	0	43	125	0	2	48	0	1	0	0	837	508	EE
ES	1	0	0	1	3	3	163	2	2	6	2	1	1	0	0	2	4	0	178	1	0	143	10	0	97	0	0	1478	1451	ES
FI	0	0	0	2	28	28	1	1	0	108	43	0	0	0	0	1	8	0	39	49	0	1	24	0	0	0	0	434	274	FI
FR	0	0	0	-4	9	14	13	3	2	18	5	3	3	0	0	2	7	0	121	6	0	70	11	0	27	0	0	1392	1316	FR
GB	0	0	0	-17	22	12	2	1	0	20	11	0	1	0	0	1	3	0	93	10	0	2	-44	0	1	0	0	95	39	GB
GE	1	1	0	1	3	18	2	19	5	319	3	1	2	0	39	244	73	12	8	6	101	26	3	213	21	0	0	2001	154	GE
GL	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4	3	GL
GR	11	44	1	2	5	64	6	117	75	126	6	4	15	0	2	105	123	1	22	9	44	365	8	11	79	0	0	2174	1546	GR
HR	14	5	0	2	8	124	5	66	83	49	9	59	51	0	0	10	51	0	27	14	2	198	15	3	45	0	0	2380	1895	HR
HU	5	4	0	3	11	260	3	195	93	78	13	31	132	0	0	9	113	0	27	21	4	53	19	2	23	0	0	2342	1919	HU
IE	0	0	0	-11	14	4	2	1	0	8	7	0	1	0	0	1	2	0	88	4	0	2	-4	0	1	0	0	241	208	IE
IS	0	0	0	-2	19	3	0	0	0	15	9	0	0	0	0	0	1	0	52	7	0	0	12	0	0	0	0	135	81	IS
IT	6	4	1	1	6	47	10	21	24	25	5	36	16	0	0	7	21	0	40	7	1	399	13	2	107	0	0	2000	1813	IT
KG	0	0	0	0	1	8	3	3	1	115	2	0	1	141	64	30	10	591	5	2	2	8	1	440	14	0	0	1841	87	KG
KZ	0	0	0	1	7	14	2	5	1	602	7	0	1	2	20	11	27	35	13	9	2	4	6	56	6	0	0	1143	107	KZ
LT	0	1	0	3	28	158	2	17	4	213	49	1	5	0	0	5	88	0	41	119	3	7	47	1	5	0	0	1179	718	LT
LU	0	0	0	-15	13	39	6	5	2	23	7	2	6	0	0	3	8	0	71	7	1	20	5	1	11	0	0	670	592	LU
LV	0	0	0	2	31	87	1	10	2	216	65	0	3	0	0	4	52	0	41	125	1	4	45	1	3	0	0	973	585	LV
MD	2	3	0	3	9	179	2	221	19	305	16	3	21	0	1	48	487	1	17	28	49	27	14	5	12	0	0	1937	791	MD
ME	501	23	0	2	6	82	6	92	225	53	6	7	31	0	1	21	52	0	27	8	5	259	10	6	76	0	0	2316	1105	ME
MK	23	278	0	2	5	81	6	116	297	81	6	5	28	0	1	43	76	1	23	7	13	155	9	8	72	0	0	2416	1375	MK
MT	6	4	-717	2	5	27	13	20	23	13	4	5	8	0	0	9	11	0	47	4	2	238	12	1	187	0	0	310	197	MT
NL	0	0	0	-604	25	49	4	4	2	23	12	1	4	0	0	2	7	0	69	7	0	8	-243	0	3	0	0	-236	-313	NL
NO	0	0	0	2	95	24	1	2	0	44	31	0	1	0	0	1	8	0	78	21	0	1	46	0	1	0	0	393	234	NO
PL	1	1	0	2	24	417	3	46	13	89	38	6	40	0	0	7	97	0	44	66	3	17	37	1	12	0	0	1484	1187	PL
PT	0	0	0	0	3	1	527	1	0	3	1	1	0	0	0	1	1	0	302	1	0	40	9	0	41	0	0	1116	1103	PT
RO	5	6	0	3	8	188	2	720	59	175	13	5	40	0	1	42	260	1	17	19	36	40	13	5	19	0	0	2215	1527	RO
RS	37	29	0	3	8	140	4	230	358	84	9	10	58	0	1	26	87	1	22	12	10	88	13	5	37	0	0	2231	1399	RS
RU	0	0	0	1	8	16	1	4	1	452	8	0	1	0	3	7	32	2	14	13	3	3	7	9	2	0	0	663	97	RU
SE	0	0	0	3	58	54	1	3	1	64	92	0	2	0	0	2	17	0	62	54	0	2	45	0	1	0	0	553	393	SE
SI	3	2	0	2	9	109	5	34	29	42	9	376	43	0	0	6	38	0	28	14	1	130	15	2	42	0	0	2431	2212	SI
SK	3	3	0	3	14	385	4	128	56	80	18	21	272	0	0	8	112	0	32	28	3	37	23	2	21	0	0	2274	1914	SK
TJ	0	0	0	0	1	7	2	3	1	75	1	0	1	584	116	36	6	432	4	1	1	7	1	709	14	0	0	1483	65	TJ
TM	0	1	0	1	3	11	2	5	1	280	4	0	1	9	329	31	25	213	7	5	4	8	3	310	10	0	0	1202	91	TM
TR	2	4	0	1	3	32	3	36	13	188	4	1	5	0	6	844	98	2	11	7	89	126	4	297	56	0	0	1613	327	TR
UA	1	1	0	2	11	170	2	79	12	492	16	2	16	0	2	31	477	1	19	35	29	19	16	5	10	0	0	1756	589	UA
UZ	0	0	0	1	4	12	2	4	1	293	4	0	1	42	99	23	22	315	7	5	3	7	3	152	10	0	0	1170	93	UZ
ATL	0	0	0	-0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	7	5	ATL
BAS	0	0	0	-2	18	33	0	2	1	36	31	0	1	0	0	1	8	0	25	-31	0	1	20	0	1	0	0	264	190	BAS
BLS	0	0	0	0	1	14	0	15	2	94	2	0	1	0	1	24	61	0	2	4	48	4	2	3	2	0	0	282	70	BLS
MED	2	1	-0	0	1	8	3	10	5	16	1	2	2	0	0	25	14	0	9	1	8	110	2	-0	21	0	0	267	187	MED
NOS	0	0	0	-8	5	4	0	0	0	5	3	0	0	0	0	0	1	0	18	1	0	0	-34	0	0	0	0	41	28	NOS
AST	0	1	0	0	1	5	1	3	2	65	1	0	1	15	72	91	10	56	3	1	4	34	1	1216	18	0	0	484	63	AST
NOA	1	2	1	0	1	5	27	7	5	8	1	1	1	0	0	19	7	0	77	1	3	168	3	-0	562	0	0	367	314	NOA
EXC	2	2	0	-1	12	41	9	25	9	329	12	3	6	8	18	48	52	29	30	16	9	29	9	51	14	0	0	1023	378	EXC
EU	2	3	0	-8	19	90	34	66	17	63	24	9	18	0	0	12	45	0	78	25	6	80	12	2	32	0	0	1282	1069	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	

Table D.5: 2019 country-to-country blame matrices for $\mathbf{AOT40}_f^{\mathbf{uc}}$.
Units: ppb.h per 15% emis. red. of VOC. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	80	0	8	2	16	6	7	5	5	0	18	70	3	0	19	1	40	23	0	19	12	14	3	0	113	0	1	1	1	1	3	AL
AM	0	126	1	385	1	1	1	5	1	1	3	16	1	0	4	1	9	6	24	2	1	2	1	0	12	0	10	1	0	0	1	AM
AT	1	0	91	1	4	13	1	6	29	0	39	261	5	0	14	1	69	44	0	1	7	9	4	0	103	0	0	1	2	1	1	AT
AZ	0	13	1	727	1	2	1	9	1	0	3	19	2	0	4	2	10	9	17	2	1	2	1	0	10	0	20	1	0	1	2	AZ
BA	4	0	14	2	85	7	4	8	6	0	27	96	4	0	16	1	40	23	0	5	21	21	2	0	93	0	1	1	1	1	2	BA
BE	0	0	4	1	1	109	0	4	4	0	15	133	5	0	10	1	125	116	0	1	1	2	10	0	9	0	0	1	6	1	1	BE
BG	2	0	8	5	6	5	42	12	4	0	16	69	5	1	10	1	29	21	1	18	5	15	2	0	40	0	3	2	1	1	9	BG
BY	0	0	3	1	1	5	1	43	2	0	8	51	6	1	5	2	21	33	0	1	2	4	4	0	11	0	1	4	0	3	2	BY
CH	0	0	15	0	1	14	0	3	210	0	13	207	3	0	21	1	131	47	0	1	2	2	5	0	174	0	0	1	1	1	1	CH
CY	2	1	4	21	4	3	5	9	3	39	8	38	2	0	12	1	25	14	2	28	4	5	2	0	48	0	3	1	0	1	4	CY
CZ	1	0	22	1	4	19	1	7	10	0	121	239	8	1	10	1	68	53	0	1	7	15	5	0	38	0	1	2	2	1	1	CZ
DE	0	0	14	0	1	32	1	6	16	0	23	339	7	0	11	1	91	85	0	1	2	4	8	0	21	0	0	1	3	1	1	DE
DK	0	0	1	0	0	14	0	9	1	0	5	107	60	1	4	1	37	92	0	1	1	2	11	0	4	0	0	2	1	1	1	DK
EE	0	0	1	0	0	5	0	7	1	0	2	38	8	5	2	6	16	38	0	0	0	1	5	0	2	0	0	2	0	4	0	EE
ES	0	0	2	0	1	3	0	1	2	0	2	17	1	0	166	0	49	19	0	0	2	1	3	0	28	0	0	0	0	0	0	ES
FI	0	0	0	0	0	3	0	3	0	0	1	18	3	1	1	5	9	18	0	0	0	0	2	0	1	0	0	1	0	1	0	FI
FR	0	0	5	0	1	16	0	3	12	0	6	81	3	0	33	1	172	61	0	1	2	2	7	0	45	0	0	1	1	1	0	FR
GB	0	0	1	0	0	11	0	2	1	0	4	41	5	0	3	1	37	181	0	0	0	0	13	0	2	0	0	1	1	1	0	GB
GE	0	14	2	305	1	2	2	9	1	0	4	20	2	0	5	1	10	9	59	4	1	3	1	0	13	0	10	1	0	1	2	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	GL
GR	8	0	8	6	8	5	17	10	4	0	15	65	4	0	17	1	39	23	1	105	7	12	3	0	80	0	3	2	1	1	6	GR
HR	3	0	26	1	33	8	3	8	8	0	34	131	5	0	16	1	49	29	0	3	52	26	3	0	143	0	1	2	1	1	2	HR
HU	1	0	24	2	12	9	5	10	9	0	39	140	6	1	10	1	46	29	0	3	15	67	3	0	62	0	1	2	1	1	4	HU
IE	0	0	1	0	0	9	0	1	1	0	3	27	3	0	2	0	30	56	0	0	0	0	27	0	3	0	0	0	0	0	0	IE
IS	0	0	0	0	0	3	0	1	0	0	0	11	2	0	1	0	9	26	0	0	0	0	2	0	1	0	0	0	0	0	0	IS
IT	2	0	21	1	9	8	2	6	16	0	19	106	4	0	34	1	82	32	0	4	16	11	3	0	579	0	1	1	1	1	1	IT
KG	0	1	1	21	0	1	0	3	1	0	2	10	1	0	4	1	6	5	1	1	0	1	0	0	6	53	70	0	0	0	1	KG
KZ	0	0	1	10	0	1	0	6	1	0	2	15	2	0	3	1	7	11	0	1	0	1	1	0	5	2	44	1	0	1	1	KZ
LT	0	0	1	1	1	7	1	19	1	0	6	61	10	1	4	3	22	42	0	1	1	2	6	0	6	0	1	13	0	4	1	LT
LU	0	0	6	0	1	48	0	4	7	0	14	166	4	0	12	1	119	77	0	1	1	3	7	0	15	0	0	1	29	1	1	LU
LV	0	0	1	1	0	6	0	12	1	0	4	45	9	1	3	3	18	39	0	1	0	1	5	0	3	0	1	5	0	9	1	LV
MD	1	0	5	4	3	4	4	22	3	0	14	61	5	1	6	2	26	20	1	4	3	9	2	0	23	0	3	4	0	2	50	MD
ME	17	0	9	2	24	6	5	6	5	0	20	73	3	0	18	1	37	21	0	8	12	15	2	0	93	0	1	1	1	1	3	ME
MK	12	0	8	4	10	5	14	6	4	0	19	70	3	0	15	1	33	21	0	43	7	16	2	0	61	0	2	1	1	1	5	MK
MT	3	0	7	1	8	7	3	4	6	0	12	62	3	0	46	1	74	32	0	9	7	7	5	0	205	0	1	1	1	0	1	MT
NL	0	0	3	0	1	58	0	6	2	0	12	169	6	0	7	1	76	140	0	1	1	2	10	0	6	0	0	1	2	1	1	NL
NO	0	0	0	0	0	4	0	3	0	0	1	22	6	0	1	1	12	31	0	0	0	0	4	0	1	0	0	0	0	0	0	NO
PL	0	0	7	1	3	14	1	11	4	0	28	139	10	1	7	2	43	52	0	2	4	11	5	0	22	0	1	3	1	2	3	PL
PT	0	0	1	0	0	2	0	1	1	0	1	8	1	0	85	0	33	20	0	0	1	1	3	0	10	0	0	0	0	0	0	PT
RO	2	0	8	3	6	5	10	15	4	0	16	71	5	1	8	2	28	20	0	6	5	19	2	0	34	0	2	3	1	1	12	RO
RS	6	0	12	3	22	6	11	9	6	0	28	93	4	0	12	1	36	24	0	10	12	29	3	0	58	0	2	2	1	1	5	RS
RU	0	0	0	6	0	1	0	4	0	0	1	10	1	0	1	1	5	8	0	0	0	1	1	0	2	0	4	1	0	0	0	RU
SE	0	0	0	0	0	4	0	4	1	0	2	32	9	1	2	2	14	32	0	0	0	1	4	0	2	0	0	1	0	1	0	SE
SI	1	0	55	1	9	10	2	7	12	0	34	176	6	0	16	1	56	37	0	2	32	17	3	0	249	0	1	2	1	1	2	SI
SK	1	0	19	2	8	10	3	9	7	0	46	144	7	1	9	2	44	34	0	3	10	35	3	0	50	0	1	2	1	1	3	SK
TJ	0	1	1	24	0	1	0	2	1	0	1	8	1	0	3	1	5	4	1	1	0	1	0	0	5	6	30	0	0	0	0	TJ
TM	0	2	1	56	1	1	1	6	1	0	3	16	1	0	4	1	9	8	2	1	1	1	1	0	8	1	27	1	0	1	1	TM
TR	1	4	3	36	2	2	3	9	2	1	5	28	2	0	8	1	16	11	4	9	2	4	1	0	25	0	4	1	0	1	3	TR
UA	1	0	4	5	2	4	2	21	2	0	10	53	5	1	6	3	23	24	1	3	2	7	2	0	17	0	3	3	0	2	7	UA
UZ	0	1	1	25	1	1	1	5	1	0	2	15	1	0	4	1	8	8	1	1	1	1	1	0	7	7	44	1	0	1	1	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	3	0	3	0	0	1	28	9	1	1	3	9	23	0	0	0	1	3	0	1	0	0	1	0	2	0	BAS
BLS	0	0	1	4	0	1	1	4	0	0	1	7	1	0	1	0	3	3	2	1	0	1	0	0	3	0	1	1	0	0	1	BLS
MED	1	0	2	1	2	1	1	2	1	0	3	13	1	0	9	0	13	5	0	8	2	2	1	0	32	0	0	0	0	0	1	MED
NOS	0	0	0	0	0	2	0	1	0	0	1	10	2	0	1	0	8	19	0	0	0	0	2	0	0	0	0	0	0	0	0	NOS
AST	0	1	1	28	0	1	1	2	1	1	1	7	1	0	3	0	5	3	1	2	0	1	0	0	7	2	15	0	0	0	1	AST
NOA	1	0	2	1	1	2	1	1	1	0	3	14	1	0	24	0	21	10	0	5	1	2	2	0	27	0	0	0	0	0	1	NOA
EXC	1	1	3	13	1	4	1	6	3	0	5	35	3	0	10	1	20	20	1	2	2	3	2	0	21	1	11	1	0	1	1	EXC
EU	1	0	8	1	3	11	3	6	6	0	14	94	6	1	32	2	60	49	0	5	4	7	5	0	66	0	1	2	1	1	2	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.5 Cont.: 2019 country-to-country blame matrices for $\mathbf{AOT40_f^{uc}}$.
Units: ppb.h per 15% emis. red. of VOC. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	
AL	9	8	0	12	3	37	2	14	35	31	3	3	10	0	0	11	11	0	0	0	0	2	0	7	28	0	0	663	441	AL
AM	0	0	0	3	2	12	1	5	3	74	2	0	1	0	10	91	12	3	0	0	0	0	0	440	11	0	0	837	89	AM
AT	0	0	0	28	3	42	2	6	6	18	3	11	12	0	0	3	6	0	0	0	0	0	1	2	13	0	0	850	770	AT
AZ	0	0	0	4	3	14	1	4	2	152	2	0	2	0	17	44	18	5	0	0	0	0	0	380	8	0	0	1129	99	AZ
BA	2	1	0	14	4	52	2	17	26	28	4	4	14	0	0	8	11	0	0	0	0	1	0	6	20	0	0	670	483	BA
BE	0	0	0	98	5	28	2	2	1	13	3	0	4	0	0	2	3	0	0	0	0	0	3	1	3	0	0	722	687	BE
BG	1	3	0	10	4	59	1	50	22	80	4	2	11	0	0	38	29	0	0	0	0	1	0	9	13	0	0	648	428	BG
BY	0	0	0	13	4	41	1	6	3	72	5	1	4	0	0	4	20	0	0	0	0	0	0	1	3	0	0	392	237	BY
CH	0	0	0	24	3	20	3	2	1	13	2	3	2	0	0	2	3	0	0	0	0	0	1	1	14	0	0	934	696	CH
CY	1	2	0	6	3	26	2	10	9	71	2	1	4	0	1	327	20	1	0	0	0	3	0	189	32	0	0	777	294	CY
CZ	0	0	0	37	5	78	2	8	8	21	4	4	18	0	0	3	8	0	0	0	0	0	1	2	8	0	0	838	767	CZ
DE	0	0	0	71	5	36	2	4	3	16	4	1	5	0	0	2	5	0	0	0	0	0	2	1	5	0	0	824	767	DE
DK	0	0	0	50	12	37	1	3	1	27	12	0	2	0	0	2	7	0	0	1	0	0	2	1	2	0	0	513	451	DK
EE	0	0	0	15	5	17	0	1	1	55	8	0	1	0	0	1	4	0	0	1	0	0	1	0	1	0	0	251	177	EE
ES	0	0	0	5	2	4	26	1	1	5	1	1	1	0	0	1	1	0	1	0	0	2	0	1	30	0	0	350	333	ES
FI	0	0	0	7	2	9	0	0	0	22	4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	116	86	FI
FR	0	0	0	26	3	12	3	1	1	11	2	1	2	0	0	2	2	0	0	0	0	0	1	1	10	0	0	523	485	FR
GB	0	0	0	27	5	9	1	0	0	10	2	0	1	0	0	1	1	0	0	0	0	0	2	1	1	0	0	363	342	GB
GE	0	0	0	4	2	17	1	7	3	114	2	0	2	0	7	56	19	2	0	0	0	0	0	149	9	0	0	718	113	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	GL
GR	1	6	0	10	4	44	2	26	21	65	4	2	9	0	0	48	23	0	0	0	0	2	0	15	28	0	0	715	501	GR
HR	1	1	0	18	4	62	2	14	21	27	4	14	16	0	0	6	10	0	0	0	0	1	0	4	18	0	0	791	663	HR
HU	1	1	0	19	5	96	1	33	30	36	5	7	33	0	0	6	18	0	0	0	0	0	0	3	10	0	0	794	658	HU
IE	0	0	0	21	2	4	0	0	0	5	1	0	1	0	0	1	1	0	0	0	0	0	1	1	1	0	0	203	191	IE
IS	0	0	0	8	2	2	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	67	IS
IT	1	1	1	15	3	32	4	7	9	18	3	12	8	0	0	5	6	0	0	0	0	3	0	3	42	0	0	1084	1005	IT
KG	0	0	0	2	1	6	1	2	1	55	1	0	1	47	11	13	4	273	0	0	0	0	0	197	5	0	0	609	52	KG
KZ	0	0	0	4	2	9	1	2	1	105	2	0	1	1	3	5	8	15	0	0	0	0	0	40	3	0	0	278	73	KZ
LT	0	0	0	20	4	39	1	4	2	55	6	0	2	0	0	3	11	0	0	1	0	0	1	1	2	0	0	364	264	LT
LU	0	0	0	54	4	27	2	2	1	13	2	1	4	0	0	2	3	0	0	0	0	0	1	1	4	0	0	635	597	LU
LV	0	0	0	17	4	24	0	3	1	52	7	0	1	0	0	2	7	0	0	1	0	0	1	1	1	0	0	290	207	LV
MD	0	1	0	9	5	59	1	37	7	102	6	1	7	0	0	23	53	0	0	0	0	0	0	6	6	0	0	596	317	MD
ME	31	3	0	12	3	39	2	16	29	30	3	2	11	0	0	11	11	0	0	0	0	1	0	7	25	0	0	588	412	ME
MK	2	38	0	11	3	43	2	20	41	40	3	2	11	0	0	23	15	0	0	0	0	1	0	9	22	0	0	617	413	MK
MT	1	1	60	11	4	27	5	8	10	17	4	2	6	0	0	7	6	0	0	0	0	9	0	3	79	0	0	675	606	MT
NL	0	0	0	214	7	30	1	2	1	14	4	0	3	0	0	2	4	0	0	0	0	0	3	1	2	0	0	786	748	NL
NO	0	0	0	10	13	8	0	1	0	9	3	0	0	0	0	1	2	0	0	0	0	0	1	0	1	0	0	136	107	NO
PL	0	0	0	34	6	161	1	11	6	32	7	2	12	0	0	5	16	0	0	0	0	0	1	2	5	0	0	669	581	PL
PT	0	0	0	3	1	2	131	0	0	3	0	0	0	0	0	1	1	0	1	0	0	0	0	0	14	0	0	311	303	PT
RO	1	2	0	10	5	68	1	91	16	68	5	2	11	0	0	21	34	0	0	0	0	0	0	6	8	0	0	620	431	RO
RS	2	5	0	14	4	62	2	35	83	42	4	3	18	0	0	14	17	0	0	0	0	0	0	6	13	0	0	701	480	RS
RU	0	0	0	3	1	7	0	1	0	73	1	0	1	0	0	3	6	0	0	0	0	0	0	7	1	0	0	148	49	RU
SE	0	0	0	12	5	15	0	1	0	18	9	0	1	0	0	1	4	0	0	0	0	0	1	0	1	0	0	182	147	SE
SI	0	1	0	22	4	53	2	9	10	22	4	77	14	0	0	4	8	0	0	0	0	1	0	3	16	0	0	962	879	SI
SK	0	1	0	23	5	133	1	23	19	32	5	5	52	0	0	6	16	0	0	0	0	0	1	3	9	0	0	779	668	SK
TJ	0	0	0	1	1	4	1	1	1	43	1	0	1	136	17	14	3	135	0	0	0	0	0	242	4	0	0	459	41	TJ
TM	0	0	0	3	2	10	1	2	1	103	2	0	1	5	57	17	10	39	0	0	0	0	0	233	6	0	0	407	79	TM
TR	0	1	0	5	2	22	1	9	5	79	2	1	3	0	2	225	20	1	0	0	0	1	0	158	18	0	0	567	167	TR
UA	0	0	0	11	5	48	1	16	5	134	5	1	5	0	0	15	66	0	0	0	0	0	0	6	6	0	0	527	260	UA
UZ	0	0	0	3	2	9	1	2	1	95	2	0	1	20	14	12	8	158	0	0	0	0	0	111	5	0	0	469	72	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	ATL
BAS	0	0	0	11	3	13	0	1	0	15	7	0	1	0	0	0	2	0	0	1	0	0	0	0	0	0	0	146	120	BAS
BLS	0	0	0	1	1	7	0	3	1	37	1	0	1	0	0	16	10	0	0	0	0	0	0	3	1	0	0	117	39	BLS
MED	0	0	0	2	1	7	1	3	2	10	1	1	1	0	0	18	3	0	0	0	0	1	0	8	17	0	0	153	109	MED
NOS	0	0	0	7	3	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	57	NOS
AST	0	0	0	1	1	5	0	2	1	34	1	0	1	5	13	38	4	17	0	0	0	0	0	780	8	0	0	209	44	AST
NOA	0	0	0	3	1	6	8	3	2	7	1	1	1	0	0	8	3	0	0	0	0	1	0	7	126	0	0	166	137	NOA
EXC	0	0	0	9	3	17	2	5	3	66	2	1	2	2	3	15	10	11	0	0	0	0	0	32	5	0	0	325	172	EXC
EU	0	1	0	24	4	37	7	11	5	24	4	3	6	0	0	6	8	0	0	0	0	1	1	2	12	0	0	528	460	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	

Table D.6: 2019 country-to-country blame matrices for **SOMO35**.
Units: ppb.d per 15% emis. red. of NO_x. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	50	0	2	0	5	0	7	0	1	0	2	4	0	0	7	0	8	0	0	17	4	4	0	0	22	0	0	0	0	0	1	AL
AM	0	-23	0	39	0	0	1	0	0	0	0	1	0	0	2	0	1	0	9	1	0	0	0	0	1	0	2	0	0	0	0	AM
AT	0	0	29	0	2	0	1	1	5	0	10	36	0	0	5	0	16	1	0	1	3	4	1	0	16	0	0	0	0	0	0	AT
AZ	0	2	0	34	0	0	1	1	0	0	0	1	0	0	1	0	1	0	8	1	0	0	0	0	1	0	7	0	0	0	0	AZ
BA	2	0	6	0	51	0	2	1	1	0	6	7	0	0	7	0	9	0	0	3	17	12	0	0	21	0	0	0	0	0	0	BA
BE	0	0	1	0	0	-56	0	0	1	0	2	-3	0	0	5	0	21	1	0	0	0	0	2	0	1	0	0	0	-1	0	0	BE
BG	2	0	2	0	2	0	58	1	0	0	2	4	0	0	4	0	5	0	0	11	1	5	0	0	6	0	1	0	0	0	3	BG
BY	0	0	1	0	0	0	0	20	0	0	1	5	1	1	1	2	3	2	0	0	0	1	1	0	1	0	0	5	0	2	1	BY
CH	0	0	4	0	0	0	0	0	34	0	1	19	0	0	9	0	45	1	0	0	1	1	1	0	23	0	0	0	0	0	0	CH
CY	1	0	1	1	1	0	2	0	0	32	0	1	0	0	3	0	3	0	0	20	0	1	0	0	5	0	0	0	0	0	0	CY
CZ	0	0	8	0	1	-0	1	1	1	0	17	31	1	0	4	1	12	2	0	1	2	5	1	0	4	0	0	0	0	0	0	CZ
DE	0	0	3	0	0	-1	0	1	2	0	5	7	1	0	4	1	18	3	0	0	0	1	1	0	3	0	0	0	1	0	0	DE
DK	0	0	0	0	0	-1	0	1	0	0	1	5	-10	0	1	1	4	5	0	0	0	1	2	0	0	0	0	1	0	1	0	DK
EE	0	0	0	0	0	0	0	4	-0	0	0	3	2	2	1	6	2	3	0	0	0	0	1	0	0	0	0	2	0	3	0	EE
ES	0	0	0	0	0	0	0	0	0	0	0	1	0	0	94	0	13	1	0	0	0	0	1	0	4	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	2	0	0	0	2	1	1	0	7	1	2	0	0	0	0	1	0	0	0	0	1	0	1	0	FI
FR	0	0	1	0	0	-0	0	0	2	0	1	6	0	0	14	0	67	3	0	0	0	0	2	0	6	0	0	0	0	0	0	FR
GB	0	0	0	0	0	-1	0	0	0	0	1	0	1	0	2	1	5	-28	0	0	0	0	4	0	0	0	0	0	0	0	0	GB
GE	0	3	0	35	0	0	1	1	0	0	0	1	0	0	2	0	1	0	46	2	0	0	0	0	2	0	3	0	0	0	1	GE
GL	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	GL
GR	5	0	2	0	2	0	22	1	0	0	1	3	0	0	6	0	6	0	0	53	1	2	0	0	14	0	0	0	0	0	1	GR
HR	1	0	11	0	19	0	2	1	1	0	7	11	0	0	6	0	10	1	0	2	35	18	0	0	23	0	0	0	0	0	0	HR
HU	1	0	10	0	5	-0	3	2	1	0	8	13	0	0	3	1	8	1	0	1	9	37	0	0	9	0	0	1	0	0	1	HU
IE	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	2	0	5	3	0	0	0	0	-2	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	-0	0	0	0	0	0	0	1	0	1	0	2	3	0	0	0	0	1	1	0	0	0	0	0	0	0	IS
IT	1	0	7	0	3	0	1	0	3	0	2	7	0	0	12	0	21	1	0	2	5	3	0	0	63	0	0	0	0	0	0	IT
KG	0	1	0	2	0	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	0	0	0	0	1	41	20	0	0	0	0	KG
KZ	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	1	1	28	0	0	0	0	KZ
LT	0	0	0	0	0	0	0	9	0	0	0	5	2	1	1	3	2	2	0	0	0	1	1	0	1	0	0	9	0	3	0	LT
LU	0	0	1	0	0	-2	0	0	1	0	2	12	0	0	6	0	36	4	0	0	0	1	1	0	2	0	0	0	-41	0	0	LU
LV	0	0	0	0	0	0	0	6	-0	0	0	4	2	2	1	4	2	2	0	0	0	0	1	0	0	0	0	5	0	4	0	LV
MD	0	0	1	0	1	-0	3	4	0	0	2	4	0	0	2	1	3	0	0	1	1	3	0	0	3	0	1	1	0	1	14	MD
ME	9	0	3	0	15	0	4	1	1	0	3	4	0	0	8	0	8	0	0	6	6	6	0	0	20	0	0	0	0	0	1	ME
MK	14	0	2	0	4	0	19	1	1	0	3	4	0	0	6	0	7	0	0	31	2	5	0	0	12	0	0	0	0	0	1	MK
MT	1	0	1	0	2	0	2	0	1	0	1	3	0	0	15	0	19	1	0	4	1	1	0	0	32	0	0	0	0	0	0	MT
NL	0	0	0	0	0	-7	0	1	0	0	2	-3	1	0	3	1	9	0	0	0	0	0	2	0	1	0	0	0	0	0	0	NL
NO	0	0	0	0	0	-0	0	1	0	0	0	2	1	0	1	2	2	4	0	0	0	0	1	0	0	0	0	0	0	0	0	NO
PL	0	0	2	0	1	-0	1	3	0	0	4	14	1	0	2	1	6	2	0	1	1	3	1	0	2	0	0	2	0	1	1	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	0	6	1	0	0	0	0	1	0	2	0	0	0	0	0	0	PT
RO	1	0	2	0	2	-0	9	2	0	0	3	6	0	0	3	1	4	0	0	3	2	8	0	0	5	0	1	1	0	0	4	RO
RS	4	0	4	0	10	0	12	1	1	0	5	7	0	0	5	0	7	1	0	5	5	13	0	0	11	0	0	0	0	0	1	RS
RU	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	RU
SE	0	0	0	0	0	0	0	1	0	0	0	4	2	0	1	4	2	3	0	0	0	0	1	0	0	0	0	1	0	1	0	SE
SI	0	0	27	0	4	-0	1	1	1	0	6	14	0	0	6	0	11	1	0	1	19	9	0	0	24	0	0	0	0	0	0	SI
SK	0	0	7	0	3	-0	2	2	1	0	13	14	1	0	3	1	7	1	0	1	4	22	0	0	6	0	0	1	0	0	1	SK
TJ	0	1	0	2	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	3	7	0	0	0	0	TJ
TM	0	1	0	7	0	0	0	1	0	0	0	1	0	0	2	0	1	0	1	1	0	0	0	0	1	0	16	0	0	0	0	TM
TR	0	1	1	3	1	0	2	1	0	1	0	1	0	0	3	0	3	0	2	5	0	1	0	0	3	0	1	0	0	0	1	TR
UA	0	0	1	0	1	0	1	6	0	0	1	4	0	0	2	1	3	1	0	1	1	2	0	0	2	0	1	1	0	1	3	UA
UZ	0	1	0	3	0	0	0	1	0	0	0	1	0	0	2	1	1	0	1	0	0	0	0	0	1	1	23	0	0	0	0	UZ
ATL	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	3	0	3	2	0	0	0	0	1	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	-0	0	2	0	0	0	3	1	1	1	6	2	3	0	0	0	0	1	0	0	0	0	2	0	2	0	BAS
BLS	0	0	1	1	1	-0	4	4	0	0	1	2	0	0	2	1	2	0	5	2	0	1	0	0	2	0	2	1	0	1	3	BLS
MED	2	0	2	0	3	0	4	1	1	1	1	3	0	0	15	0	19	0	0	13	3	2	0	0	23	0	0	0	0	0	1	MED
NOS	0	0	0	0	0	-1	0	1	0	0	0	-1	1	0	2	1	3	-3	0	0	0	0	4	1	0	0	0	0	0	0	0	NOS
AST	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	1	2	7	0	0	0	0	AST
NOA	0	0	1	0	1	0	1	0	0	0	0	1	0	0	15	0	6	0	0	4	0	0	0	0	7	0	0	0	0	0	0	NOA
EXC	0	0	1	1	1	-0	1	1	0	0	1	2	0	0	5	1	5	0	1	1	1	1	0	0	3	1	7	0	0	0	0	EXC
EU	0	0	3	0	1	-1	3	1	1	0	2	6	1	0	16	1	16	0	0	2	2	3	1	0	8	0	0	1	0	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.6 Cont.: 2019 country-to-country blame matrices for **SOMO35**.
Units: ppb.d per 15% emis. red. of NO_x. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	
AL	7	9	0	-0	0	4	1	6	19	4	0	0	2	0	0	2	4	0	3	0	0	36	0	1	10	0	0	194	92	AL
AM	0	0	0	0	0	1	0	1	0	11	0	0	0	0	3	34	3	1	1	0	2	5	0	59	3	0	0	93	11	AM
AT	0	0	0	-0	1	7	1	2	2	3	1	5	3	0	0	0	2	0	4	1	0	5	1	0	4	0	0	159	143	AT
AZ	0	0	0	0	0	1	0	1	0	31	0	0	0	0	8	13	5	2	1	0	2	2	0	35	2	0	0	120	10	AZ
BA	4	1	0	-0	1	9	1	7	11	4	1	1	4	0	0	1	4	0	3	1	0	17	0	0	7	0	0	194	113	BA
BE	0	0	0	-11	1	3	1	0	0	2	1	0	0	0	0	0	1	0	8	1	0	2	-17	0	1	0	0	-23	-30	BE
BG	1	2	0	-0	1	9	0	30	9	14	1	0	2	0	0	5	15	0	2	1	5	9	0	2	4	0	0	198	141	BG
BY	0	0	0	-0	1	12	0	2	0	27	2	0	1	0	0	1	14	0	3	5	0	1	1	0	1	0	0	110	44	BY
CH	0	0	0	-0	1	1	1	0	0	1	0	1	0	0	0	0	1	0	5	0	0	6	1	0	4	0	0	146	108	CH
CY	0	1	0	0	0	2	0	2	1	7	0	0	0	0	0	64	4	0	1	0	3	74	0	14	7	0	0	156	75	CY
CZ	0	0	0	-0	1	17	0	3	2	4	1	1	5	0	0	0	2	0	4	2	0	3	1	0	2	0	0	130	117	CZ
DE	0	0	0	-3	2	8	0	1	1	3	1	0	1	0	0	0	1	0	6	1	0	2	-2	0	1	0	0	66	55	DE
DK	0	0	0	-2	4	7	0	1	0	6	4	0	0	0	0	0	2	0	7	-5	0	1	-0	0	0	0	0	38	23	DK
EE	0	0	0	-0	3	4	0	0	0	21	6	0	0	0	0	0	3	0	4	8	0	0	3	0	0	0	0	66	35	EE
ES	0	0	0	-0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	16	0	0	11	1	0	9	0	0	132	130	ES
FI	0	0	0	0	3	3	0	0	0	12	4	0	0	0	0	0	1	0	4	4	0	0	2	0	0	0	0	44	25	FI
FR	0	0	0	-1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	11	0	0	6	0	0	3	0	0	109	104	FR
GB	0	0	0	-2	2	2	0	0	0	2	1	0	0	0	0	0	0	0	7	1	0	0	-7	0	0	0	0	-8	-14	GB
GE	0	0	0	0	0	2	0	2	1	29	0	0	0	0	3	27	7	1	1	1	10	4	0	18	3	0	0	174	16	GE
GL	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	GL
GR	1	4	0	0	0	5	1	10	6	9	0	0	1	0	0	10	9	0	2	1	3	36	0	2	9	0	0	180	130	GR
HR	1	0	0	-0	1	9	1	5	7	4	1	4	4	0	0	1	4	0	3	1	0	19	1	0	6	0	0	191	150	HR
HU	0	0	0	-0	1	19	0	16	8	6	1	3	12	0	0	1	9	0	3	1	0	5	1	0	3	0	0	193	157	HU
IE	0	0	0	-1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	8	0	0	0	-1	0	1	0	0	12	9	IE
IS	0	0	0	-1	2	1	0	0	0	2	1	0	0	0	0	0	0	0	7	1	0	0	1	0	0	0	0	16	10	IS
IT	1	0	0	-0	0	3	1	2	2	2	0	3	1	0	0	1	2	0	4	0	0	34	1	0	11	0	0	150	135	IT
KG	0	0	0	0	0	1	0	0	0	9	0	0	0	14	6	3	1	45	1	0	0	2	0	61	2	0	0	150	8	KG
KZ	0	0	0	0	1	1	0	1	0	55	1	0	0	0	3	2	3	4	1	1	0	1	0	7	1	0	0	111	10	KZ
LT	0	0	0	-0	2	11	0	1	0	18	3	0	0	0	0	0	7	0	3	8	0	1	2	0	0	0	0	86	48	LT
LU	0	0	0	-2	1	3	1	0	0	2	1	0	0	0	0	0	1	0	7	1	0	2	-1	0	1	0	0	33	26	LU
LV	0	0	0	-0	2	6	0	1	0	19	5	0	0	0	0	0	5	0	3	8	0	0	3	0	0	0	0	72	38	LV
MD	0	0	0	-0	1	12	0	20	2	24	1	0	2	0	0	4	41	0	2	2	4	3	1	1	2	0	0	157	63	MD
ME	37	2	0	-0	0	6	1	8	20	4	0	0	2	0	0	2	4	0	3	0	0	27	0	1	10	0	0	183	87	ME
MK	2	26	0	-0	0	5	1	10	25	6	0	0	2	0	0	3	5	0	3	0	1	16	0	1	8	0	0	200	112	MK
MT	1	1	-86	-0	0	2	1	2	2	1	0	0	1	0	0	1	1	0	5	0	0	2	1	0	27	0	0	13	1	MT
NL	0	0	0	-69	2	5	0	1	0	3	1	0	0	0	0	0	1	0	6	1	0	1	-27	0	0	0	0	-44	-52	NL
NO	0	0	0	-0	8	3	0	0	0	6	4	0	0	0	0	0	1	0	8	2	0	0	2	0	0	0	0	39	21	NO
PL	0	0	0	-1	2	29	0	4	1	8	3	0	3	0	0	1	8	0	4	5	0	2	1	0	1	0	0	108	83	PL
PT	0	0	0	0	0	0	47	0	0	0	0	0	0	0	0	0	0	0	29	0	0	4	1	0	5	0	0	104	103	PT
RO	1	1	0	-0	1	14	0	61	5	14	1	0	3	0	0	4	21	0	2	1	3	4	1	1	3	0	0	183	126	RO
RS	3	3	0	-0	1	10	0	20	29	6	1	1	5	0	0	2	7	0	3	1	1	10	1	1	5	0	0	181	113	RS
RU	0	0	0	-0	1	1	0	0	0	42	1	0	0	0	0	1	3	0	2	1	0	0	1	1	0	0	0	62	9	RU
SE	0	0	0	-0	5	5	0	0	0	7	8	0	0	0	0	0	2	0	6	4	0	0	3	0	0	0	0	51	33	SE
SI	0	0	0	-0	1	8	1	3	2	3	1	22	4	0	0	0	3	0	3	1	0	12	1	0	5	0	0	173	156	SI
SK	0	0	0	-0	1	29	0	10	4	6	1	2	18	0	0	1	9	0	3	2	0	4	1	0	3	0	0	172	144	SK
TJ	0	0	0	0	0	0	0	0	0	6	0	0	0	54	11	4	0	32	1	0	0	1	0	90	2	0	0	125	6	TJ
TM	0	0	0	0	0	1	0	1	0	32	0	0	0	1	44	5	3	23	1	1	1	2	0	49	2	0	0	146	11	TM
TR	0	0	0	0	0	2	0	3	1	14	0	0	0	0	0	76	7	0	1	0	7	14	0	25	5	0	0	138	28	TR
UA	0	0	0	-0	1	12	0	7	1	39	1	0	1	0	0	3	40	0	2	2	2	2	1	1	1	0	0	142	45	UA
UZ	0	0	0	0	0	1	0	1	0	35	0	0	0	4	15	4	3	26	1	1	1	1	0	29	1	0	0	127	11	UZ
ATL	0	0	0	-0	1	0	1	0	0	2	1	0	0	0	0	0	0	0	20	0	0	0	1	0	1	0	0	17	13	ATL
BAS	0	0	0	-1	4	8	0	1	0	11	8	0	0	0	0	0	3	0	7	-20	0	0	2	0	0	0	0	63	41	BAS
BLS	0	0	0	-0	1	7	0	10	1	56	1	0	1	0	0	10	37	0	2	2	37	3	1	2	2	0	0	163	40	BLS
MED	1	1	0	-0	0	3	2	4	3	5	0	1	1	0	0	13	4	0	6	0	2	84	0	1	17	0	0	130	98	MED
NOS	0	0	0	-6	4	3	0	0	0	4	2	0	0	0	0	0	1	0	14	0	0	0	-40	0	0	0	0	19	8	NOS
AST	0	0	0	0	0	0	0	0	0	9	0	0	0	2	7	9	1	5	1	0	0	4	0	113	2	0	0	52	7	AST
NOA	0	0	0	0	0	1	3	1	1	1	0	0	0	0	0	3	1	0	9	0	0	23	0	-0	81	0	0	50	42	NOA
EXC	0	0	0	-0	1	3	1	2	1	30	1	0	1	1	2	5	5	3	3	1	1	3	0	6	2	0	0	91	31	EXC
EU	0	0	0	-1	2	7	3	6	1	6	2	1	1	0	0	1	4	0	7	2	0	7	-0	0	3	0	0	101	83	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	

Table D.7: 2019 country-to-country blame matrices for **SOMO35**.
Units: ppb.d per 15% emis. red. of VOC. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	9	0	1	0	2	1	1	1	1	0	2	7	0	0	2	0	4	2	0	2	1	2	0	0	12	0	0	0	0	0	0	AL
AM	0	19	0	37	0	0	0	1	0	0	0	2	0	0	1	0	1	1	3	0	0	0	0	0	2	0	1	0	0	0	0	AM
AT	0	0	10	0	0	1	0	1	3	0	4	25	0	0	2	0	7	4	0	0	1	1	0	0	12	0	0	0	0	0	0	AT
AZ	0	2	0	85	0	0	0	1	0	0	0	2	0	0	1	0	1	1	3	0	0	0	0	0	1	0	2	0	0	0	0	AZ
BA	1	0	2	0	11	1	0	1	1	0	3	10	0	0	2	0	5	3	0	1	2	2	0	0	11	0	0	0	0	0	0	BA
BE	0	0	0	0	0	11	0	0	0	0	2	16	0	0	1	0	14	11	0	0	0	0	1	0	1	0	0	0	1	0	0	BE
BG	0	0	1	1	1	0	5	1	0	0	2	7	0	0	1	0	3	2	0	2	1	1	0	0	4	0	0	0	0	0	1	BG
BY	0	0	0	0	0	0	0	4	0	0	1	5	1	0	0	0	2	3	0	0	0	0	0	0	1	0	0	0	0	0	0	BY
CH	0	0	2	0	0	1	0	0	23	0	1	20	0	0	2	0	14	4	0	0	0	0	0	0	20	0	0	0	0	0	0	CH
CY	0	0	0	2	1	0	1	1	0	4	1	4	0	0	1	0	3	2	0	3	0	1	0	0	5	0	0	0	0	0	0	CY
CZ	0	0	3	0	1	2	0	1	1	0	13	23	1	0	1	0	7	5	0	0	1	1	0	0	5	0	0	0	0	0	0	CZ
DE	0	0	2	0	0	3	0	1	2	0	2	34	1	0	1	0	9	7	0	0	0	0	1	0	2	0	0	0	0	0	0	DE
DK	0	0	0	0	0	1	0	1	0	0	1	10	6	0	0	0	3	8	0	0	0	0	1	0	0	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	1	0	0	0	4	1	0	0	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	EE
ES	0	0	0	0	0	0	0	0	0	0	0	2	0	0	18	0	5	2	0	0	0	0	0	0	3	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	FI
FR	0	0	1	0	0	2	0	0	1	0	1	8	0	0	3	0	18	5	0	0	0	0	1	0	5	0	0	0	0	0	0	FR
GB	0	0	0	0	0	1	0	0	0	0	1	5	1	0	1	0	5	17	0	0	0	0	1	0	0	0	0	0	0	0	0	GB
GE	0	2	0	30	0	0	0	1	0	0	1	2	0	0	1	0	1	1	8	0	0	0	0	0	2	0	1	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	1	0	1	1	1	0	2	1	0	0	2	6	0	0	2	0	4	2	0	12	1	1	0	0	8	0	0	0	0	0	1	GR
HR	0	0	3	0	4	1	0	1	1	0	4	13	0	0	2	0	5	3	0	0	6	3	0	0	17	0	0	0	0	0	0	HR
HU	0	0	3	0	2	1	1	1	1	0	4	14	1	0	1	0	5	3	0	0	2	7	0	0	7	0	0	0	0	0	0	HU
IE	0	0	0	0	0	1	0	0	0	0	0	4	0	0	1	0	4	6	0	0	0	0	3	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	IS
IT	0	0	2	0	1	1	0	1	2	0	2	10	0	0	4	0	8	3	0	0	2	1	0	0	65	0	0	0	0	0	0	IT
KG	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	9	6	0	0	0	0	KG
KZ	0	0	0	2	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	1	1	6	0	0	0	0	KZ
LT	0	0	0	0	0	1	0	2	0	0	1	6	1	0	0	0	2	4	0	0	0	0	0	0	1	0	0	1	0	0	0	LT
LU	0	0	1	0	0	5	0	0	1	0	1	19	0	0	1	0	13	7	0	0	0	0	1	0	2	0	0	0	3	0	0	LU
LV	0	0	0	0	0	1	0	1	0	0	1	5	1	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	1	0	LV
MD	0	0	1	1	0	0	1	2	0	0	2	6	1	0	1	0	3	2	0	0	0	1	0	0	2	0	0	0	0	0	5	MD
ME	2	0	1	0	3	1	1	1	1	0	2	8	0	0	3	0	4	3	0	1	1	2	0	0	10	0	0	0	0	0	0	ME
MK	2	0	1	0	1	1	2	1	0	0	2	7	0	0	2	0	3	2	0	6	1	2	0	0	6	0	0	0	0	0	0	MK
MT	0	0	1	0	1	1	0	0	1	0	1	6	0	0	6	0	8	3	0	1	1	1	1	0	25	0	0	0	0	0	0	MT
NL	0	0	0	0	0	6	0	1	0	0	1	18	1	0	1	0	8	12	0	0	0	0	1	0	1	0	0	0	0	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	1	0	0	1	0	1	0	0	3	13	1	0	1	0	4	5	0	0	0	1	0	0	2	0	0	0	0	0	0	PL
PT	0	0	0	0	0	0	0	0	0	0	0	1	0	0	9	0	3	2	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	0	0	1	0	1	0	1	1	0	0	2	7	1	0	1	0	3	2	0	1	1	2	0	0	4	0	0	0	0	0	1	RO
RS	1	0	1	0	3	1	1	1	1	0	3	9	0	0	1	0	4	3	0	1	1	3	0	0	6	0	0	0	0	0	0	RS
RU	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	RU
SE	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	SE
SI	0	0	6	0	1	1	0	1	1	0	4	17	1	0	2	0	6	4	0	0	4	2	0	0	29	0	0	0	0	0	0	SI
SK	0	0	2	0	1	1	0	1	1	0	6	14	1	0	1	0	5	3	0	0	1	4	0	0	6	0	0	0	0	0	0	SK
TJ	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	0	0	0	0	TJ
TM	0	0	0	10	0	0	0	1	0	0	0	2	0	0	1	0	1	1	0	0	0	0	0	0	1	0	4	0	0	0	0	TM
TR	0	1	0	3	0	0	0	1	0	0	1	3	0	0	1	0	2	1	0	1	0	0	0	0	3	0	0	0	0	0	0	TR
UA	0	0	0	1	0	0	0	2	0	0	1	5	0	0	1	0	2	2	0	0	0	1	0	0	2	0	0	0	0	0	1	UA
UZ	0	0	0	4	0	0	0	1	0	0	0	2	0	0	1	0	1	1	0	0	0	0	0	0	1	1	5	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	1	0	1	0	0	1	8	2	0	0	1	3	6	0	0	0	0	1	0	0	0	0	1	0	1	0	BAS
BLS	0	0	0	4	0	0	1	2	0	0	1	5	1	0	1	0	3	2	2	1	0	1	0	0	3	0	1	0	0	0	1	BLS
MED	1	0	1	1	1	1	1	1	1	0	2	7	0	0	7	0	9	3	0	3	1	1	0	0	21	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	2	0	1	0	0	1	9	2	0	1	0	6	18	0	0	0	0	2	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	5	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	2	0	0	4	0	3	2	0	1	0	0	0	0	4	0	0	0	0	0	0	NOA
EXC	0	0	0	2	0	0	0	1	0	0	1	4	0	0	1	0	2	2	0	0	0	0	0	0	2	0	2	0	0	0	0	EXC
EU	0	0	1	0	0	1	0	1	1	0	2	9	1	0	3	0	6	5	0	1	0	1	1	0	7	0	0	0	0	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.7 Cont.: 2019 country-to-country blame matrices for **SOMO35**.
Units: ppb.d per 15% emis. red. of VOC. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	
AL	1	1	0	1	0	4	0	2	4	3	0	0	1	0	0	2	1	0	0	0	0	0	0	1	4	0	0	72	47	AL
AM	0	0	0	0	0	2	0	1	0	7	0	0	0	0	1	13	1	0	0	0	0	0	0	70	2	0	0	96	12	AM
AT	0	0	0	2	0	4	0	1	1	2	0	1	1	0	0	0	1	0	0	0	0	0	0	0	2	0	0	86	78	AT
AZ	0	0	0	0	0	2	0	1	0	16	0	0	0	0	2	6	2	1	0	0	0	0	0	53	1	0	0	132	12	AZ
BA	0	0	0	1	0	5	0	2	3	3	0	0	2	0	0	1	1	0	0	0	0	0	0	1	3	0	0	75	54	BA
BE	0	0	0	10	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	72	BE
BG	0	0	0	1	0	6	0	5	2	7	0	0	1	0	0	5	3	0	0	0	0	0	0	3	2	0	0	66	44	BG
BY	0	0	0	1	0	4	0	1	0	6	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	38	24	BY
CH	0	0	0	2	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	98	73	CH
CY	0	0	0	1	0	3	0	1	1	6	0	0	1	0	0	31	2	0	0	0	0	0	0	26	4	0	0	76	31	CY
CZ	0	0	0	3	0	8	0	1	1	2	0	1	2	0	0	0	1	0	0	0	0	0	0	0	1	0	0	82	75	CZ
DE	0	0	0	6	0	4	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	80	74	DE
DK	0	0	0	4	1	4	0	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	49	43	DK
EE	0	0	0	1	0	2	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	18	EE
ES	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	36	34	ES
FI	0	0	0	1	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	10	FI
FR	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	53	49	FR
GB	0	0	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	37	GB
GE	0	0	0	0	0	2	0	1	0	12	0	0	0	0	1	9	2	0	0	0	0	0	0	24	1	0	0	80	14	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	GL
GR	0	1	0	1	0	4	0	3	2	5	0	0	1	0	0	6	2	0	0	0	0	0	0	4	4	0	0	72	51	GR
HR	0	0	0	2	0	6	0	1	2	2	0	1	2	0	0	1	1	0	0	0	0	0	0	0	3	0	0	85	72	HR
HU	0	0	0	2	0	9	0	3	3	3	0	1	4	0	0	1	2	0	0	0	0	0	0	1	1	0	0	80	67	HU
IE	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	23	IE
IS	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	11	IS
IT	0	0	0	1	0	3	0	1	1	2	0	1	1	0	0	1	1	0	0	0	0	0	0	0	5	0	0	117	109	IT
KG	0	0	0	0	0	1	0	0	0	5	0	0	0	6	1	1	0	31	0	0	0	0	0	34	1	0	0	69	5	KG
KZ	0	0	0	0	0	1	0	0	0	12	0	0	0	0	1	1	1	3	0	0	0	0	0	13	0	0	0	36	9	KZ
LT	0	0	0	2	0	4	0	0	0	5	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	35	26	LT
LU	0	0	0	6	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	66	62	LU
LV	0	0	0	2	0	3	0	0	0	5	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	28	21	LV
MD	0	0	0	1	0	6	0	4	1	9	1	0	1	0	0	3	5	0	0	0	0	0	0	1	1	0	0	60	34	MD
ME	4	0	0	1	0	4	0	2	3	3	0	0	1	0	0	1	1	0	0	0	0	0	0	1	4	0	0	66	47	ME
MK	0	5	0	1	0	4	0	2	4	3	0	0	1	0	0	3	1	0	0	0	0	0	0	3	3	0	0	67	44	MK
MT	0	0	4	1	0	3	1	1	1	2	0	0	1	0	0	1	1	0	0	0	0	1	0	1	12	0	0	75	67	MT
NL	0	0	0	20	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	73	NL
NO	0	0	0	1	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	12	NO
PL	0	0	0	3	1	15	0	1	1	3	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	63	55	PL
PT	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	33	32	PT
RO	0	0	0	1	0	7	0	10	2	6	0	0	1	0	0	3	3	0	0	0	0	0	0	2	1	0	0	65	47	RO
RS	0	1	0	1	0	6	0	4	9	4	0	0	2	0	0	2	2	0	0	0	0	0	0	2	2	0	0	73	50	RS
RU	0	0	0	0	0	1	0	0	0	10	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	19	6	RU
SE	0	0	0	1	1	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	15	SE
SI	0	0	0	2	0	5	0	1	1	2	0	8	2	0	0	0	1	0	0	0	0	0	0	0	2	0	0	102	94	SI
SK	0	0	0	2	0	13	0	2	2	3	0	1	6	0	0	1	1	0	0	0	0	0	0	1	1	0	0	80	69	SK
TJ	0	0	0	0	0	0	0	0	0	4	0	0	0	24	2	2	0	15	0	0	0	0	0	40	1	0	0	58	4	TJ
TM	0	0	0	0	0	1	0	0	0	13	0	0	0	1	10	3	1	6	0	0	0	0	0	65	1	0	0	63	12	TM
TR	0	0	0	0	0	2	0	1	1	7	0	0	0	0	0	28	2	0	0	0	0	0	0	29	2	0	0	63	18	TR
UA	0	0	0	1	0	5	0	2	1	12	0	0	1	0	0	2	6	0	0	0	0	0	0	1	1	0	0	52	27	UA
UZ	0	0	0	0	0	1	0	0	0	12	0	0	0	3	3	2	1	21	0	0	0	0	0	28	1	0	0	64	10	UZ
ATL	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	11	10	ATL
BAS	0	0	0	3	1	5	0	0	0	5	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	45	36	BAS
BLS	0	0	0	1	1	5	0	3	1	27	1	0	1	0	0	14	6	0	0	0	0	0	0	8	2	0	0	92	32	BLS
MED	0	0	0	1	0	4	1	2	1	4	0	1	1	0	0	8	2	0	0	0	0	1	0	6	13	0	0	89	69	MED
NOS	0	0	0	6	2	2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	50	NOS
AST	0	0	0	0	0	1	0	0	0	4	0	0	0	1	2	4	1	2	0	0	0	0	0	123	1	0	0	28	6	AST
NOA	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	20	0	0	26	22	NOA
EXC	0	0	0	1	0	2	0	1	0	8	0	0	0	0	1	2	1	2	0	0	0	0	0	8	1	0	0	37	19	EXC
EU	0	0	0	2	0	4	1	1	1	2	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	0	0	54	47	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	DMS	VOL	EXC	EU	

Table D.8: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of PPM. **Emitters →, Receptors ↓**.

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	188	0	1	0	4	0	2	0	0	0	1	1	0	0	1	0	1	0	0	6	2	2	0	0	7	0	0	0	0	0	0	AL
AM	0	123	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	217	0	1	0	0	0	3	0	10	16	0	0	0	0	3	1	0	0	5	7	0	0	10	-0	0	0	0	0	0	AT
AZ	0	10	0	235	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	1	0	0	0	0	AZ
BA	1	0	3	0	316	0	1	0	0	0	3	3	0	0	1	0	1	0	0	0	30	10	0	0	7	0	0	0	0	0	0	BA
BE	0	-0	2	-0	0	199	0	0	1	0	2	35	0	0	1	0	83	16	-0	0	0	0	0	0	0	-0	-0	0	6	0	0	BE
BG	1	0	1	0	2	0	156	1	0	0	1	1	0	0	0	0	1	0	0	7	1	3	0	0	1	0	0	0	0	0	4	BG
BY	0	0	1	0	1	0	0	97	0	0	2	3	1	1	0	0	1	1	0	0	1	2	0	0	1	0	0	7	0	3	3	BY
CH	0	0	8	-0	0	0	0	0	170	0	1	21	0	0	1	0	25	1	0	0	0	0	0	0	16	-0	-0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	CY
CZ	0	0	21	0	2	1	0	0	1	0	207	28	0	0	0	0	6	2	0	0	4	10	0	0	3	-0	0	0	0	0	0	CZ
DE	0	-0	13	-0	0	5	0	0	5	-0	9	187	1	0	0	0	20	5	-0	0	1	1	0	0	2	-0	0	0	1	0	0	DE
DK	0	0	1	0	0	3	0	0	0	0	2	20	83	0	0	0	6	9	0	0	0	1	0	0	0	-0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	5	0	0	1	2	1	105	0	4	1	1	0	0	0	0	0	0	0	0	0	4	0	14	1	EE
ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	0	5	1	0	0	0	0	0	0	2	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	24	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	FI
FR	0	-0	1	-0	0	4	0	0	4	0	0	11	0	0	4	0	189	6	0	0	0	0	0	0	4	-0	0	0	0	0	0	FR
GB	0	-0	0	-0	0	2	0	0	0	-0	0	4	0	0	1	0	10	172	-0	0	0	0	3	0	0	-0	0	0	0	0	0	GB
GE	0	10	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	178	0	0	0	0	0	0	0	0	0	0	0	0	GE
GL	0	0	0	-0	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	-0	0	0	0	0	0	GL
GR	4	0	0	0	1	0	8	0	0	0	0	1	0	0	1	0	1	0	0	103	1	1	0	0	3	0	0	0	0	0	1	GR
HR	1	0	10	0	65	0	1	0	0	0	5	4	0	0	1	0	2	0	0	0	239	24	0	0	19	0	0	0	0	0	0	HR
HU	1	0	17	0	13	0	2	1	0	0	9	6	0	0	0	0	2	1	0	1	26	250	0	0	6	-0	0	0	0	0	0	HU
IE	0	-0	0	-0	0	1	0	0	0	-0	0	1	0	0	1	0	5	15	-0	0	0	0	43	0	0	-0	-0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	IS
IT	0	0	5	0	2	0	0	0	2	0	1	2	0	0	2	0	6	0	0	0	4	2	0	0	322	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	5	0	0	0	0	KG
KZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	36	0	0	0	0	KZ
LT	0	0	1	0	0	0	0	20	0	0	2	5	1	1	0	1	2	2	0	0	1	1	0	0	1	0	0	125	0	10	1	LT
LU	0	0	3	-0	0	26	0	0	2	0	2	70	0	0	1	0	93	6	-0	0	0	0	0	0	1	0	0	0	62	0	0	LU
LV	0	0	0	0	0	0	0	11	0	0	1	3	1	6	0	1	1	2	0	0	0	1	0	0	0	0	0	21	0	95	1	LV
MD	0	0	1	0	1	0	5	2	0	0	1	2	0	0	0	0	1	1	1	1	1	2	0	0	1	0	0	1	0	0	377	MD
ME	14	0	1	0	14	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	3	3	0	0	5	0	0	0	0	0	0	ME
MK	14	0	1	0	2	0	7	0	0	0	1	1	0	0	1	0	1	0	0	19	1	3	0	0	3	0	0	0	0	0	1	MK
MT	1	0	1	0	2	0	0	0	0	0	0	1	0	0	3	0	5	0	0	1	1	1	0	0	17	0	0	0	0	0	0	MT
NL	0	-0	1	-0	0	46	0	0	0	-0	3	67	0	0	1	0	31	19	-0	0	0	0	0	0	0	-0	-0	0	1	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	-0	0	0	0	0	0	NO
PL	0	0	3	0	1	1	0	4	0	0	14	15	1	0	0	0	3	2	0	0	2	5	0	0	1	0	0	2	0	1	1	PL
PT	0	-0	0	-0	0	0	0	0	0	0	0	0	0	0	32	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	1	0	1	0	2	0	13	1	0	0	1	2	0	0	0	0	1	0	0	1	1	9	0	0	1	0	0	0	0	0	10	RO
RS	4	0	2	0	24	0	9	0	0	0	3	3	0	0	0	0	1	0	0	3	10	18	0	0	3	0	0	0	0	0	1	RS
RU	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	RU
SE	0	0	0	0	0	0	0	1	0	0	0	2	2	0	0	1	1	1	0	0	0	0	0	0	0	-0	0	1	0	0	0	SE
SI	0	0	51	0	5	0	0	0	1	0	5	6	0	0	1	0	2	0	0	0	53	10	0	0	44	0	0	0	0	0	0	SI
SK	0	0	11	0	5	0	1	1	0	0	18	6	0	0	0	0	2	1	0	0	7	49	0	0	3	-0	0	0	0	0	0	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	TJ
TM	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	TM
TR	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	TR
UA	0	0	1	0	1	0	2	7	0	0	1	2	0	0	0	0	1	0	1	0	1	2	0	0	1	0	0	1	0	0	14	UA
UZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	8	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	1	0	0	1	0	2	0	0	1	9	6	4	0	5	2	3	0	0	0	1	0	0	0	0	0	3	0	4	0	BAS
BLS	0	0	0	1	0	0	4	1	0	0	0	1	0	0	0	0	0	0	11	1	0	0	0	0	0	0	0	0	0	0	4	BLS
MED	1	0	1	0	2	0	1	0	0	0	0	1	0	0	8	0	6	0	0	6	2	1	0	0	18	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	3	0	0	0	0	1	7	2	0	1	0	11	25	0	0	0	0	1	0	0	-0	0	0	0	0	0	NOS
AST	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	0	NOA
EXC	0	0	2	2	2	1	1	2	1	0	2	5	0	1	4	1	7	3	1	1	1	2	0	0	6	1	7	1	0	1	1	EXC
EU	0	0	7	0	2	3	5	1	1	0	7	21	1	1	15	2	29	12	0	3	5	8	1	0	24	0	0	3	0	2	1	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.8 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of PPM. **Emitters** →, **Receptors** ↓.

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	10	10	0	0	0	3	0	4	26	1	0	0	1	0	0	1	2	0	0	0	0	4	0	0	1	0	0	0	274	31	AL
AM	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	31	1	0	0	0	0	0	0	7	0	0	0	0	192	1	AM
AT	0	0	0	0	0	8	0	1	1	0	0	9	4	-0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	300	293	AT
AZ	0	0	0	0	0	0	0	0	0	18	0	0	0	0	1	9	2	0	0	0	0	0	0	8	0	0	0	0	299	1	AZ
BA	4	0	0	0	0	8	0	3	16	1	0	1	2	0	0	0	2	0	0	0	0	2	0	0	1	0	0	0	415	74	BA
BE	0	0	0	18	0	2	0	0	0	0	0	0	0	-0	-0	-0	0	-0	1	0	0	0	16	-0	0	0	0	0	366	365	BE
BG	0	2	0	0	0	6	0	33	13	5	0	0	1	0	0	13	13	0	0	0	1	2	0	0	0	0	0	0	266	213	BG
BY	0	0	0	0	0	37	0	6	1	17	1	0	1	0	0	2	38	0	0	1	0	0	0	0	0	0	0	0	229	70	BY
CH	0	0	0	0	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	0	0	0	0	0	0	0	0	0	0	245	74	CH
CY	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	77	4	0	0	0	0	14	0	11	1	0	0	0	123	38	CY
CZ	0	0	0	1	0	41	0	2	3	1	0	2	11	-0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	349	339	CZ
DE	0	0	0	6	0	15	0	0	0	1	0	0	1	-0	-0	0	1	-0	0	1	0	0	3	-0	0	0	0	0	274	267	DE
DK	0	0	0	3	2	17	0	1	0	1	2	0	1	-0	0	0	2	-0	1	7	0	0	7	0	0	0	0	0	159	151	DK
EE	0	0	0	0	1	9	0	1	0	12	2	0	0	0	0	0	7	0	0	3	0	0	0	0	0	0	0	0	172	146	EE
ES	0	0	0	0	0	0	9	0	0	0	0	0	0	-0	0	0	0	0	3	0	0	6	0	0	2	0	0	0	135	135	ES
FI	0	0	0	0	1	2	0	0	0	5	2	0	0	-0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	42	33	FI
FR	0	0	0	1	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	1	0	0	2	2	0	0	0	0	0	226	222	FR
GB	0	0	0	1	0	2	0	0	0	0	0	0	0	-0	-0	-0	0	-0	3	0	0	0	6	-0	0	0	0	0	198	197	GB
GE	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	15	2	0	0	0	0	0	0	2	0	0	0	0	231	1	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	0	0	-0	0	0	0	0	0	-0	0	0	0	0	0	0	GL
GR	0	4	0	0	0	3	0	5	5	3	0	0	0	0	0	13	7	0	0	0	0	12	0	0	1	0	0	0	168	128	GR
HR	1	0	0	0	0	10	0	3	17	1	0	15	4	0	0	0	2	0	0	0	0	4	0	0	1	0	0	0	428	339	HR
HU	0	1	0	0	0	28	0	36	28	2	0	5	25	0	0	1	10	0	0	0	0	1	0	0	0	0	0	0	473	416	HU
IE	0	0	0	0	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	4	0	0	0	1	-0	0	0	0	0	69	68	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	0	0	0	1	0	0	0	0	0	0	0	0	0	5	2	IS
IT	0	0	0	0	0	2	0	1	1	0	0	4	1	0	0	0	0	0	0	0	0	11	0	0	2	0	0	0	359	352	IT
KG	0	0	0	0	0	0	0	0	0	1	0	0	0	7	0	0	0	16	0	0	0	0	0	11	0	0	0	0	66	0	KG
KZ	0	0	0	0	0	0	0	0	0	15	0	0	0	1	1	0	3	4	0	0	0	0	0	6	0	0	0	0	62	1	KZ
LT	0	0	0	0	1	44	0	3	1	13	1	0	1	0	0	1	14	0	0	2	0	0	1	0	0	0	0	0	256	203	LT
LU	0	0	0	4	0	2	0	0	0	0	0	0	0	0	0	-0	0	-0	1	0	0	0	2	-0	0	0	0	0	273	271	LU
LV	0	0	0	0	1	19	0	2	0	10	1	0	1	0	0	1	11	0	0	2	0	0	1	0	0	0	0	0	193	157	LV
MD	0	0	0	0	0	17	0	90	2	11	0	0	1	0	0	8	77	0	0	0	1	1	0	0	0	0	0	0	604	123	MD
ME	135	1	0	0	0	4	0	4	21	1	0	0	1	0	0	0	2	0	0	0	0	2	0	0	1	0	0	0	218	28	ME
MK	1	146	0	0	0	4	0	6	35	1	0	0	1	0	0	2	4	0	0	0	0	2	0	0	1	0	0	0	254	48	MK
MT	0	0	50	0	0	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	99	0	0	11	0	0	0	89	83	MT
NL	0	0	0	133	0	5	0	0	0	0	0	0	0	-0	-0	-0	0	-0	1	0	0	0	27	-0	0	0	0	0	312	310	NL
NO	0	0	0	0	24	1	0	0	0	1	1	0	0	-0	0	0	1	-0	1	0	0	0	1	0	0	0	0	0	31	6	NO
PL	0	0	0	1	0	426	0	6	2	4	1	1	6	0	0	0	16	0	0	1	0	0	1	0	0	0	0	0	522	492	PL
PT	0	0	0	0	0	0	170	0	0	0	0	0	0	0	-0	0	0	-0	9	0	0	1	0	0	1	0	0	0	207	207	PT
RO	0	1	0	0	0	12	0	330	11	5	0	0	2	0	0	5	21	0	0	0	1	1	0	0	0	0	0	0	433	376	RO
RS	5	7	0	0	0	10	0	25	294	2	0	1	3	0	0	2	5	0	0	0	0	1	0	0	0	0	0	0	438	93	RS
RU	0	0	0	0	0	1	0	1	0	70	0	0	0	0	0	1	7	0	0	0	0	0	0	0	0	0	0	0	88	5	RU
SE	0	0	0	0	4	5	0	0	0	2	15	0	0	-0	0	0	2	0	0	2	0	0	1	0	0	0	0	0	38	30	SE
SI	0	0	0	0	0	7	0	1	2	0	0	243	2	-0	0	0	1	0	0	0	0	3	0	0	1	0	0	0	435	425	SI
SK	0	0	0	0	0	58	0	15	7	1	0	2	165	-0	0	1	13	0	0	0	0	1	0	0	0	0	0	0	371	341	SK
TJ	0	0	0	0	0	0	0	0	0	1	0	0	0	118	1	1	0	16	0	0	0	0	0	27	0	0	0	0	141	0	TJ
TM	0	0	0	0	0	0	0	0	0	6	0	0	0	2	33	2	2	13	0	0	0	0	0	7	0	0	0	0	67	1	TM
TR	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	268	5	0	0	0	1	3	0	6	0	0	0	0	287	6	TR
UA	0	0	0	0	0	20	0	19	2	29	0	0	1	0	0	6	296	0	0	0	1	0	0	0	0	0	0	0	409	53	UA
UZ	0	0	0	0	0	0	0	0	0	6	0	0	0	14	7	1	2	87	0	0	0	0	0	3	0	0	0	0	132	1	UZ
ATL	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	9	8	ATL
BAS	0	0	0	1	1	23	0	1	0	7	7	0	0	0	0	0	4	0	0	14	0	0	1	0	0	0	0	0	90	73	BAS
BLS	0	0	0	0	0	4	0	10	1	33	0	0	0	0	0	90	50	0	0	0	14	2	0	1	0	0	0	0	218	23	BLS
MED	0	0	0	0	0	2	1	2	1	2	0	1	0	0	0	21	3	0	1	0	0	39	0	2	10	0	0	0	83	50	MED
NOS	0	0	0	4	4	3	0	0	0	1	0	0	0	-0	-0	0	1	-0	2	1	0	0	18	0	0	0	0	0	65	60	NOS
AST	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1	8	1	1	0	0	0	0	0	225	0	0	0	0	18	0	AST
NOA	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	1	0	2	0	0	6	0	1	46	0	0	0	16	12	NOA
EXC	0	0	0	1	1	11	1	6	2	32	1	1	1	1	1	12	15	3	0	0	0	1	0	2	0	0	0	0	143	58	EXC
EU	0	0	0	2	1	37	5	21	2	2	2	2	3	0	0	1	4	0	1	1	0	2	2	0	1	0	0	0	237	221	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.9: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of SO_x. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	35	0	0	0	20	0	8	0	0	0	3	4	0	0	2	0	1	0	0	11	1	1	0	0	10	0	1	0	0	0	0	AL
AM	0	37	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	8	0	0	0	0	AM
AT	0	0	21	0	4	1	1	0	1	0	13	31	0	0	1	0	3	1	0	0	1	2	0	0	7	-0	0	0	0	0	0	AT
AZ	0	5	0	178	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	22	0	0	0	0	AZ
BA	1	0	1	0	136	0	3	0	0	0	8	10	0	0	2	0	2	1	0	2	3	3	0	0	7	0	1	0	0	0	0	BA
BE	0	-0	1	-0	0	44	0	0	0	0	4	38	0	0	2	0	31	18	-0	0	0	0	1	0	0	-0	0	0	1	0	0	BE
BG	0	0	0	0	6	0	94	1	0	0	3	5	0	0	1	0	1	0	0	9	0	1	0	0	2	0	2	0	0	0	1	BG
BY	0	0	0	0	2	0	2	31	0	0	3	8	1	2	0	1	1	2	0	1	0	1	0	0	1	0	1	3	0	1	1	BY
CH	0	0	1	0	0	1	0	0	25	0	2	20	0	0	2	0	11	2	0	0	0	0	0	0	6	-0	0	0	0	0	0	CH
CY	0	0	0	1	2	0	3	0	0	43	0	1	0	0	1	0	0	0	0	17	0	0	0	0	3	0	2	0	0	0	0	CY
CZ	0	0	5	0	5	2	1	1	1	0	79	53	0	0	1	0	4	3	0	0	1	3	0	0	3	-0	0	0	0	0	0	CZ
DE	0	0	3	0	1	5	0	0	1	0	13	99	1	0	1	0	10	7	0	0	0	0	0	0	1	-0	0	0	0	0	0	DE
DK	0	0	0	0	1	2	0	1	0	0	3	23	14	0	1	1	3	12	0	0	0	0	1	1	0	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	4	0	0	1	4	1	10	0	6	1	2	0	0	0	0	0	0	0	0	0	2	0	2	0	EE
ES	0	0	0	0	1	0	0	0	0	0	0	2	0	0	69	0	4	1	0	0	0	0	0	0	2	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	1	0	0	0	2	0	1	0	14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	FI
FR	0	0	0	0	0	4	0	0	1	0	1	14	0	0	9	0	33	9	0	0	0	0	0	0	3	-0	0	0	0	0	0	FR
GB	0	-0	0	-0	0	1	0	0	0	0	1	5	0	0	1	0	4	81	-0	0	0	0	3	1	0	-0	0	0	0	0	0	GB
GE	0	4	0	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0	0	0	0	0	7	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	2	0	0	0	7	0	28	1	0	0	2	3	0	0	2	0	1	0	0	46	0	1	0	0	7	0	2	0	0	0	0	GR
HR	1	0	3	0	50	0	3	0	0	0	11	15	0	0	2	0	2	1	0	1	14	5	0	0	14	0	0	0	0	0	0	HR
HU	0	0	3	0	19	1	7	1	0	0	15	20	0	0	1	0	2	2	0	2	3	23	0	0	5	0	1	0	0	0	0	HU
IE	0	-0	0	-0	0	1	0	0	0	0	0	2	0	0	2	0	2	16	-0	0	0	0	21	1	0	-0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	40	0	0	0	0	0	0	0	IS
IT	0	0	2	0	9	0	1	0	1	0	4	7	0	0	5	0	7	1	0	1	2	1	0	0	56	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43	64	0	0	0	0	KG
KZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	216	0	0	0	0	KZ
LT	0	0	0	0	1	1	1	10	0	0	3	10	1	2	0	2	1	3	0	0	0	1	0	0	1	0	1	13	0	1	0	LT
LU	0	0	1	-0	0	17	0	0	1	0	4	50	0	0	2	0	28	11	-0	0	0	0	0	0	1	0	0	0	9	0	0	LU
LV	0	0	0	0	1	1	1	8	0	0	2	6	1	3	0	3	1	3	0	0	0	0	0	0	0	0	1	7	0	5	0	LV
MD	0	0	0	1	3	0	12	4	0	0	3	7	0	0	0	0	1	1	1	2	0	1	0	0	1	0	4	1	0	0	32	MD
ME	4	0	0	0	43	0	4	0	0	0	4	5	0	0	2	0	1	0	0	3	1	2	0	0	6	0	1	0	0	0	0	ME
MK	7	0	0	0	10	0	20	0	0	0	3	4	0	0	1	0	1	0	0	24	0	1	0	0	3	0	1	0	0	0	0	MK
MT	0	0	0	0	8	0	3	0	0	0	2	3	0	0	7	0	5	1	0	3	1	1	0	0	36	0	0	0	0	0	0	MT
NL	0	-0	1	-0	0	28	0	0	0	-0	5	55	0	0	2	0	18	19	-0	0	0	0	1	1	0	-0	0	0	0	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	1	0	3	1	2	2	0	0	13	31	1	0	1	1	2	4	0	0	1	2	0	0	1	0	0	1	0	0	0	PL
PT	0	0	0	-0	0	0	0	0	0	0	0	1	0	0	34	0	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	0	0	1	0	6	0	22	2	0	0	4	7	0	0	1	0	1	1	0	3	0	3	0	0	1	0	2	0	0	0	2	RO
RS	2	0	1	0	34	0	19	1	0	0	7	10	0	0	1	0	1	1	0	5	1	4	0	0	3	0	1	0	0	0	0	RS
RU	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	RU
SE	0	0	0	0	0	0	0	1	0	0	1	4	1	0	0	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	SE
SI	0	0	7	0	12	0	1	0	0	0	11	19	0	0	2	0	2	1	0	1	10	3	0	0	27	-0	0	0	0	0	0	SI
SK	0	0	2	0	10	1	4	1	0	0	19	21	0	0	1	0	2	2	0	1	2	10	0	0	3	0	0	0	0	0	0	SK
TJ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	33	0	0	0	0	TJ
TM	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	66	0	0	0	0	TM
TR	0	1	0	3	1	0	3	0	0	1	0	1	0	0	0	0	0	0	1	4	0	0	0	0	1	0	2	0	0	0	0	TR
UA	0	0	0	1	3	0	4	7	0	0	2	6	0	1	0	1	1	1	1	1	0	1	0	0	1	0	5	1	0	0	2	UA
UZ	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	107	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	1	0	2	0	0	2	9	2	1	0	4	1	5	0	0	0	0	0	0	0	0	0	1	0	0	0	BAS
BLS	0	0	0	4	1	0	6	2	0	0	1	2	0	0	0	0	0	0	7	2	0	0	0	0	1	0	6	0	0	0	1	BLS
MED	1	0	0	0	8	0	6	0	0	1	2	4	0	0	11	0	5	1	0	12	1	1	0	0	21	0	1	0	0	0	0	MED
NOS	0	0	0	0	0	2	0	0	0	0	1	7	1	0	1	0	4	20	0	0	0	0	1	1	0	0	0	0	0	0	0	NOS
AST	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	23	0	0	0	0	AST
NOA	0	0	0	0	2	0	2	0	0	0	0	1	0	0	8	0	1	0	0	3	0	0	0	0	4	0	0	0	0	0	0	NOA
EXC	0	0	0	2	2	0	2	1	0	0	2	5	0	0	3	1	2	2	1	1	0	0	0	0	2	1	50	0	0	0	0	EXC
EU	0	0	1	0	3	2	5	1	0	0	6	18	1	0	11	1	7	8	0	2	1	1	1	0	6	0	0	1	0	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.9 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of SO_x. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	11	66	0	0	0	11	0	7	95	3	0	0	1	0	0	11	6	0	1	0	0	35	0	2	10	10	8	55	311	63	AL
AM	0	0	0	0	0	0	0	0	1	6	0	0	0	0	3	97	3	1	0	0	0	1	0	134	3	20	1	6	248	2	AM
AT	0	1	0	1	0	17	0	1	13	1	0	3	2	-0	0	1	1	0	1	0	0	6	0	0	4	4	3	7	130	107	AT
AZ	0	1	0	0	0	1	0	0	1	28	0	0	0	0	6	47	8	2	0	0	0	1	0	125	2	13	1	4	312	3	AZ
BA	11	6	0	0	0	20	0	7	93	2	0	0	2	0	0	5	4	0	1	0	0	14	0	1	7	7	4	22	331	71	BA
BE	0	0	0	10	0	7	0	0	1	1	0	0	0	-0	-0	0	0	-0	8	0	0	2	6	-0	1	4	18	1	162	159	BE
BG	2	17	0	0	0	18	0	30	71	13	0	0	1	0	0	64	29	0	0	0	7	11	0	5	4	7	6	11	372	165	BG
BY	0	2	0	0	0	40	0	4	10	24	1	0	1	0	0	11	32	0	1	1	1	2	0	2	1	4	4	3	188	72	BY
CH	0	0	0	1	0	4	0	0	1	0	0	0	0	-0	-0	0	0	-0	1	0	0	4	0	0	2	4	3	2	77	51	CH
CY	1	5	0	0	0	2	0	2	8	7	0	0	0	0	0	651	11	0	0	0	4	81	0	112	15	37	35	40	761	72	CY
CZ	1	2	0	1	0	45	0	2	22	2	0	1	5	-0	0	1	2	0	2	0	0	4	1	0	3	4	5	6	249	212	CZ
DE	0	0	0	5	0	19	0	1	4	2	0	0	1	-0	-0	0	1	-0	3	0	0	2	2	0	2	4	11	2	180	169	DE
DK	0	1	0	2	2	19	0	1	4	4	2	0	0	-0	0	1	2	0	5	3	0	1	4	0	1	4	19	1	101	86	DK
EE	0	1	0	0	1	10	0	1	2	18	2	0	0	0	0	3	10	0	2	2	0	0	1	1	0	3	6	1	83	43	EE
ES	0	0	0	0	0	1	8	0	2	0	0	0	0	0	0	0	0	0	23	0	0	37	0	0	17	12	16	5	92	89	ES
FI	0	0	0	0	1	4	0	0	1	29	2	0	0	0	0	1	4	0	2	1	0	0	0	0	0	2	8	0	63	27	FI
FR	0	0	0	2	0	3	0	0	1	0	0	0	0	-0	0	0	0	-0	12	0	0	11	2	0	4	6	16	2	84	80	FR
GB	0	0	0	1	0	3	0	0	1	1	0	0	0	-0	-0	0	0	-0	18	0	0	1	3	-0	1	5	27	0	104	101	GB
GE	0	1	0	0	0	1	0	0	1	15	0	0	0	0	2	90	7	0	0	0	3	1	0	46	1	10	3	5	248	3	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	0	1	0	GL
GR	3	32	0	0	0	10	0	10	41	8	0	0	1	0	0	79	20	0	1	0	3	57	0	6	11	12	14	49	306	111	GR
HR	3	6	0	0	0	25	0	6	71	2	0	2	3	0	0	5	4	0	1	0	0	24	0	1	7	6	5	20	253	109	HR
HU	2	9	0	1	0	51	0	21	99	4	0	1	9	0	0	12	10	0	1	0	1	8	0	1	4	5	4	12	327	167	HU
IE	0	0	0	0	0	1	0	0	0	0	0	0	0	-0	-0	0	0	-0	18	0	0	1	1	0	1	9	33	0	48	46	IE
IS	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	5	24	0	45	4	IS
IT	1	4	0	0	0	7	0	2	16	1	0	1	1	0	0	3	1	0	2	0	0	64	0	1	17	8	14	68	135	99	IT
KG	0	0	0	0	0	0	0	0	0	2	0	0	0	12	3	5	0	114	0	0	0	0	0	50	0	15	0	2	245	0	KG
KZ	0	0	0	0	0	1	0	0	1	40	0	0	0	1	3	4	7	15	0	0	0	0	0	21	0	12	1	1	294	3	KZ
LT	0	1	0	1	1	39	0	2	6	17	1	0	1	0	0	7	19	0	1	1	0	1	1	1	1	3	7	2	147	83	LT
LU	0	0	0	7	0	7	0	0	1	1	0	0	0	0	-0	0	0	-0	5	0	0	3	3	-0	2	4	12	1	142	139	LU
LV	0	1	0	0	1	18	0	1	4	17	2	0	0	0	0	5	16	0	1	1	0	1	1	1	0	3	6	1	109	56	LV
MD	1	6	0	0	0	37	0	30	21	25	0	0	1	0	0	51	73	0	1	0	7	5	0	4	2	6	4	6	321	98	MD
ME	54	15	0	0	0	13	0	7	114	2	0	0	1	0	0	6	4	0	1	0	0	17	0	1	7	8	4	32	292	50	ME
MK	4	165	0	0	0	12	0	10	108	4	0	0	1	0	0	29	10	0	1	0	1	13	0	3	6	8	4	24	423	83	MK
MT	2	7	3	0	0	5	1	3	22	1	0	0	0	0	0	9	2	0	3	0	0	253	0	1	50	23	45	188	130	77	MT
NL	0	0	0	27	0	11	0	0	2	1	0	0	0	-0	-0	0	1	-0	7	0	0	1	9	-0	1	4	21	1	177	171	NL
NO	0	0	0	0	6	4	0	0	1	8	1	0	0	0	0	0	2	0	6	0	0	0	1	0	0	7	14	0	30	12	NO
PL	1	2	0	1	0	143	0	4	15	6	1	0	3	0	0	5	11	0	2	1	0	2	1	1	2	3	7	4	263	215	PL
PT	0	0	0	0	0	0	43	0	1	0	0	0	0	0	0	0	0	-0	57	0	0	10	0	0	10	14	22	2	84	83	PT
RO	2	12	0	0	0	32	0	83	50	12	0	0	2	0	0	39	30	0	0	0	5	5	0	4	3	5	4	9	322	163	RO
RS	10	35	0	0	0	26	0	24	284	5	0	0	3	0	0	21	11	0	1	0	1	8	0	2	4	6	3	19	513	110	RS
RU	0	0	0	0	0	3	0	0	1	71	0	0	0	0	0	5	12	1	1	0	0	0	0	3	0	32	4	1	131	8	RU
SE	0	0	0	0	3	7	0	0	1	10	6	0	0	0	0	1	3	0	3	1	0	0	1	0	0	2	9	0	46	26	SE
SI	1	3	0	0	0	19	0	2	23	1	0	20	2	0	0	2	2	0	1	0	0	21	0	0	7	4	4	13	172	128	SI
SK	1	5	0	1	0	67	0	11	50	4	0	1	20	0	0	6	8	0	1	0	0	5	0	1	4	4	3	9	254	168	SK
TJ	0	0	0	0	0	0	0	0	0	3	0	0	0	78	12	8	0	89	0	0	0	0	0	55	0	17	0	2	229	0	TJ
TM	0	0	0	0	0	1	0	0	1	19	0	0	0	4	51	17	7	33	0	0	0	0	0	100	1	19	0	3	214	3	TM
TR	0	3	0	0	0	3	0	2	6	8	0	0	0	0	0	555	14	0	0	0	6	16	0	96	6	26	8	14	610	15	TR
UA	1	3	0	0	0	31	0	10	15	40	0	0	1	0	0	34	104	0	1	0	4	3	0	4	2	5	3	5	279	62	UA
UZ	0	0	0	0	0	1	0	0	1	22	0	0	0	13	18	11	7	145	0	0	0	0	0	45	1	14	0	2	337	3	UZ
ATL	0	0	0	0	0	1	2	0	0	4	0	0	0	0	0	0	0	0	19	0	0	2	0	0	3	33	35	0	15	9	ATL
BAS	0	0	0	1	1	17	0	1	2	12	4	0	0	0	0	2	6	0	3	4	0	0	1	0	0	3	11	1	79	52	BAS
BLS	0	2	0	0	0	11	0	7	9	45	0	0	0	0	0	166	67	0	0	0	33	7	0	16	2	7	17	6	345	34	BLS
MED	2	7	0	0	0	6	1	3	19	4	0	0	1	0	0	123	9	0	6	0	2	161	0	21	40	21	40	93	251	76	MED
NOS	0	0	0	2	1	5	0	0	1	2	0	0	0	-0	0	0	1	0	10	0	0	1	6	0	1	5	29	0	52	45	NOS
AST	0	0	0	0	0	0	0	0	1	5	0	0	0	1	6	52	2	7	0	0	0	3	0	291	4	111	2	4	106	2	AST
NOA	1	3	0	0	0	1	2	1	5	1	0	0	0	0	0	21	2	0	13	0	0	45	0	5	127	71	17	36	61	25	NOA
EXC	0	2	0	0	0	8	0	3	7	38	0	0	0	1	3	31	12	9	2	0	1	4	0	14	2	18	6	4	194	33	EXC
EU	1	3	0	1	1	21	2	7	13	6	1	0	1	0	0	9	6	0	8	0	1	14	1	1	5	6	12	9	149	105	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.10: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of NO$_x$. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	53	0	1	0	3	0	2	0	0	0	0	2	0	0	1	0	1	0	0	6	2	1	0	0	11	0	0	0	0	0	0	AL
AM	0	79	0	75	0	0	0	-0	0	0	0	0	0	-0	0	-0	0	0	9	0	0	0	0	0	0	0	0	-0	0	-0	0	AM
AT	0	0	94	0	1	2	0	0	8	0	18	76	1	0	1	0	10	3	0	0	5	6	0	0	23	0	0	0	0	0	0	AT
AZ	0	16	0	261	0	0	0	-0	0	0	0	0	0	-0	0	-0	0	0	15	0	0	0	0	0	0	0	3	-0	0	-0	0	AZ
BA	1	0	6	0	45	0	1	0	0	0	5	11	0	0	1	0	2	1	0	1	12	11	0	0	10	0	0	0	0	0	0	BA
BE	0	0	4	0	0	45	0	0	3	0	5	110	2	0	2	0	114	58	0	0	0	0	3	0	1	0	0	0	8	0	0	BE
BG	0	0	1	0	1	0	44	0	0	0	1	3	0	0	0	0	1	0	0	5	0	2	0	0	1	0	0	0	0	0	2	BG
BY	0	0	2	0	1	1	0	30	0	0	4	14	1	1	0	2	3	3	0	0	1	3	0	0	1	0	0	6	0	2	2	BY
CH	0	0	13	0	0	4	0	0	151	0	3	86	0	0	1	0	45	4	0	0	0	0	0	0	32	0	0	0	1	0	0	CH
CY	0	0	0	0	0	0	0	-0	0	20	0	0	0	-0	0	-0	0	0	0	10	0	0	0	0	1	0	0	-0	0	-0	0	CY
CZ	0	0	31	0	1	4	0	1	4	0	91	96	1	0	1	0	14	5	0	0	4	12	0	0	7	0	0	1	1	0	0	CZ
DE	0	0	18	0	0	14	0	0	11	0	15	219	3	0	1	0	38	20	0	0	0	1	1	0	4	0	0	0	3	0	0	DE
DK	0	0	1	0	0	11	0	1	1	0	4	88	42	0	1	1	19	35	0	0	0	1	2	0	1	0	0	1	1	1	0	DK
EE	0	0	0	0	0	1	0	5	0	0	1	5	1	6	0	5	1	2	0	0	0	0	0	0	0	0	0	3	0	4	0	EE
ES	0	0	0	-0	0	0	0	-0	0	0	0	1	0	0	73	0	7	1	-0	0	0	0	0	0	1	0	-0	-0	0	0	0	ES
FI	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	FI
FR	0	0	2	0	0	13	0	0	8	0	1	45	0	0	6	0	127	27	0	0	0	0	2	0	5	0	0	0	2	0	0	FR
GB	0	0	1	0	0	6	0	0	0	0	2	26	1	0	1	0	25	131	0	0	0	0	12	0	0	0	0	0	1	0	0	GB
GE	0	10	0	50	0	0	0	0	0	0	0	0	0	-0	0	-0	0	0	48	0	0	0	0	0	0	0	0	-0	0	-0	0	GE
GL	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	GL
GR	2	0	0	0	1	0	8	0	0	0	0	0	0	-0	1	-0	1	0	0	41	0	0	0	0	4	0	0	0	0	-0	0	GR
HR	1	0	18	0	21	1	1	0	1	0	10	19	0	0	1	0	3	1	0	0	43	22	0	0	29	0	0	0	0	0	0	HR
HU	1	0	23	0	9	1	3	1	1	0	19	29	1	0	1	0	5	2	0	1	15	86	0	0	12	0	0	0	0	0	0	HU
IE	0	0	1	0	0	5	0	0	0	0	1	13	1	0	1	0	18	59	0	0	0	0	54	0	0	0	0	0	0	0	0	IE
IS	0	0	0	-0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	0	0	0	0	0	-1	0	0	0	0	0	0	0	IS
IT	0	0	11	0	2	1	0	0	5	0	3	11	0	0	3	0	9	1	0	0	4	2	0	0	235	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	-0	0	0	-0	0	0	-0	-0	-0	0	0	0	0	0	0	0	0	0	24	3	-0	0	-0	-0	KG
KZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	1	11	0	0	0	0	KZ
LT	0	0	2	0	0	2	0	13	0	0	5	22	3	1	0	2	4	5	0	0	0	2	0	0	1	0	0	20	0	4	1	LT
LU	0	0	6	0	0	45	0	0	5	0	5	158	1	0	2	0	107	26	0	0	0	0	1	0	2	0	0	0	17	0	0	LU
LV	0	0	1	0	0	1	0	10	0	0	2	11	2	2	0	3	2	3	0	0	0	1	0	0	1	0	0	11	0	9	0	LV
MD	0	0	1	0	1	0	7	3	0	0	2	6	1	0	0	0	1	1	0	1	0	2	0	0	1	0	0	1	0	0	53	MD
ME	6	0	1	0	7	0	1	0	0	0	1	2	0	-0	1	0	1	0	0	1	2	1	0	0	6	0	0	0	0	-0	0	ME
MK	6	0	0	0	1	0	6	0	0	0	0	1	0	-0	1	-0	1	0	0	19	0	1	0	0	3	0	0	0	0	-0	0	MK
MT	0	0	0	0	1	0	0	-0	0	0	-0	0	-0	-0	3	-0	4	0	0	1	0	0	0	0	20	0	0	-0	0	-0	0	MT
NL	0	0	3	0	0	39	0	1	2	0	9	139	3	0	3	0	73	69	0	0	0	1	4	0	1	0	0	0	4	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	5	0	1	3	0	3	1	0	19	54	3	0	1	1	7	6	0	0	1	6	0	0	3	0	0	2	0	1	1	PL
PT	0	0	0	-0	0	0	0	-0	0	0	0	0	0	-0	31	-0	2	0	0	0	0	0	0	0	0	0	-0	-0	0	-0	0	PT
RO	0	0	2	0	1	0	12	1	0	0	3	7	0	0	0	0	1	1	0	1	1	9	0	0	2	0	0	0	0	0	5	RO
RS	3	0	5	0	11	1	8	1	1	0	7	13	0	0	1	0	3	1	0	3	6	20	0	0	6	0	0	0	0	0	0	RS
RU	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	RU
SE	0	0	0	0	0	1	0	1	0	0	0	6	3	0	0	1	2	3	0	0	0	0	0	0	0	0	0	1	0	0	0	SE
SI	0	0	58	0	4	1	0	0	2	0	12	34	1	0	1	0	5	2	0	0	28	12	0	0	86	0	0	0	0	0	0	SI
SK	0	0	15	0	3	1	1	1	1	0	21	24	1	0	0	0	4	2	0	0	5	36	0	0	7	0	0	0	0	0	0	SK
TJ	0	0	-0	0	0	0	0	-0	0	0	-0	-0	0	-0	-0	-0	-0	0	0	0	-0	-0	0	0	0	3	3	-0	0	-0	-0	TJ
TM	0	0	0	3	0	0	0	-0	0	0	0	0	0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	6	-0	0	-0	0	TM
TR	0	2	0	2	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	3	0	0	0	0	1	0	0	0	0	0	0	TR
UA	0	0	1	0	0	0	2	5	0	0	2	5	1	0	0	0	1	1	0	0	0	2	0	0	1	0	1	1	0	0	7	UA
UZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	13	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	3	0	0	0	0	1	0	0	0	0	0	0	0	0	ATL
BAS	0	0	1	0	0	2	0	2	0	0	2	24	5	1	0	2	5	7	0	0	0	0	1	0	0	0	0	2	0	1	0	BAS
BLS	0	0	0	1	0	0	2	0	0	0	0	1	0	-0	0	-0	0	0	3	1	0	0	0	0	0	0	0	0	0	-0	1	BLS
MED	1	0	0	0	1	0	1	-0	0	0	0	0	0	-0	4	-0	3	0	0	5	1	0	0	0	14	0	0	-0	0	-0	0	MED
NOS	0	0	0	0	0	4	0	0	0	0	1	28	4	0	1	0	18	33	0	0	0	0	2	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	2	0	0	0	-0	0	0	0	0	0	-0	0	-0	0	0	0	0	0	0	0	0	0	0	2	-0	0	-0	0	AST
NOA	0	0	0	0	0	0	0	-0	0	0	0	0	0	-0	2	-0	1	0	0	1	0	0	0	0	2	0	0	-0	0	-0	0	NOA
EXC	0	0	2	2	0	1	1	1	1	0	2	10	0	0	2	1	6	4	0	1	1	1	1	0	5	1	4	0	0	0	1	EXC
EU	0	0	7	0	1	5	2	1	3	0	6	39	2	0	10	1	26	16	0	2	2	4	2	0	20	0	0	1	1	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.10 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of NO_x. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	5	7	0	0	0	1	0	3	15	0	-0	0	0	0	0	1	1	0	0	0	0	15	0	0	2	14	0	0	119	33	AL
AM	0	0	0	0	0	0	0	0	0	1	-0	0	0	0	1	29	0	0	0	0	0	1	0	53	0	14	0	0	197	1	AM
AT	0	0	0	3	0	11	0	0	1	1	0	9	3	0	0	0	0	0	1	1	0	3	4	0	1	14	0	0	278	265	AT
AZ	0	0	0	0	0	0	0	0	0	13	-0	0	0	0	3	9	1	1	0	0	0	1	0	62	0	18	0	0	322	1	AZ
BA	2	0	0	1	0	7	0	3	9	1	0	1	3	0	0	0	1	0	0	1	0	5	2	0	1	12	0	0	136	76	BA
BE	0	0	0	41	1	5	0	0	0	1	1	0	0	0	0	0	0	0	8	3	0	1	72	0	1	38	0	0	408	401	BE
BG	0	1	0	0	0	4	0	22	7	4	0	0	1	0	0	7	8	0	0	0	4	3	1	1	1	12	0	0	119	86	BG
BY	0	0	0	2	1	42	0	4	1	25	2	0	2	0	0	1	27	0	1	8	0	1	4	0	0	10	0	0	184	95	BY
CH	0	0	0	4	0	3	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	2	6	0	1	15	0	0	348	197	CH
CY	0	0	0	0	0	0	0	0	0	1	-0	0	0	0	0	42	1	0	0	0	1	39	0	18	2	23	0	0	78	33	CY
CZ	0	0	0	5	1	34	0	1	2	1	1	3	11	0	0	0	1	0	1	3	0	2	9	0	1	17	0	0	335	323	CZ
DE	0	0	0	28	2	15	0	0	0	1	2	1	1	0	0	0	0	0	3	9	0	1	38	0	1	25	0	0	401	386	DE
DK	0	0	0	24	6	23	0	1	0	3	9	0	1	0	0	0	2	0	4	53	0	1	74	0	0	21	0	0	280	267	DK
EE	0	0	0	1	1	7	0	1	0	11	3	0	0	0	0	0	4	0	1	12	0	0	3	0	0	6	0	0	63	41	EE
ES	0	0	0	0	0	0	6	0	0	-0	0	0	0	0	0	0	-0	0	6	0	0	11	1	0	3	13	0	0	92	91	ES
FI	0	0	0	0	1	1	0	0	0	4	2	0	0	0	0	0	0	0	0	4	0	0	1	0	0	4	0	0	22	16	FI
FR	0	0	0	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	4	33	0	1	17	0	0	252	242	FR
GB	0	0	0	12	1	4	0	0	0	1	1	0	0	0	0	0	0	0	15	2	0	0	49	0	0	22	0	0	227	224	GB
GE	0	0	0	0	0	0	0	0	0	4	-0	0	0	0	1	13	1	0	0	0	2	0	0	10	0	9	0	0	128	1	GE
GL	0	0	0	0	0	0	-0	0	0	0	0	0	0	-0	-0	0	0	-0	0	0	0	0	0	0	-0	0	0	0	0	0	GL
GR	0	3	0	0	0	1	0	3	3	2	-0	0	0	0	0	7	3	0	0	0	1	17	0	1	2	14	0	0	80	59	GR
HR	1	0	0	1	0	11	0	3	10	1	0	8	5	0	0	0	1	0	0	1	0	11	2	0	1	13	0	0	215	179	HR
HU	1	1	0	2	0	30	0	28	27	2	0	5	21	0	0	1	6	0	1	1	0	4	3	0	1	16	0	0	335	285	HU
IE	0	0	0	7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	21	1	0	0	29	0	0	15	0	0	165	164	IE
IS	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	2	0	0	5	5	IS
IT	0	0	0	1	0	2	0	0	1	0	0	6	1	0	0	0	0	0	1	0	0	38	1	0	4	19	0	0	301	292	IT
KG	0	0	0	0	0	-0	0	-0	0	-0	-0	-0	-0	4	1	0	-0	24	0	-0	0	0	0	22	0	6	0	0	57	0	KG
KZ	0	0	0	0	0	0	0	0	0	17	0	0	0	0	1	0	1	2	0	0	0	0	0	15	0	12	0	0	35	1	KZ
LT	0	0	0	3	1	49	0	2	1	14	4	0	2	0	0	0	13	0	1	19	0	1	7	0	0	11	0	0	179	135	LT
LU	0	0	0	29	1	4	0	0	0	1	1	0	0	0	0	0	0	0	4	2	0	1	37	0	1	25	0	0	414	407	LU
LV	0	0	0	2	1	19	0	1	0	12	3	0	1	0	0	0	8	0	1	14	0	0	5	0	0	8	0	0	107	74	LV
MD	0	0	0	1	0	19	0	57	3	14	1	0	1	0	0	6	57	0	0	3	8	3	2	1	0	15	0	0	244	106	MD
ME	24	1	0	0	0	1	0	2	10	0	-0	0	0	0	0	0	1	0	0	0	0	6	0	0	1	11	0	0	72	22	ME
MK	1	21	0	0	0	1	0	3	15	1	-0	0	0	0	0	1	2	0	0	0	0	4	0	0	1	12	0	0	87	39	MK
MT	0	0	-2	0	-0	0	0	0	1	-0	-0	0	0	0	0	0	0	0	1	-0	0	51	0	0	11	17	0	0	31	28	MT
NL	0	0	0	68	2	12	0	0	0	2	2	0	1	0	0	0	1	0	10	8	0	1	105	0	1	50	0	0	440	433	NL
NO	0	0	0	0	5	1	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0	3	0	0	3	0	0	16	9	NO
PL	0	0	0	5	1	132	0	4	2	5	2	1	6	0	0	0	9	0	1	12	0	1	10	0	0	17	0	0	287	263	PL
PT	0	0	0	0	0	0	46	0	0	-0	-0	0	0	0	0	0	0	0	17	0	0	2	0	0	1	12	0	0	81	81	PT
RO	0	1	0	1	0	13	0	97	8	5	0	0	3	0	0	4	16	0	0	1	4	2	1	0	1	13	0	0	198	154	RO
RS	3	4	0	1	0	12	0	20	60	2	0	1	5	0	0	1	4	0	0	1	0	3	2	0	1	16	0	0	200	111	RS
RU	0	0	0	0	0	2	0	0	0	56	0	0	0	0	0	0	4	0	0	1	0	0	0	1	0	7	0	0	74	6	RU
SE	0	0	0	2	2	3	0	0	0	1	6	0	0	0	0	0	1	0	1	8	0	0	5	0	0	4	0	0	34	28	SE
SI	0	0	0	2	0	11	0	1	2	1	0	69	4	0	0	0	1	0	1	1	0	14	3	0	1	15	0	0	338	327	SI
SK	0	0	0	2	0	33	0	11	8	1	0	3	36	0	0	0	5	0	1	1	0	2	3	0	1	12	0	0	224	203	SK
TJ	0	0	0	0	-0	-0	0	-0	0	-0	-0	-0	-0	37	2	0	-0	25	0	-0	0	0	0	26	0	8	0	0	71	-0	TJ
TM	0	0	0	0	0	0	0	0	0	4	-0	0	0	1	33	1	0	17	0	0	0	0	0	28	0	14	0	0	66	0	TM
TR	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	88	3	0	0	0	4	9	0	17	1	19	0	0	110	9	TR
UA	0	0	0	1	0	19	0	14	1	35	1	0	1	0	0	3	78	0	0	3	4	1	2	1	0	13	0	0	187	55	UA
UZ	0	0	0	0	0	0	0	0	0	7	-0	0	0	5	9	1	1	52	0	0	0	0	0	12	0	15	0	0	95	1	UZ
ATL	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	2	0	0	5	0	0	10	9	ATL
BAS	0	0	0	5	1	13	0	0	0	4	4	0	0	0	0	0	2	0	1	16	0	0	12	0	0	8	0	0	85	75	BAS
BLS	0	0	0	0	0	1	0	5	0	23	-0	0	0	0	0	18	11	0	0	0	17	2	0	1	0	11	0	0	71	12	BLS
MED	0	0	0	0	0	-0	0	0	1	1	-0	0	0	0	0	6	1	0	1	-0	1	33	0	2	6	15	0	0	41	30	MED
NOS	0	0	0	10	1	5	0	0	0	1	1	0	0	0	0	0	0	0	4	7	0	0	27	0	0	12	0	0	114	110	NOS
AST	0	0	0	0	0	0	0	0	0	1	-0	0	0	1	2	4	0	1	0	0	0	1	0	164	0	27	0	0	15	1	AST
NOA	0	0	0	0	0	0	1	0	0	0	-0	0	0	0	0	1	0	0	2	0	0	11	0	1	26	23	0	0	11	8	NOA
EXC	0	0	0	2	0	6	0	3	1	27	1	0	1	1	1	4	6	3	1	2	1	2	4	5	0	11	0	0	104	50	EXC
EU	0	0	0	6	1	16	2	7	2	2	1	1	2	0	0	1	3	0	4	4	0	6	15	0	1	15	0	0	195	181	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.11: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of NH_3. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	55	-0	1	-0	0	0	0	0	0	0	1	2	0	0	1	0	1	0	-0	3	1	3	0	0	5	-0	-0	0	0	0	0	AL
AM	0	139	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	-0	0	0	-0	0	0	0	0	AM
AT	0	0	66	0	0	1	0	0	3	-0	13	30	1	0	0	0	4	1	0	0	3	6	0	0	9	-0	-0	0	0	0	0	AT
AZ	0	14	0	260	0	0	0	0	0	-0	0	0	0	0	0	-0	0	0	11	0	0	0	0	-0	0	0	-0	0	0	0	0	AZ
BA	1	-0	3	-0	76	0	0	0	0	-0	6	8	1	0	1	0	1	1	0	0	15	12	0	0	7	-0	-0	0	0	0	0	BA
BE	0	-0	1	-0	-0	136	0	0	1	-0	2	50	1	0	1	0	52	32	-0	0	0	0	3	0	1	-0	-0	0	4	0	0	BE
BG	1	0	1	0	1	0	77	1	0	0	2	4	0	0	1	0	1	0	0	6	1	5	0	0	2	0	-0	0	0	0	2	BG
BY	0	0	1	0	0	1	1	58	1	0	3	12	2	0	0	0	3	2	0	0	1	3	0	0	1	0	0	3	0	1	2	BY
CH	0	-0	2	-0	0	1	-0	0	72	-0	1	21	0	0	0	0	12	1	-0	-0	0	0	0	-0	12	-0	-0	0	0	0	0	CH
CY	-0	0	0	0	-0	0	0	0	0	54	-0	0	0	-0	-0	-0	0	0	0	-0	-0	0	0	-0	-0	0	-0	0	0	0	0	CY
CZ	0	0	12	0	1	3	1	1	2	0	110	59	2	0	0	0	8	4	0	0	3	11	1	0	3	-0	-0	0	0	0	0	CZ
DE	0	-0	7	-0	0	11	0	0	4	-0	13	184	2	0	1	0	21	11	-0	0	1	2	1	0	2	-0	-0	0	1	0	0	DE
DK	0	0	1	0	0	9	0	1	1	0	5	59	103	0	1	0	14	28	0	0	0	2	4	0	1	-0	0	1	0	0	0	DK
EE	0	0	0	0	0	1	0	11	0	0	1	10	3	24	0	3	2	3	0	0	0	1	1	0	0	0	0	6	0	8	0	EE
ES	-0	-0	0	-0	-0	0	-0	0	0	-0	0	1	0	0	54	0	6	1	0	-0	0	0	0	0	1	0	-0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	3	0	0	0	2	1	1	0	17	1	1	0	0	0	0	0	-0	0	-0	0	1	0	1	0	FI
FR	0	-0	1	-0	-0	7	-0	0	4	-0	1	16	0	0	4	0	93	12	0	0	0	0	1	0	4	-0	-0	0	1	0	0	FR
GB	0	-0	0	-0	0	8	0	0	0	-0	2	21	2	0	2	0	23	159	-0	0	0	0	8	0	0	-0	-0	0	0	0	0	GB
GE	0	11	0	33	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	-0	0	0	-0	0	0	0	0	GE
GL	-0	-0	0	-0	-0	0	-0	0	0	-0	0	0	0	0	-0	-0	0	0	-0	-0	-0	-0	0	-0	0	-0	-0	0	0	0	0	GL
GR	2	0	0	0	0	0	3	0	0	0	1	1	0	0	0	0	0	0	0	53	0	1	0	0	2	0	-0	0	0	0	0	GR
HR	0	0	7	0	13	0	0	0	0	-0	9	12	1	0	1	0	2	1	0	0	59	15	0	0	25	0	-0	0	0	0	0	HR
HU	0	0	8	0	3	1	1	1	1	0	14	19	1	0	0	0	3	2	0	1	8	87	0	0	7	-0	-0	0	0	0	0	HU
IE	0	-0	0	-0	0	3	0	0	0	-0	1	8	1	0	2	0	16	32	-0	0	0	0	46	0	0	-0	-0	0	0	0	0	IE
IS	-0	-0	0	-0	-0	0	-0	0	0	-0	0	1	0	0	0	-0	2	2	-0	-0	0	0	1	1	0	-0	-0	0	0	0	0	IS
IT	0	0	3	0	0	0	0	0	2	0	2	4	0	0	2	0	3	0	0	0	2	2	0	0	140	-0	-0	0	0	0	0	IT
KG	-0	0	0	0	-0	0	-0	0	0	-0	0	0	0	-0	0	-0	0	0	0	-0	0	0	0	-0	0	36	1	0	0	0	0	KG
KZ	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	20	0	0	0	0	KZ
LT	0	0	1	0	0	2	0	19	0	0	4	21	6	0	1	0	5	5	0	0	1	3	1	0	1	0	0	43	0	3	1	LT
LU	0	-0	2	-0	-0	40	0	0	3	0	3	85	1	0	1	0	47	14	-0	0	0	0	2	0	1	0	-0	0	44	0	0	LU
LV	0	0	1	0	0	1	0	18	0	0	2	16	4	1	0	1	3	4	0	0	0	2	1	0	1	0	0	18	0	29	1	LV
MD	0	0	1	0	0	0	4	3	0	0	1	7	1	0	0	0	1	1	1	1	0	2	0	0	1	0	0	0	0	0	62	MD
ME	8	-0	1	-0	7	0	0	0	0	0	3	4	0	0	1	0	1	0	0	1	3	6	0	0	5	0	-0	0	0	0	0	ME
MK	8	0	1	0	1	0	3	0	0	0	2	4	0	0	1	0	1	0	0	18	1	5	0	0	2	-0	-0	0	0	0	0	MK
MT	0	-0	0	-0	0	0	0	0	0	0	0	1	0	0	3	0	3	0	0	0	0	1	0	0	10	0	-0	0	0	0	0	MT
NL	0	-0	2	-0	0	37	0	0	1	-0	4	69	2	0	1	0	31	41	-0	0	0	0	4	0	0	-0	-0	0	1	0	0	NL
NO	0	-0	0	-0	0	0	0	0	0	-0	0	3	2	0	0	0	1	2	-0	-0	0	0	0	-0	0	-0	0	0	0	0	0	NO
PL	0	0	3	0	1	3	0	3	1	0	15	47	5	0	1	0	7	6	0	0	2	9	1	0	2	-0	0	1	0	0	1	PL
PT	-0	-0	0	-0	-0	0	-0	0	0	-0	0	0	0	0	19	0	2	0	-0	-0	0	0	0	0	0	0	-0	0	0	0	-0	PT
RO	0	0	1	0	1	0	5	1	0	0	2	6	1	0	0	0	1	1	0	1	1	7	0	0	2	0	-0	0	0	0	3	RO
RS	2	0	2	0	6	1	6	1	0	0	6	9	1	0	1	0	2	1	0	3	5	15	0	0	3	-0	-0	0	0	0	0	RS
RU	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	3	0	0	0	0	RU
SE	0	0	0	0	0	1	0	1	0	0	1	9	6	0	0	1	2	3	0	0	0	0	1	-0	0	-0	0	1	0	0	0	SE
SI	0	-0	21	-0	1	1	0	0	1	-0	8	16	1	0	1	0	2	1	0	0	16	7	0	0	65	-0	-0	0	0	0	0	SI
SK	0	0	6	0	2	2	1	1	1	0	22	24	2	0	0	0	4	3	0	0	4	35	0	0	5	-0	-0	1	0	0	0	SK
TJ	0	0	0	0	0	0	0	-0	0	-0	0	0	0	-0	0	-0	0	0	0	0	0	0	0	-0	0	3	0	-0	0	-0	0	TJ
TM	0	0	0	3	0	0	0	0	0	-0	0	0	0	-0	0	-0	0	0	0	0	0	0	0	-0	0	0	1	-0	0	0	0	TM
TR	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	-0	0	0	0	0	TR
UA	0	0	1	1	0	0	2	6	0	0	2	6	1	0	0	0	1	1	1	1	0	3	0	0	1	0	0	1	0	0	5	UA
UZ	0	0	0	1	0	0	0	0	0	-0	0	0	0	-0	0	-0	0	0	0	0	0	0	0	-0	0	4	5	0	0	0	0	UZ
ATL	-0	0	0	0	-0	0	0	0	0	-0	0	1	0	0	2	0	3	4	0	-0	0	0	1	-0	0	-0	-0	0	0	0	0	ATL
BAS	0	0	1	0	0	3	0	5	0	0	4	40	19	2	1	4	7	9	0	0	0	2	1	0	1	0	0	4	0	2	0	BAS
BLS	0	0	0	1	0	0	4	2	0	0	0	2	0	0	0	0	1	0	6	2	0	1	0	0	1	0	0	0	0	0	2	BLS
MED	0	0	0	0	-0	0	0	0	0	0	0	1	0	0	4	0	2	0	0	1	1	0	0	-0	3	0	-0	0	0	0	0	MED
NOS	0	-0	1	-0	0	12	0	1	0	-0	2	42	11	0	1	0	28	73	-0	0	0	0	6	-0	0	-0	0	0	0	0	0	NOS
AST	0	0	0	2	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0	0	0	0	AST
NOA	-0	0	0	0	-0	0	0	0	0	-0	0	0	0	0	1	0	0	0	0	0	0	0	0	-0	-2	-0	-0	0	0	0	0	NOA
EXC	0	0	1	2	0	1	1	2	0	0	2	8	1	0	2	0	5	4	0	1	0	1	0	0	3	1	4	0	0	0	0	EXC
EU	0	0	3	0	0	4	2	1	1	0	6	28	3	0	8	1	18	14	0	2	2	4	2	0	12	-0	0	1	0	1	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.11 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of NH_3. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	2	1	0	0	0	2	-0	3	14	-0	0	0	1	-0	-0	0	0	-0	0	0	0	0	0	-0	-0	0	0	0	97	24	AL
AM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	42	0	0	0	0	0	0	0	27	0	1	0	0	236	1	AM
AT	0	0	0	2	0	6	0	1	2	0	0	5	2	-0	-0	0	0	-0	0	0	0	0	0	-0	-0	0	0	0	157	151	AT
AZ	0	0	0	0	-0	-0	0	0	0	13	0	0	0	0	1	16	0	0	0	0	0	0	0	37	0	1	0	0	317	1	AZ
BA	2	0	0	1	0	7	-0	3	19	0	0	1	3	0	-0	0	1	-0	0	0	0	0	0	-0	0	0	0	0	170	70	BA
BE	0	0	0	34	0	2	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	321	320	BE
BG	0	1	0	0	0	4	0	28	15	2	0	0	1	0	0	21	5	0	0	0	0	0	0	0	0	0	0	0	184	136	BG
BY	0	0	0	2	0	33	0	6	1	17	1	0	2	0	0	3	27	0	0	0	0	0	0	0	0	0	0	0	190	78	BY
CH	0	-0	-0	1	0	1	-0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	127	55	CH
CY	-0	-0	-0	0	0	-0	-0	0	-0	1	0	0	0	0	0	23	0	0	0	0	0	0	0	4	0	1	0	0	78	54	CY
CZ	0	0	0	5	0	29	0	3	5	1	1	2	8	-0	-0	0	1	-0	0	0	0	0	0	0	0	0	0	0	278	268	CZ
DE	0	0	0	21	0	12	0	1	1	0	1	0	1	-0	-0	0	1	-0	0	0	0	0	0	-0	0	0	0	0	298	292	DE
DK	0	0	0	21	1	24	0	2	1	1	6	0	1	-0	-0	0	2	-0	0	0	0	0	0	0	0	0	0	0	292	285	DK
EE	0	0	0	2	0	16	0	2	0	12	3	0	0	0	0	1	6	0	0	0	0	0	0	0	0	0	0	0	119	87	EE
ES	-0	-0	0	0	0	0	2	0	-0	-0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	65	65	ES
FI	0	0	0	1	0	2	0	0	0	7	2	0	0	-0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	42	31	FI
FR	0	-0	-0	5	0	1	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	150	146	FR
GB	0	0	0	12	0	3	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	0	0	0	0	243	242	GB
GE	0	0	0	0	0	-0	0	0	-0	4	0	0	0	0	-0	24	0	-0	0	0	0	0	0	6	0	1	0	0	138	0	GE
GL	-0	-0	-0	0	0	0	-0	0	-0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	-1	0	0	0	0	GL
GR	0	2	0	0	0	1	-0	4	3	1	0	0	0	0	0	16	1	-0	0	0	0	0	0	0	0	0	0	0	96	69	GR
HR	0	0	0	1	0	8	-0	3	13	0	0	6	3	0	-0	0	1	-0	0	0	0	0	0	-0	0	0	0	0	182	153	HR
HU	0	0	0	2	0	24	0	17	18	1	0	2	14	-0	-0	1	3	-0	0	0	0	0	0	0	0	0	0	0	242	214	HU
IE	0	0	0	4	0	1	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	0	0	0	0	116	115	IE
IS	-0	-0	-0	0	0	0	0	0	-0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	-0	0	0	9	7	IS
IT	0	0	0	0	0	1	0	0	0	0	0	2	1	0	-0	0	0	-0	0	0	0	0	0	0	0	0	0	0	166	163	IT
KG	-0	-0	-0	0	0	0	0	0	-0	-0	0	0	0	3	0	0	0	18	0	0	0	0	0	11	-0	1	0	0	59	0	KG
KZ	0	0	0	0	0	0	0	0	0	26	0	0	0	1	1	0	1	7	0	0	0	0	0	17	-0	0	0	0	59	1	KZ
LT	0	0	0	4	0	54	0	4	1	12	3	0	1	0	0	1	10	0	0	0	0	0	0	0	0	0	0	0	209	163	LT
LU	-0	0	-0	17	0	2	0	0	-0	0	0	0	0	0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	262	259	LU
LV	0	0	0	3	0	30	0	2	1	11	4	0	1	0	0	1	9	0	0	0	0	0	0	0	0	0	0	0	168	126	LV
MD	0	0	0	1	0	17	0	37	2	15	0	0	1	0	0	12	44	0	0	0	0	0	0	0	0	0	0	0	221	80	MD
ME	43	0	0	0	0	4	0	5	25	0	0	0	2	0	-0	0	1	-0	0	0	0	0	0	-0	0	0	0	0	123	38	ME
MK	0	40	0	0	0	3	0	6	27	0	0	0	1	0	-0	1	1	-0	0	0	0	0	0	-0	0	0	0	0	130	49	MK
MT	0	0	81	0	0	0	-0	1	1	-0	0	0	0	0	-0	0	0	-0	0	0	0	0	0	-0	0	1	0	0	103	101	MT
NL	0	0	0	181	0	4	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	0	0	0	0	382	380	NL
NO	0	-0	0	1	9	2	0	0	0	0	1	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	0	-0	0	0	25	15	NO
PL	0	0	0	6	0	170	0	6	3	2	2	1	6	-0	0	1	7	0	0	0	0	0	0	0	0	0	0	0	311	293	PL
PT	-0	-0	-0	0	0	0	55	-0	-0	0	0	0	0	0	-0	-0	0	-0	0	0	0	0	0	-0	-0	0	0	0	77	77	PT
RO	0	0	0	1	0	10	0	94	8	3	0	0	2	0	0	6	9	0	0	0	0	0	0	0	0	0	0	0	167	136	RO
RS	2	4	0	1	0	9	0	22	139	0	0	0	4	0	-0	2	2	-0	0	0	0	0	0	0	0	0	0	0	248	90	RS
RU	0	0	0	0	0	2	0	1	0	65	0	0	0	0	0	1	4	0	0	0	0	0	0	2	0	0	0	0	83	6	RU
SE	0	0	0	2	1	6	0	0	0	1	17	0	0	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	57	52	SE
SI	0	0	0	1	0	5	0	1	3	0	0	77	2	-0	-0	0	0	-0	0	0	0	0	0	-0	0	0	0	0	233	226	SI
SK	0	0	0	3	0	53	0	13	10	1	1	2	73	-0	-0	1	4	-0	0	0	0	0	0	0	0	0	0	0	275	255	SK
TJ	0	0	0	0	-0	-0	-0	0	-0	-0	0	0	0	26	0	0	-0	15	0	0	0	0	0	6	-0	0	0	0	45	0	TJ
TM	0	0	0	0	-0	-0	-0	0	0	2	0	0	0	1	30	1	0	14	0	0	0	0	0	16	0	0	0	0	52	0	TM
TR	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	164	1	-0	0	0	0	0	0	4	0	1	0	0	176	6	TR
UA	0	0	0	1	0	20	0	14	2	39	1	0	1	0	0	11	119	0	0	0	0	0	0	1	0	0	0	0	242	57	UA
UZ	0	0	0	0	-0	-0	-0	0	-0	3	0	0	0	4	3	0	0	67	0	0	0	0	0	4	-0	0	0	0	88	0	UZ
ATL	-0	-0	-0	1	0	0	0	0	-0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	-0	-0	-2	0	0	13	13	ATL
BAS	0	0	0	8	1	35	0	2	1	7	14	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	179	160	BAS
BLS	0	0	0	0	0	3	0	12	1	32	0	0	0	0	0	71	21	0	0	0	0	0	0	1	0	1	0	0	164	28	BLS
MED	-0	0	-0	0	0	0	-0	1	0	1	0	0	0	0	0	10	1	0	0	0	0	0	0	1	-0	-0	0	0	27	14	MED
NOS	0	0	0	28	2	6	0	0	0	1	2	0	0	-0	-0	-0	1	-0	0	0	0	0	0	-0	0	0	0	0	218	214	NOS
AST	0	0	0	0	0	0	0	0	-0	2	0	0	0	0	1	4	0	0	0	0	0	0	0	92	1	6	0	0	9	0	AST
NOA	-0	-0	-0	0	0	0	0	0	-0	0	0	0	0	-0	0	1	0	0	0	0	0	0	0	0	15	8	0	0	1	1	NOA
EXC	0	0	0	2	0	6	0	3	1	32	1	0	1	0	1	8	7	3	0	0	0	0	0	4	0	0	0	0	107	43	EXC
EU	0	0	0	6	0	19	1	7	2	2	2	1	2	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	162	151	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.12: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of VOC. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	1	0	0	0	1	0	0	0	0	0	1	3	0	0	1	0	2	1	0	1	1	1	0	0	5	0	0	0	0	0	0	AL
AM	0	9	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	2	0	0	0	0	0	1	0	1	5	0	0	1	0	2	1	0	0	0	0	0	0	3	0	0	0	0	0	0	AT
AZ	0	2	0	26	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	0	1	0	0	0	0	AZ
BA	0	0	1	0	2	0	0	0	0	0	1	4	0	0	1	0	2	1	0	0	1	1	0	0	4	0	0	0	0	0	0	BA
BE	0	0	1	0	0	5	0	0	1	0	1	15	0	0	1	0	7	7	0	0	0	0	1	0	1	0	0	0	0	0	0	BE
BG	0	0	0	0	0	0	1	1	0	0	1	3	0	0	1	0	1	1	0	1	0	1	0	0	2	0	0	0	0	0	0	BG
BY	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	-0	0	0	0	BY
CH	0	0	1	0	0	0	0	0	5	0	0	4	0	0	1	0	3	0	0	0	0	0	0	0	3	0	0	0	0	0	0	CH
CY	0	0	0	1	0	0	0	1	0	-0	0	2	0	0	1	0	1	0	0	2	0	0	0	0	3	0	0	0	0	0	0	CY
CZ	0	0	1	0	0	0	0	0	1	0	3	8	0	0	1	0	3	1	0	0	0	1	0	0	2	0	0	0	0	0	0	CZ
DE	0	0	1	0	0	1	0	0	1	0	2	14	0	0	1	0	5	3	0	0	0	0	0	0	2	0	0	0	0	0	0	DE
DK	0	0	0	0	0	1	0	0	0	0	1	5	0	0	0	0	3	2	0	0	0	0	0	0	1	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	EE
ES	0	0	0	0	0	0	0	0	0	0	0	1	0	0	6	0	2	1	0	0	0	0	0	0	2	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FI
FR	0	0	0	0	0	0	0	0	1	0	0	3	0	0	2	0	4	1	0	0	0	0	0	0	2	0	0	0	0	0	0	FR
GB	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	GB
GE	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	0	0	0	0	0	0	0	1	0	0	1	3	0	0	1	0	2	1	0	4	0	1	0	0	4	0	0	0	0	0	0	GR
HR	0	0	1	0	1	0	0	0	0	0	1	5	0	0	1	0	2	1	0	0	2	1	0	0	7	0	0	0	0	0	0	HR
HU	0	0	1	0	1	0	0	0	0	0	2	6	0	0	1	0	2	1	0	0	1	1	0	0	3	0	0	0	0	0	0	HU
IE	0	0	0	0	0	-0	0	0	0	0	0	0	-0	0	0	0	0	-0	0	0	0	0	-1	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	IS
IT	0	0	1	0	0	0	0	0	1	0	1	5	0	0	2	0	4	1	0	0	1	1	0	0	33	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	KG
KZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	KZ
LT	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	-0	0	0	0	LT
LU	0	0	1	0	0	1	0	0	1	0	1	10	0	0	1	0	4	3	0	0	0	0	0	0	1	0	0	0	0	0	0	LU
LV	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	-0	0	0	0	LV
MD	0	0	0	0	0	0	0	1	0	0	1	3	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	MD
ME	0	0	0	0	1	0	0	0	0	0	1	3	0	0	1	0	1	1	0	0	1	1	0	0	4	0	0	0	0	0	0	ME
MK	0	0	0	0	0	0	0	0	0	0	1	3	0	0	1	0	1	1	0	2	0	1	0	0	2	0	0	0	0	0	0	MK
MT	0	0	0	0	1	0	0	0	0	0	1	3	0	0	3	0	4	1	0	1	1	1	0	0	13	0	0	0	0	0	0	MT
NL	0	0	1	0	0	5	0	0	1	0	3	20	0	0	1	0	11	10	0	0	0	0	1	0	2	0	0	0	0	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	1	0	0	0	0	1	0	0	2	6	0	0	0	0	2	2	0	0	0	1	0	0	2	0	0	0	0	0	0	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	0	0	0	0	0	0	0	1	0	0	1	3	0	0	0	0	1	1	0	0	0	1	0	0	2	0	0	0	0	0	0	RO
RS	0	0	0	0	1	0	0	0	0	0	1	4	0	0	1	0	1	1	0	1	0	1	0	0	3	0	0	0	0	0	0	RS
RU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	RU
SE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	SE
SI	0	0	2	0	1	0	0	0	1	0	1	6	0	0	1	0	2	1	0	0	1	1	0	0	11	0	0	0	0	0	0	SI
SK	0	0	1	0	1	0	0	0	0	0	1	5	0	0	0	0	2	1	0	0	0	1	0	0	2	0	0	0	0	0	0	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	TJ
TM	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	TM
TR	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	TR
UA	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	UA
UZ	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	BAS
BLS	0	0	0	1	0	0	0	1	0	0	0	2	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	1	BLS
MED	0	0	0	0	0	0	0	0	0	0	1	3	0	0	3	0	4	1	0	1	1	1	0	0	9	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	1	0	0	0	0	0	4	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	NOA
EXC	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	EXC
EU	0	0	0	0	0	0	0	0	0	0	1	4	0	0	1	0	2	1	0	0	0	0	0	0	4	0	0	0	0	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.12 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of VOC. **Emitters** →, **Receptors** ↓.

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	0	0	0	0	0	2	0	1	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	-2	0	0	26	19	AL
AM	0	0	0	0	0	0	0	0	0	4	0	0	0	0	1	3	0	0	0	0	0	0	0	21	0	-2	0	0	27	3	AM
AT	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-3	0	0	20	18	AT
AZ	0	0	0	0	0	1	0	0	0	11	0	0	0	0	1	3	1	0	0	0	0	0	0	35	1	0	0	0	53	5	AZ
BA	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	24	19	BA
BE	0	0	0	6	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	52	49	BE
BG	0	0	0	0	0	2	0	1	0	5	0	0	0	0	0	2	1	0	0	0	0	0	0	1	1	-2	0	0	25	15	BG
BY	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	-2	0	0	15	8	BY
CH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-3	0	0	20	14	CH
CY	0	0	0	0	0	1	0	1	0	5	0	0	0	0	0	10	1	0	0	0	0	0	0	9	2	-3	0	0	32	12	CY
CZ	0	0	0	1	0	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	28	25	CZ
DE	0	0	0	3	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	39	35	DE
DK	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	21	18	DK
EE	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	9	5	EE
ES	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	-1	0	0	14	13	ES
FI	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	5	3	FI
FR	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	17	15	FR
GB	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	18	17	GB
GE	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	3	1	0	0	0	0	0	0	8	0	-1	0	0	20	3	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	0	0	0	0	0	2	0	1	0	4	0	0	0	0	0	2	1	0	0	0	0	0	0	1	2	-2	0	0	31	21	GR
HR	0	0	0	1	0	2	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	32	27	HR
HU	0	0	0	1	0	3	0	1	0	2	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	-2	0	0	31	24	HU
IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	1	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	1	1	IS
IT	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	-2	0	0	57	53	IT
KG	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	6	0	0	0	0	0	5	0	-1	0	0	14	1	KG
KZ	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	-2	0	0	13	2	KZ
LT	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	0	0	13	9	LT
LU	0	0	0	3	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	30	27	LU
LV	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	11	7	LV
MD	0	0	0	0	0	2	0	2	0	6	0	0	0	0	0	2	2	0	0	0	0	0	0	1	1	-2	0	0	29	15	MD
ME	0	0	0	0	0	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-2	0	0	22	16	ME
MK	0	1	0	0	0	2	0	1	0	2	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	-2	0	0	23	16	MK
MT	0	0	2	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	6	-2	0	0	37	33	MT
NL	0	0	0	12	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	74	71	NL
NO	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	3	2	NO
PL	0	0	0	1	0	4	0	1	0	2	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	-1	0	0	29	24	PL
PT	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	11	11	PT
RO	0	0	0	0	0	2	0	2	0	4	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	-2	0	0	25	15	RO
RS	0	0	0	0	0	2	0	1	0	3	0	0	1	0	0	1	1	0	0	0	0	0	0	1	1	-2	0	0	27	19	RS
RU	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	0	0	8	2	RU
SE	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	6	4	SE
SI	0	0	0	1	0	2	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	-3	0	0	36	32	SI
SK	0	0	0	1	0	3	0	1	0	2	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	-2	0	0	25	20	SK
TJ	0	0	0	0	0	0	0	0	0	2	0	0	0	4	1	1	0	6	0	0	0	0	0	9	0	-1	0	0	16	1	TJ
TM	0	0	0	0	0	0	0	0	0	6	0	0	0	0	2	1	0	2	0	0	0	0	0	20	0	-2	0	0	18	3	TM
TR	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	6	1	0	0	0	0	0	0	8	1	-3	0	0	19	6	TR
UA	0	0	0	0	0	2	0	1	0	7	0	0	0	0	0	1	2	0	0	0	0	0	0	1	0	-2	0	0	23	10	UA
UZ	0	0	0	0	0	0	0	0	0	5	0	0	0	1	1	1	0	12	0	0	0	0	0	11	0	-2	0	0	27	2	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	2	2	ATL
BAS	0	0	0	1	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	14	10	BAS
BLS	0	0	0	0	0	2	0	1	0	12	0	0	0	0	0	5	2	0	0	0	0	0	0	3	1	-1	0	0	34	10	BLS
MED	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	2	1	0	0	0	0	0	0	2	4	-2	0	0	35	27	MED
NOS	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	17	16	NOS
AST	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	2	0	1	0	0	0	0	0	42	0	-2	0	0	9	2	AST
NOA	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	5	-1	0	0	13	11	NOA
EXC	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	1	0	1	0	0	0	0	0	2	0	-2	0	0	14	7	EXC
EU	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	22	19	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.13: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of PPM, SO_x, NO_x, NH_3 and VOC. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	333	0	3	0	28	1	13	1	1	0	6	12	0	0	5	0	6	2	0	27	6	8	0	0	37	0	1	0	0	0	1	AL
AM	0	387	0	228	0	0	0	0	0	0	0	1	0	0	0	0	1	0	41	1	0	0	0	0	1	0	9	0	0	0	0	AM
AT	0	0	401	0	7	4	1	1	15	0	55	159	2	0	3	0	22	6	0	1	14	20	0	0	52	0	0	1	1	0	0	AT
AZ	0	47	0	961	0	0	1	1	0	0	0	1	0	0	0	0	1	0	62	1	0	0	0	0	1	0	27	0	0	0	0	AZ
BA	4	0	14	0	575	1	5	2	1	0	23	35	1	0	5	0	8	3	0	3	61	36	0	0	35	0	1	0	0	0	0	BA
BE	0	0	8	0	0	428	0	1	6	0	15	248	3	0	8	1	288	131	0	0	0	1	8	1	4	0	0	0	19	0	0	BE
BG	2	0	3	1	9	1	371	3	1	0	8	16	1	0	2	0	5	2	1	28	3	11	0	0	8	0	3	1	0	0	9	BG
BY	0	0	4	1	4	2	4	217	1	0	13	39	5	3	2	4	9	8	1	1	2	10	1	0	5	0	2	19	0	6	7	BY
CH	0	0	25	0	0	7	0	0	423	0	7	152	1	0	5	0	96	8	0	0	1	1	1	0	69	0	0	0	1	0	0	CH
CY	1	0	0	2	2	0	4	1	0	148	1	3	0	0	2	0	2	1	1	31	0	1	0	0	7	0	3	0	0	0	1	CY
CZ	1	0	70	0	10	10	3	3	8	0	490	244	4	0	3	1	34	15	0	1	13	36	1	0	18	0	0	2	1	1	0	CZ
DE	0	0	43	0	2	37	1	2	22	0	52	702	7	0	4	1	95	45	0	0	2	5	3	0	11	0	0	1	5	1	0	DE
DK	0	0	4	0	1	26	1	3	2	0	15	195	243	1	4	3	44	86	0	0	1	4	7	1	2	0	0	2	2	1	1	DK
EE	0	0	1	0	1	2	1	25	1	0	3	22	5	145	1	18	6	9	0	0	0	2	1	0	1	0	1	15	0	29	1	EE
ES	0	0	1	0	1	1	0	0	1	0	1	5	0	0	318	0	24	4	0	0	0	0	1	0	8	0	0	0	0	0	0	ES
FI	0	0	0	0	0	1	0	6	0	0	1	7	2	5	0	63	2	4	0	0	0	0	0	0	0	0	0	2	0	2	0	FI
FR	0	0	5	0	1	28	0	0	18	0	4	90	1	0	24	0	446	55	0	0	1	1	4	0	19	0	0	0	3	0	0	FR
GB	0	0	2	0	0	18	0	1	1	0	5	60	4	0	5	0	64	548	0	0	0	0	26	1	1	0	0	0	1	0	0	GB
GE	0	35	0	152	0	0	1	1	0	0	0	1	0	0	0	0	0	0	365	1	0	0	0	0	1	0	8	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	11	0	2	1	9	0	47	2	0	0	4	8	0	0	4	0	4	1	0	248	2	4	0	0	20	0	2	0	0	0	3	GR
HR	3	0	38	0	150	2	5	2	2	0	37	57	2	0	5	0	11	4	0	3	357	67	0	0	93	0	0	0	0	0	0	HR
HU	2	0	52	0	45	4	14	4	3	0	59	79	3	0	3	1	14	7	0	4	53	447	1	0	33	0	1	1	1	1	1	HU
IE	0	0	1	0	0	10	0	0	1	0	2	24	3	0	6	0	41	123	0	0	0	0	163	1	1	0	0	0	1	0	0	IE
IS	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	3	7	0	0	0	0	1	43	0	0	0	0	0	0	0	IS
IT	1	0	22	0	14	1	2	1	10	0	11	29	1	0	14	0	30	3	0	2	13	7	0	0	786	0	0	0	0	0	0	IT
KG	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	75	0	0	0	0	KG
KZ	0	0	0	3	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6	285	0	0	0	0	KZ
LT	0	0	4	0	2	5	1	64	1	0	14	59	12	4	2	6	13	16	0	1	2	7	1	0	4	0	1	200	0	18	4	LT
LU	0	0	13	0	0	130	0	1	12	0	16	373	2	0	6	0	279	60	0	0	0	1	4	0	6	0	0	0	132	0	0	LU
LV	0	0	2	0	1	3	1	48	1	0	7	37	8	12	1	8	8	13	0	0	1	4	1	0	2	0	1	57	0	138	2	LV
MD	1	0	3	2	6	1	28	13	1	0	7	24	3	1	2	1	5	5	2	6	2	8	0	0	5	0	5	2	0	1	526	MD
ME	33	0	4	0	72	1	6	1	1	0	9	15	1	0	4	0	5	2	0	6	10	13	0	0	26	0	1	0	0	0	1	ME
MK	34	0	3	0	15	1	36	2	1	0	7	13	1	0	4	0	4	2	0	82	3	11	0	0	14	0	1	0	0	0	2	MK
MT	2	0	2	0	11	1	5	0	1	0	3	8	0	0	18	0	21	2	0	6	3	3	0	0	97	0	0	0	0	0	0	MT
NL	0	0	8	0	1	156	1	2	4	0	24	350	6	0	8	1	163	159	0	0	1	2	10	1	4	0	0	1	6	0	0	NL
NO	0	0	0	0	0	1	0	1	0	0	1	8	3	0	1	1	3	7	0	0	0	0	1	0	0	0	0	1	0	0	0	NO
PL	0	0	13	0	6	7	3	13	3	0	64	154	11	1	3	2	22	19	0	1	6	23	2	0	10	0	1	5	1	2	3	PL
PT	0	0	0	0	0	1	0	0	0	0	0	2	0	0	119	0	11	3	0	0	0	0	1	0	2	0	0	0	0	0	0	PT
RO	2	0	5	1	11	1	52	5	1	0	11	24	1	0	2	0	5	4	1	7	4	28	0	0	8	0	2	1	0	0	21	RO
RS	12	0	11	0	76	2	42	3	1	0	24	37	1	0	3	0	8	4	0	15	24	58	0	0	18	0	1	1	0	0	2	RS
RU	0	0	0	3	0	0	0	6	0	0	1	3	0	1	0	2	1	1	1	0	0	1	0	0	0	0	41	1	0	1	1	RU
SE	0	0	1	0	0	2	0	4	0	0	2	22	11	1	1	4	6	11	0	0	0	1	1	0	0	0	0	2	0	1	0	SE
SI	1	0	138	0	22	3	2	1	5	0	38	80	2	0	5	0	14	4	0	2	108	32	0	0	233	0	0	1	0	0	0	SI
SK	1	0	35	0	20	4	7	4	3	0	82	80	4	0	2	1	13	9	0	2	18	132	1	0	21	0	1	2	0	1	1	SK
TJ	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	38	0	0	0	0	TJ
TM	0	2	0	20	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	1	77	0	0	0	0	TM
TR	0	5	0	6	1	0	6	1	0	2	1	3	0	0	1	0	1	1	3	8	0	1	0	0	3	0	3	0	0	0	1	TR
UA	1	0	3	3	4	1	10	27	1	0	7	21	2	1	1	1	4	5	2	3	2	8	0	0	4	0	6	3	0	1	28	UA
UZ	0	1	0	7	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	23	134	0	0	0	0	UZ
ATL	0	0	0	0	0	1	0	0	0	0	0	4	0	0	8	0	8	10	0	0	0	0	2	1	0	0	0	0	0	0	0	ATL
BAS	0	0	2	0	1	7	1	11	1	0	8	85	33	8	2	15	16	25	0	0	1	3	2	0	2	0	0	10	0	8	1	BAS
BLS	0	1	1	8	2	1	17	7	0	0	2	7	1	0	1	0	2	2	28	6	1	2	0	0	3	0	7	1	0	0	9	BLS
MED	4	0	2	1	11	1	8	1	1	2	4	9	0	0	30	0	20	2	0	25	5	3	0	0	64	0	1	0	0	0	1	MED
NOS	0	0	2	0	0	21	0	1	1	0	5	89	18	0	4	1	63	155	0	0	0	1	10	1	1	0	0	1	1	1	0	NOS
AST	0	1	0	10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	2	27	0	0	0	0	AST
NOA	0	0	0	0	2	0	2	0	0	0	1	2	0	0	18	0	6	1	0	6	1	0	0	0	9	0	0	0	0	0	0	NOA
EXC	1	1	5	8	4	4	5	7	2	0	7	30	2	1	11	2	21	13	2	3	3	5	1	0	16	3	65	2	0	1	3	EXC
EU	1	0	19	0	7	14	15	5	6	0	25	110	6	2	45	6	82	52	0	9	9	18	6	0	65	0	0	5	1	3	2	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.13 Cont.: 2019 country-to-country blame matrices for **PM2.5**.
Units: ng/m^3 per 15% emis. red. of PPM, SO_x, NO_x, NH_3 and VOC. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	28	84	0	1	0	19	0	17	150	6	0	1	3	0	0	13	10	0	1	0	0	55	1	2	14	23	8	55	827	171	AL
AM	0	1	0	0	0	1	0	1	1	13	0	0	0	0	5	203	5	1	0	0	1	2	0	240	4	33	1	6	901	7	AM
AT	1	1	0	6	1	43	0	3	18	3	1	26	12	0	0	1	3	0	1	1	0	10	5	0	6	15	3	7	885	833	AT
AZ	0	1	0	0	0	2	0	1	1	82	0	0	0	0	12	85	12	3	0	0	1	2	0	267	3	32	1	4	1304	10	AZ
BA	19	7	0	2	0	44	0	17	137	6	0	3	11	0	0	6	8	0	1	1	0	20	2	1	10	17	4	22	1076	309	BA
BE	0	0	0	109	2	17	1	1	1	3	2	0	1	0	0	0	1	0	17	4	0	3	95	0	3	43	18	1	1310	1294	BE
BG	3	21	0	1	0	34	0	115	106	29	1	1	5	0	0	107	55	0	1	1	12	16	1	8	6	17	6	11	966	616	BG
BY	1	2	0	4	2	152	0	19	14	86	4	1	6	0	0	17	125	0	2	9	1	2	5	2	1	13	4	3	805	324	BY
CH	0	0	0	6	0	9	0	0	1	1	0	1	1	0	0	0	0	0	2	1	0	6	7	0	4	16	3	2	817	391	CH
CY	1	6	0	0	0	4	0	4	9	16	0	0	0	0	0	804	17	0	1	0	6	134	0	154	20	58	35	40	1072	210	CY
CZ	1	2	0	13	2	152	0	9	32	6	2	9	35	0	0	2	5	0	3	3	0	6	10	1	4	20	5	6	1239	1167	CZ
DE	0	1	0	61	3	62	0	2	6	5	3	2	4	0	0	0	3	0	7	10	0	3	43	0	3	28	11	2	1192	1149	DE
DK	0	1	0	53	11	84	0	5	5	12	20	0	3	0	0	1	9	0	9	63	0	1	84	0	1	24	19	1	853	807	DK
EE	0	1	0	4	3	42	0	4	3	57	10	0	1	0	0	4	27	0	2	17	0	1	4	1	0	8	6	1	447	322	EE
ES	0	0	0	1	0	1	26	0	2	0	0	0	0	0	0	0	0	0	32	0	0	53	2	0	23	23	16	5	398	393	ES
FI	0	0	0	1	3	10	0	1	1	47	8	0	0	0	0	1	7	0	3	6	0	0	2	0	0	6	8	0	175	109	FI
FR	0	0	0	18	1	6	1	0	1	1	1	1	0	0	0	0	0	0	20	1	0	16	38	0	5	21	16	2	729	706	FR
GB	0	0	0	28	2	13	1	1	1	3	1	0	0	0	0	0	1	0	36	2	0	1	58	0	1	27	27	0	791	780	GB
GE	0	1	0	0	0	2	0	1	2	34	0	0	0	0	3	144	10	1	0	0	5	1	0	70	2	19	3	5	765	8	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	0	1	0	GL
GR	3	41	0	1	0	16	0	22	53	17	0	0	2	0	0	116	33	0	1	0	5	86	0	8	15	24	14	49	681	389	GR
HR	6	7	0	4	1	57	1	15	111	5	1	32	16	0	0	6	9	0	1	1	0	38	3	1	11	17	5	20	1110	807	HR
HU	4	11	0	5	1	136	0	104	173	10	1	14	70	0	0	15	30	0	2	2	1	12	4	2	6	19	4	12	1407	1106	HU
IE	0	0	0	12	1	4	1	0	0	1	1	0	0	0	0	0	0	0	43	1	0	1	32	0	2	22	33	0	399	394	IE
IS	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	4	0	0	0	2	0	0	7	24	0	65	20	IS
IT	2	4	0	2	0	15	1	3	19	2	0	15	3	0	0	3	2	0	3	0	0	113	2	1	26	26	14	68	1018	960	IT
KG	0	0	0	0	0	0	0	0	0	4	0	0	0	27	4	6	0	179	0	-0	0	0	0	98	0	21	0	2	440	1	KG
KZ	0	0	0	0	0	2	0	1	1	104	0	0	0	2	6	6	12	29	0	0	0	0	0	63	0	22	1	1	463	8	KZ
LT	0	2	0	9	3	187	0	11	9	59	9	1	5	0	0	9	57	0	2	21	1	2	9	2	1	13	7	2	805	593	LT
LU	0	0	0	59	1	16	0	0	1	2	1	0	1	0	0	0	1	0	10	2	0	4	42	0	3	27	12	1	1122	1102	LU
LV	0	1	0	6	3	87	0	7	5	52	10	1	3	0	0	7	44	0	2	17	0	1	6	2	1	10	6	1	587	420	LV
MD	1	7	0	3	1	92	0	216	29	72	2	1	4	0	0	80	253	0	1	3	16	8	2	6	4	19	4	6	1419	421	MD
ME	256	17	0	1	0	24	0	19	170	5	0	1	5	0	0	7	8	0	1	0	0	26	1	1	11	18	4	32	726	155	ME
MK	6	373	0	1	0	22	0	25	186	9	0	1	4	0	0	36	16	0	1	0	1	19	0	4	9	19	4	24	916	235	MK
MT	3	7	133	1	0	9	1	6	26	2	0	1	1	0	0	11	4	0	4	0	0	404	1	1	79	39	45	188	391	323	MT
NL	0	0	0	421	3	35	1	2	2	5	3	1	2	0	0	0	2	0	18	8	0	3	141	0	3	57	21	1	1385	1364	NL
NO	0	0	0	2	45	9	0	0	1	10	4	0	0	0	0	0	3	0	7	2	0	0	6	0	0	9	14	0	105	44	NO
PL	1	3	0	13	3	875	0	21	22	20	5	3	22	0	0	6	43	0	3	14	1	4	11	1	3	19	7	4	1411	1287	PL
PT	0	0	0	0	0	0	317	0	1	0	0	0	0	0	0	0	0	0	83	0	0	13	1	0	13	25	22	2	459	457	PT
RO	3	13	0	2	1	69	0	606	78	30	1	1	9	0	0	56	77	0	1	1	10	8	2	6	5	17	4	9	1145	844	RO
RS	20	51	0	3	1	60	0	93	776	12	1	2	15	0	0	25	22	0	1	1	1	12	2	3	7	20	3	19	1426	423	RS
RU	0	0	0	0	0	8	0	2	1	267	1	0	0	0	1	7	28	1	1	1	1	0	1	7	0	38	4	1	385	27	RU
SE	0	0	0	5	11	22	0	1	1	15	44	0	1	0	0	1	7	0	4	10	0	0	7	0	0	6	9	0	181	140	SE
SI	1	3	0	5	1	44	0	4	30	4	1	411	11	0	0	2	4	0	1	1	0	38	3	1	10	17	4	13	1213	1138	SI
SK	2	6	0	6	1	213	0	51	75	9	2	7	295	0	0	8	31	0	2	2	1	8	4	1	5	15	3	9	1150	987	SK
TJ	0	0	0	0	0	0	0	0	0	5	0	0	0	263	17	9	1	152	0	-0	0	0	0	123	0	24	0	2	502	1	TJ
TM	0	0	0	0	0	2	0	1	1	37	0	0	0	8	149	22	10	79	0	0	0	1	0	171	1	31	0	3	417	7	TM
TR	0	3	0	0	0	5	0	7	7	21	0	0	0	0	1	1082	24	0	0	0	11	29	0	132	9	44	8	14	1201	42	TR
UA	1	4	0	2	1	91	0	58	19	151	2	1	4	0	1	56	599	1	1	3	9	4	2	6	3	16	3	5	1140	237	UA
UZ	0	0	0	0	0	2	0	1	1	42	0	0	0	38	38	13	9	363	0	0	0	1	0	75	1	27	0	2	678	7	UZ
ATL	0	0	0	1	1	1	4	0	0	4	0	0	0	0	0	0	0	0	26	0	0	2	2	0	4	36	35	0	49	41	ATL
BAS	0	1	0	16	5	89	0	4	4	33	29	1	2	0	0	2	17	0	4	34	0	1	15	1	1	11	11	1	447	370	BAS
BLS	1	3	0	1	0	21	0	35	12	145	0	0	1	0	1	349	151	0	0	0	63	11	0	22	3	18	17	6	832	106	BLS
MED	3	8	-0	1	0	9	2	7	22	10	0	2	1	0	0	162	14	0	7	0	3	235	0	28	60	35	40	93	436	198	MED
NOS	0	0	0	46	8	21	0	1	2	5	4	0	1	0	0	0	2	0	16	8	0	1	51	0	1	17	29	0	466	445	NOS
AST	0	0	0	0	0	1	0	0	1	12	0	0	0	3	11	69	4	10	0	0	0	5	0	813	6	142	2	4	157	6	AST
NOA	1	3	0	0	0	2	5	2	6	3	0	0	0	0	0	25	4	0	17	0	1	61	0	7	219	101	17	36	101	56	NOA
EXC	1	2	0	4	2	31	2	14	11	132	2	1	3	4	6	57	39	19	4	2	1	7	5	28	3	28	6	4	563	192	EXC
EU	1	4	0	17	2	94	10	42	20	13	7	5	9	0	0	13	15	0	13	5	1	22	18	2	7	19	12	9	765	677	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.14: 2019 country-to-country blame matrices for **fine EC**.
Units: 0.1 ng/m^3 per 15% emis. red. of PPM. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	250	0	1	0	6	0	3	0	0	0	1	1	0	0	1	0	2	0	0	8	3	3	0	0	9	0	0	0	0	0	0	AL
AM	0	195	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	333	0	2	0	0	0	4	0	12	24	0	0	1	0	6	1	0	0	5	8	0	0	13	0	0	0	0	0	0	AT
AZ	0	16	0	589	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0	1	0	0	0	0	AZ
BA	2	0	5	0	359	0	1	0	0	0	4	4	0	0	1	0	3	1	0	1	32	12	0	0	10	0	0	0	0	0	0	BA
BE	0	0	2	0	0	264	0	0	1	0	2	43	0	0	1	0	134	21	0	0	0	0	1	0	1	0	0	0	5	0	0	BE
BG	1	0	1	0	2	0	211	1	0	0	1	2	0	0	1	0	1	0	1	9	1	4	0	0	2	0	0	0	0	0	4	BG
BY	0	0	1	0	1	0	1	133	0	0	2	5	1	1	0	1	2	1	0	0	1	3	0	0	1	0	0	8	0	3	3	BY
CH	0	0	12	0	0	1	0	0	240	0	1	29	0	0	1	0	43	1	0	0	0	0	0	0	19	0	0	0	0	0	0	CH
CY	0	0	0	1	0	0	1	0	0	65	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	CY
CZ	0	0	30	0	3	1	1	1	2	0	242	39	0	0	1	0	10	2	0	0	4	11	0	0	4	0	0	0	0	0	0	CZ
DE	0	0	18	0	0	6	0	0	6	0	10	266	1	0	1	0	34	7	0	0	1	1	0	0	2	0	0	0	1	0	0	DE
DK	0	0	1	0	0	3	0	1	0	0	2	28	90	0	1	0	9	14	0	0	0	1	1	0	0	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	6	0	0	1	3	1	99	0	6	2	2	0	0	0	0	0	0	0	0	0	5	0	14	1	EE
ES	0	0	0	0	0	0	0	0	0	0	0	1	0	0	153	0	9	1	0	0	0	0	0	0	2	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	33	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	FI
FR	0	0	1	0	0	4	0	0	5	0	1	14	0	0	5	0	305	9	0	0	0	0	0	0	5	0	0	0	0	0	0	FR
GB	0	0	0	0	0	2	0	0	0	0	1	5	0	0	1	0	15	272	0	0	0	0	4	0	0	0	0	0	0	0	0	GB
GE	0	10	0	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	309	0	0	0	0	0	0	0	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	7	0	1	0	2	0	11	0	0	0	1	1	0	0	1	0	1	0	0	136	1	1	0	0	5	0	0	0	0	0	1	GR
HR	1	0	16	0	76	0	1	0	0	0	6	7	0	0	1	0	4	1	0	1	252	28	0	0	30	0	0	0	0	0	0	HR
HU	1	0	25	0	15	0	3	1	1	0	11	10	0	0	1	0	4	1	0	1	26	290	0	0	8	0	0	0	0	0	1	HU
IE	0	0	0	0	0	1	0	0	0	0	0	2	0	0	2	0	8	21	0	0	0	0	79	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	8	0	0	0	0	0	0	0	IS
IT	1	0	7	0	3	0	0	0	3	0	2	3	0	0	3	0	11	0	0	0	5	2	0	0	381	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	6	0	0	0	0	KG
KZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	42	0	0	0	0	KZ
LT	0	0	1	0	1	1	0	20	0	0	2	7	1	1	0	1	3	3	0	0	1	2	0	0	1	0	0	140	0	9	2	LT
LU	0	0	4	0	0	34	0	0	2	0	2	91	0	0	1	0	153	9	0	0	0	0	0	0	1	0	0	0	61	0	0	LU
LV	0	0	1	0	0	0	0	13	0	0	1	5	1	5	0	2	2	2	0	0	0	1	0	0	0	0	0	24	0	97	1	LV
MD	0	0	1	1	1	0	7	3	0	0	1	3	0	0	0	0	1	1	1	1	1	2	0	0	1	0	0	1	0	0	416	MD
ME	20	0	2	0	19	0	1	0	0	0	2	2	0	0	1	0	2	0	0	1	4	4	0	0	7	0	0	0	0	0	0	ME
MK	19	0	1	0	3	0	11	0	0	0	1	2	0	0	1	0	1	0	0	25	1	4	0	0	4	0	0	0	0	0	1	MK
MT	1	0	1	0	2	0	1	0	0	0	1	1	0	0	5	0	8	0	0	1	1	1	0	0	24	0	0	0	0	0	0	MT
NL	0	0	2	0	0	55	0	0	1	0	3	83	0	0	1	0	46	26	0	0	0	0	1	0	1	0	0	0	1	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	4	0	2	1	1	4	1	0	16	22	1	0	0	0	6	3	0	0	2	7	0	0	2	0	0	2	0	1	1	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	4	1	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	1	0	2	0	3	0	18	1	0	0	2	3	0	0	0	0	1	1	1	2	1	10	0	0	2	0	0	0	0	0	12	RO
RS	7	0	4	0	28	0	13	1	0	0	4	4	0	0	1	0	2	1	0	4	11	21	0	0	5	0	0	0	0	0	1	RS
RU	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	RU
SE	0	0	0	0	0	0	0	1	0	0	0	3	2	0	0	1	2	2	0	0	0	0	0	0	0	0	0	1	0	0	0	SE
SI	0	0	76	0	6	0	0	0	1	0	6	9	0	0	1	0	4	1	0	0	56	12	0	0	74	0	0	0	0	0	0	SI
SK	0	0	17	0	6	1	2	1	1	0	21	10	0	0	1	0	4	2	0	1	7	58	0	0	5	0	0	0	0	0	0	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	TJ
TM	0	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	TM
TR	0	3	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	TR
UA	0	0	1	1	1	0	2	9	0	0	1	2	0	0	0	0	1	1	1	1	1	3	0	0	1	0	0	1	0	1	15	UA
UZ	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	11	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	1	0	0	1	0	3	0	0	2	12	7	4	0	7	4	5	0	0	0	1	0	0	0	0	0	4	0	4	1	BAS
BLS	0	1	0	3	0	0	5	2	0	0	0	1	0	0	0	0	1	0	20	2	0	1	0	0	1	0	0	0	0	0	5	BLS
MED	2	0	1	0	3	0	2	0	0	0	1	1	0	0	12	0	11	0	0	10	3	1	0	0	26	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	3	0	0	0	0	1	9	2	0	1	0	17	39	0	0	0	0	1	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	2	0	0	1	0	0	0	0	3	0	0	0	0	0	0	NOA
EXC	1	1	3	4	2	1	2	3	1	0	2	7	0	0	5	1	11	5	2	1	1	3	0	0	7	1	8	1	0	1	2	EXC
EU	0	0	11	0	2	4	7	1	2	0	8	29	1	1	19	3	47	19	0	5	5	9	2	0	29	0	0	3	0	2	1	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.14 Cont.: 2019 country-to-country blame matrices for **fine EC**.
Units: 0.1 ng/m^3 per 15% emis. red. of PPM. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	14	11	0	0	0	7	0	5	38	1	0	0	1	0	0	1	3	0	0	0	0	6	0	0	2	0	0	0	371	47	AL
AM	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	39	1	0	0	0	0	0	0	13	0	0	0	0	322	1	AM
AT	0	0	0	1	0	16	0	1	2	0	0	9	5	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	447	437	AT
AZ	0	0	0	0	0	0	0	0	0	20	0	0	0	0	1	11	3	1	0	0	0	0	0	17	0	0	0	0	680	1	AZ
BA	6	0	0	0	0	18	0	4	21	1	0	1	3	0	0	0	3	0	0	0	0	2	0	0	1	0	0	0	494	100	BA
BE	0	0	0	24	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	41	0	0	0	0	0	506	504	BE
BG	0	2	0	0	0	13	0	38	18	6	0	0	1	0	0	14	17	0	0	0	2	2	0	0	1	0	0	0	354	287	BG
BY	0	0	0	0	0	72	0	6	2	20	1	0	1	0	0	2	51	0	0	2	0	0	1	0	0	0	0	0	325	112	BY
CH	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	351	111	CH
CY	0	0	0	0	0	1	0	1	1	3	0	0	0	0	0	77	5	0	0	0	1	17	0	14	2	0	0	0	164	76	CY
CZ	0	0	0	1	0	84	0	2	3	1	0	2	12	0	0	0	2	0	0	1	0	0	2	0	0	0	0	0	463	450	CZ
DE	0	0	0	8	0	27	0	1	0	1	0	0	1	0	0	0	1	0	0	2	0	0	9	0	0	0	0	0	395	386	DE
DK	0	0	0	5	3	31	0	1	0	2	2	0	1	0	0	0	3	0	1	19	0	0	18	0	0	0	0	0	202	192	DK
EE	0	0	0	0	1	18	0	1	0	14	2	0	0	0	0	0	9	0	0	9	0	0	1	0	0	0	0	0	187	155	EE
ES	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	3	0	0	7	0	0	2	0	0	0	177	176	ES
FI	0	0	0	0	1	4	0	0	0	7	2	0	0	0	0	0	2	0	0	3	0	0	1	0	0	0	0	0	57	46	FI
FR	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	6	0	1	0	0	0	355	350	FR
GB	0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	16	0	0	0	0	0	308	307	GB
GE	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	20	3	0	0	0	0	0	0	3	0	0	0	0	401	2	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	1	5	0	0	0	6	0	6	7	4	0	0	1	0	0	15	10	0	0	0	1	14	0	0	2	0	0	0	224	173	GR
HR	2	0	0	0	0	23	0	4	21	1	0	15	4	0	0	0	3	0	0	0	0	5	1	0	1	0	0	0	500	394	HR
HU	1	1	0	0	0	60	0	40	35	2	0	5	27	0	0	1	15	0	0	0	0	1	1	0	1	0	0	0	585	513	HU
IE	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	3	0	0	0	0	0	116	115	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	12	3	IS
IT	0	0	0	0	0	5	0	1	1	0	0	4	1	0	0	0	1	0	0	0	0	13	0	0	4	0	0	0	436	426	IT
KG	0	0	0	0	0	0	0	0	0	1	0	0	0	13	1	1	0	23	0	0	0	0	0	15	0	0	0	0	95	0	KG
KZ	0	0	0	0	0	1	0	0	0	15	0	0	0	1	1	1	3	6	0	0	0	0	0	8	0	0	0	0	74	2	KZ
LT	0	0	0	1	1	88	0	4	1	18	1	0	1	0	0	1	19	0	0	5	0	0	2	0	0	0	0	0	331	269	LT
LU	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	7	0	0	0	0	0	371	368	LU
LV	0	0	0	1	1	39	0	2	1	12	1	0	1	0	0	1	15	0	0	5	0	0	2	0	0	0	0	0	231	187	LV
MD	0	0	0	0	0	36	0	94	3	13	0	0	1	0	0	9	108	0	0	1	2	1	0	0	0	0	0	0	709	152	MD
ME	189	1	0	0	0	10	0	5	29	1	0	0	1	0	0	0	3	0	0	0	0	3	0	0	1	0	0	0	306	43	ME
MK	1	167	0	0	0	9	0	7	49	2	0	0	1	0	0	3	5	0	0	0	0	2	0	0	1	0	0	0	321	70	MK
MT	1	0	139	0	0	3	0	2	2	0	0	0	0	0	0	1	1	0	0	0	0	116	0	0	16	0	0	0	199	190	MT
NL	0	0	0	230	0	10	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	71	0	0	0	0	0	463	460	NL
NO	0	0	0	0	28	3	0	0	0	1	1	0	0	0	0	0	1	0	1	1	0	0	3	0	0	0	0	0	39	9	NO
PL	0	0	0	1	1	859	0	7	3	6	1	1	7	0	0	1	21	0	0	3	0	0	2	0	0	0	0	0	983	944	PL
PT	0	0	0	0	0	0	185	0	0	0	0	0	0	0	0	0	0	0	11	0	0	2	0	0	1	0	0	0	232	231	PT
RO	1	1	0	0	0	27	0	355	14	6	0	0	2	0	0	6	31	0	0	0	1	1	0	0	0	0	0	0	504	428	RO
RS	8	8	0	0	0	23	0	32	376	2	0	1	4	0	0	2	7	0	0	0	0	1	0	0	1	0	0	0	568	128	RS
RU	0	0	0	0	0	3	0	1	0	75	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0	0	0	99	7	RU
SE	0	0	0	0	4	9	0	0	0	2	14	0	0	0	0	0	2	0	0	5	0	0	2	0	0	0	0	0	46	36	SE
SI	0	0	0	0	0	15	0	1	3	1	0	244	3	0	0	0	2	0	0	0	0	4	0	0	1	0	0	0	517	504	SI
SK	0	0	0	1	0	123	0	17	10	2	0	2	182	0	0	1	18	0	0	1	0	1	1	0	0	0	0	0	492	452	SK
TJ	0	0	0	0	0	0	0	0	0	1	0	0	0	166	3	1	0	24	0	0	0	0	0	35	0	0	0	0	201	0	TJ
TM	0	0	0	0	0	1	0	0	0	6	0	0	0	4	45	2	2	21	0	0	0	0	0	13	0	0	0	0	96	1	TM
TR	0	0	0	0	0	2	0	2	1	4	0	0	0	0	0	310	6	0	0	0	1	4	0	10	1	0	0	0	337	9	TR
UA	0	0	0	0	0	41	0	21	2	32	0	0	1	0	0	7	362	0	0	1	1	1	0	0	0	0	0	0	512	80	UA
UZ	0	0	0	0	0	1	0	0	0	6	0	0	0	24	13	1	2	129	0	0	0	0	0	5	0	0	0	0	199	1	UZ
ATL	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	5	0	0	0	1	0	1	0	0	0	12	10	ATL
BAS	0	0	0	1	2	45	0	1	0	10	7	0	1	0	0	0	6	0	0	38	0	0	4	0	0	0	0	0	129	107	BAS
BLS	0	0	0	0	0	9	0	12	1	37	0	0	0	0	0	75	63	0	0	0	16	2	0	1	0	0	0	0	242	33	BLS
MED	1	0	0	0	0	3	1	2	2	2	0	1	0	0	0	20	4	0	1	0	0	46	0	3	15	0	0	0	113	77	MED
NOS	0	0	0	6	6	6	0	0	0	1	0	0	0	0	0	0	1	0	2	2	0	0	48	0	0	0	0	0	96	88	NOS
AST	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	8	1	2	0	0	0	0	0	300	0	0	0	0	24	1	AST
NOA	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	2	1	0	2	0	0	7	0	1	70	0	0	0	23	18	NOA
EXC	0	0	0	1	1	22	1	7	3	34	0	1	1	2	2	14	18	5	0	1	0	1	1	3	0	0	0	0	187	84	EXC
EU	0	0	0	3	1	75	5	22	3	3	2	2	4	0	0	1	6	0	1	2	0	3	4	0	1	0	0	0	338	317	EU

ME MK MT NL NO PL PT RO RS RU SE SI SK TJ TM TR UA UZ ATL BAS BLS MED NOS AST NOA BIC DMS VOL EXC EU

Table D.15: 2019 country-to-country blame matrices for **coarse EC**.
Units: 0.1 ng/m^3 per 15% emis. red. of PPM. **Emitters →, Receptors ↓.**

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	11	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	AL
AM	0	15	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	16	0	0	0	0	0	1	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	AT
AZ	0	1	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	AZ
BA	0	0	0	0	49	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	BA
BE	0	0	0	0	0	23	0	0	0	0	0	10	0	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	1	0	0	BE
BG	0	0	0	0	1	0	21	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	BG
BY	0	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	BY
CH	0	0	0	0	0	0	0	0	145	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	CY
CZ	0	0	2	0	1	0	0	0	1	0	32	7	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	CZ
DE	0	0	1	0	0	0	0	0	2	0	3	48	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	DE
DK	0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	EE
ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	FI
FR	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	FR
GB	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	17	0	0	0	0	0	0	0	0	0	0	0	0	0	GB
GE	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	GR
HR	0	0	1	0	15	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	20	1	0	0	1	0	0	0	0	0	0	HR
HU	0	0	1	0	3	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	17	0	0	0	0	0	0	0	0	0	HU
IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	IS
IT	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	11	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	0	0	0	0	KG
KZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	KZ
LT	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	LT
LU	0	0	0	0	0	3	0	0	1	0	0	14	0	0	0	0	7	1	0	0	0	0	0	0	0	0	0	0	11	0	0	LU
LV	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	LV
MD	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	MD
ME	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ME
MK	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	MK
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	MT
NL	0	0	0	0	0	4	0	0	0	0	1	19	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	PT
RO	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	RO
RS	0	0	0	0	7	0	2	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	RS
RU	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	RU
SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	SE
SI	0	0	3	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6	1	0	0	1	0	0	0	0	0	0	SI
SK	0	0	1	0	1	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	TJ
TM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	TM
TR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	TR
UA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	UA
UZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	BAS
BLS	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	BLS
MED	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NOA
EXC	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	EXC
EU	0	0	1	0	0	0	1	0	1	0	1	5	0	0	1	1	2	1	0	1	0	1	0	0	1	0	0	0	0	0	0	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.15 Cont.: 2019 country-to-country blame matrices for **coarse EC**.
Units: 0.1 ng/m^3 per 15% emis. red. of PPM. **Emitters →, Receptors ↓.**

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	1	2	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	5	AL
AM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	22	0	AM
AT	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	26	AT
AZ	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	39	0	AZ
BA	0	0	0	0	0	2	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	8	BA
BE	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	45	BE
BG	0	0	0	0	0	1	0	4	2	1	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0	38	28	BG
BY	0	0	0	0	0	4	0	0	0	3	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	23	7	BY
CH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153	8	CH
CY	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	23	1	0	0	0	0	0	0	1	0	0	0	0	32	7	CY
CZ	0	0	0	0	0	15	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	60	CZ
DE	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	58	DE
DK	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	15	DK
EE	0	0	0	0	0	1	0	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	15	11	EE
ES	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	12	12	ES
FI	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	9	FI
FR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	18	FR
GB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	GB
GE	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	24	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	34	25	GR
HR	0	0	0	0	0	3	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	30	HR
HU	0	0	0	0	0	7	0	3	5	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	49	38	HU
IE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	8	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	IS
IT	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	17	14	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	3	0	0	0	0	12	0	KG
KZ	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	22	0	KZ
LT	0	0	0	0	0	4	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	19	13	LT
LU	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	37	LU
LV	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	15	10	LV
MD	0	0	0	0	0	3	0	5	0	3	0	0	0	0	0	2	11	0	0	0	0	0	0	0	0	0	0	0	43	10	MD
ME	9	0	0	0	0	1	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	4	ME
MK	0	24	0	0	0	1	0	1	4	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	42	11	MK
MT	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	30	28	MT
NL	0	0	0	22	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	51	NL
NO	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	NO
PL	0	0	0	0	0	55	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	70	66	PL
PT	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	13	PT
RO	0	0	0	0	0	2	0	28	2	1	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	44	35	RO
RS	1	1	0	0	0	2	0	6	50	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	75	15	RS
RU	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	16	1	RU
SE	0	0	0	0	1	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	SE
SI	0	0	0	0	0	2	0	0	1	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	35	SI
SK	0	0	0	0	0	19	0	1	2	0	0	0	21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	57	52	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	3	0	0	0	0	0	3	0	0	0	0	22	0	TJ
TM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6	0	0	2	0	0	0	0	0	2	0	0	0	0	12	0	TM
TR	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	69	1	0	0	0	0	0	0	1	0	0	0	0	73	1	TR
UA	0	0	0	0	0	2	0	1	0	12	0	0	0	0	0	2	55	0	0	0	0	0	0	0	0	0	0	0	75	5	UA
UZ	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	0	0	13	0	0	0	0	0	1	0	0	0	0	22	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	ATL
BAS	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	12	10	BAS
BLS	0	0	0	0	0	1	0	1	0	12	0	0	0	0	0	10	9	0	0	0	0	0	0	0	0	0	0	0	36	3	BLS
MED	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	7	1	0	0	0	0	0	0	1	4	0	0	0	15	5	MED
NOS	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	7	NOS
AST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	125	0	0	0	0	3	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	28	0	0	0	3	1	NOA
EXC	0	0	0	0	0	1	0	1	0	6	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	25	7	EXC
EU	0	0	0	0	0	5	0	2	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	29	25	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

Table D.16: 2019 country-to-country blame matrices for **PPM2.5**
Units: ng/m^3 per 15% emis. red. of PPM. **Emitters** $\rightarrow$, **Receptors** $\downarrow$.

	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	
AL	176	0	1	0	4	0	2	0	0	0	1	1	0	0	1	0	1	0	0	6	2	2	0	0	7	0	0	0	0	0	0	AL
AM	0	113	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	AM
AT	0	0	197	0	1	0	0	0	2	0	9	15	0	0	0	0	3	1	0	0	5	6	0	0	9	0	0	0	0	0	0	AT
AZ	0	9	0	219	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	1	0	0	0	0	AZ
BA	1	0	3	0	300	0	1	0	0	0	3	3	0	0	1	0	1	0	0	0	28	9	0	0	7	0	0	0	0	0	0	BA
BE	0	0	1	0	0	182	0	0	1	0	1	28	0	0	1	0	73	13	0	0	0	0	0	0	1	0	0	0	5	0	0	BE
BG	1	0	1	0	2	0	146	1	0	0	1	1	0	0	0	0	1	0	0	6	1	3	0	0	2	0	0	0	0	0	3	BG
BY	0	0	1	0	1	0	1	91	0	0	2	3	0	1	0	0	1	1	0	0	1	2	0	0	1	0	0	7	0	3	2	BY
CH	0	0	7	0	0	0	0	0	153	0	1	19	0	0	1	0	22	1	0	0	0	0	0	0	14	0	0	0	0	0	0	CH
CY	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	CY
CZ	0	0	18	0	2	1	0	0	1	0	189	25	0	0	0	0	5	2	0	0	4	9	0	0	3	0	0	0	0	0	0	CZ
DE	0	0	11	0	0	4	0	0	4	0	8	166	1	0	1	0	18	4	0	0	0	1	0	0	2	0	0	0	0	0	0	DE
DK	0	0	1	0	0	2	0	0	0	0	2	17	76	0	0	0	5	9	0	0	0	1	0	0	0	0	0	0	0	0	0	DK
EE	0	0	0	0	0	0	0	5	0	0	0	2	1	97	0	4	1	1	0	0	0	0	0	0	0	0	0	4	0	13	0	EE
ES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	0	5	1	0	0	0	0	0	0	2	0	0	0	0	0	0	ES
FI	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	21	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	FI
FR	0	0	1	0	0	3	0	0	3	0	0	9	0	0	4	0	173	6	0	0	0	0	0	0	4	0	0	0	0	0	0	FR
GB	0	0	0	0	0	2	0	0	0	0	0	3	0	0	1	0	8	160	0	0	0	0	2	0	0	0	0	0	0	0	0	GB
GE	0	10	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	168	0	0	0	0	0	0	0	0	0	0	0	0	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	4	0	0	0	1	0	7	0	0	0	0	1	0	0	1	0	1	0	0	95	1	1	0	0	4	0	0	0	0	0	1	GR
HR	1	0	9	0	62	0	1	0	0	0	5	4	0	0	1	0	2	0	0	0	223	22	0	0	18	0	0	0	0	0	0	HR
HU	1	0	15	0	12	0	2	1	0	0	8	6	0	0	0	0	2	1	0	1	24	231	0	0	5	0	0	0	0	0	0	HU
IE	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	5	14	0	0	0	0	40	0	0	0	0	0	0	0	0	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	IS
IT	0	0	4	0	2	0	0	0	2	0	1	2	0	0	2	0	6	0	0	0	4	2	0	0	292	0	0	0	0	0	0	IT
KG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	5	0	0	0	0	KG
KZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	35	0	0	0	0	KZ
LT	0	0	1	0	0	0	0	20	0	0	2	4	1	1	0	1	2	2	0	0	1	1	0	0	1	0	0	116	0	9	1	LT
LU	0	0	2	0	0	23	0	0	2	0	2	59	0	0	1	0	83	6	0	0	0	0	0	0	1	0	0	0	58	0	0	LU
LV	0	0	0	0	0	0	0	10	0	0	1	3	1	5	0	1	1	2	0	0	0	1	0	0	0	0	0	19	0	88	1	LV
MD	0	0	1	0	1	0	5	2	0	0	1	2	0	0	0	0	1	1	1	1	1	2	0	0	1	0	0	1	0	0	357	MD
ME	14	0	1	0	14	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	3	3	0	0	5	0	0	0	0	0	0	ME
MK	13	0	1	0	2	0	6	0	0	0	1	1	0	0	1	0	1	0	0	18	1	3	0	0	3	0	0	0	0	0	1	MK
MT	1	0	1	0	2	0	0	0	0	0	0	1	0	0	3	0	5	0	0	1	1	1	0	0	17	0	0	0	0	0	0	MT
NL	0	0	1	0	0	39	0	0	0	0	2	54	0	0	1	0	25	16	0	0	0	0	0	0	0	0	0	0	1	0	0	NL
NO	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
PL	0	0	3	0	1	1	0	4	0	0	12	14	1	0	0	0	3	2	0	0	2	5	0	0	1	0	0	1	0	1	1	PL
PT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	PT
RO	1	0	1	0	2	0	12	1	0	0	1	2	0	0	0	0	1	0	0	1	1	8	0	0	1	0	0	0	0	0	10	RO
RS	4	0	2	0	23	0	8	0	0	0	3	3	0	0	1	0	1	0	0	3	10	16	0	0	3	0	0	0	0	0	1	RS
RU	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	RU
SE	0	0	0	0	0	0	0	1	0	0	0	2	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	SE
SI	0	0	45	0	5	0	0	0	0	0	4	5	0	0	1	0	2	0	0	0	49	9	0	0	41	0	0	0	0	0	0	SI
SK	0	0	10	0	5	0	1	1	0	0	16	6	0	0	0	0	2	1	0	0	6	45	0	0	3	0	0	0	0	0	0	SK
TJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	TJ
TM	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	TM
TR	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	TR
UA	0	0	1	0	1	0	2	7	0	0	1	2	0	0	0	0	1	1	1	0	1	2	0	0	1	0	0	1	0	0	13	UA
UZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	8	0	0	0	0	UZ
ATL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	ATL
BAS	0	0	0	0	0	1	0	2	0	0	1	8	5	4	0	4	2	3	0	0	0	1	0	0	0	0	0	3	0	4	0	BAS
BLS	0	0	0	1	0	0	4	1	0	0	0	1	0	0	0	0	0	0	11	1	0	0	0	0	0	0	0	0	0	0	4	BLS
MED	1	0	1	0	2	0	1	0	0	0	1	1	0	0	8	0	6	0	0	6	2	1	0	0	17	0	0	0	0	0	0	MED
NOS	0	0	0	0	0	2	0	0	0	0	1	6	2	0	1	0	10	24	0	0	0	0	1	0	0	0	0	0	0	0	0	NOS
AST	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	AST
NOA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	0	NOA
EXC	0	0	2	1	1	1	1	2	1	0	2	5	0	0	3	1	6	3	1	1	1	2	0	0	5	1	7	1	0	1	1	EXC
EU	0	0	7	0	2	3	5	1	1	0	6	18	1	1	14	2	26	11	0	3	4	7	1	0	22	0	0	2	0	2	1	EU
	AL	AM	AT	AZ	BA	BE	BG	BY	CH	CY	CZ	DE	DK	EE	ES	FI	FR	GB	GE	GR	HR	HU	IE	IS	IT	KG	KZ	LT	LU	LV	MD	

Table D.16 Cont.: 2019 country-to-country blame matrices for **PPM2.5**
Units: ng/m^3 per 15% emis. red. of PPM. **Emitters** →, **Receptors** ↓.

	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	
AL	9	9	0	0	0	3	0	4	25	1	0	0	1	0	0	1	2	0	0	0	0	5	0	0	1	0	0	0	260	32	AL
AM	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	29	1	0	0	0	0	0	0	7	0	0	0	0	179	1	AM
AT	0	0	0	0	0	7	0	1	1	0	0	8	4	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	274	267	AT
AZ	0	0	0	0	0	0	0	0	0	17	0	0	0	0	1	8	2	0	0	0	0	0	0	8	0	0	0	0	279	1	AZ
BA	4	0	0	0	0	8	0	3	16	1	0	1	2	0	0	0	2	0	0	0	0	2	0	0	1	0	0	0	397	72	BA
BE	0	0	0	15	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	14	0	0	0	0	0	327	325	BE
BG	0	2	0	0	0	6	0	32	13	5	0	0	1	0	0	13	13	0	0	0	1	2	0	0	0	0	0	0	254	201	BG
BY	0	0	0	0	0	34	0	5	1	16	0	0	1	0	0	2	36	0	0	0	0	0	0	0	0	0	0	0	215	65	BY
CH	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	221	68	CH
CY	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	83	4	0	0	0	0	14	0	11	1	0	0	0	128	37	CY
CZ	0	0	0	1	0	38	0	2	3	1	0	2	10	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	320	310	CZ
DE	0	0	0	5	0	13	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	3	0	0	0	0	0	243	237	DE
DK	0	0	0	3	2	16	0	1	0	1	2	0	1	0	0	0	2	0	1	6	0	0	6	0	0	0	0	0	144	137	DK
EE	0	0	0	0	1	9	0	1	0	11	2	0	0	0	0	0	7	0	0	3	0	0	0	0	0	0	0	0	160	135	EE
ES	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	3	0	0	6	0	0	2	0	0	0	126	126	ES
FI	0	0	0	0	1	2	0	0	0	5	2	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	39	30	FI
FR	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	2	0	0	0	0	0	207	203	FR
GB	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	5	0	0	0	0	0	182	181	GB
GE	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	15	2	0	0	0	0	0	0	2	0	0	0	0	221	1	GE
GL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GL
GR	0	4	0	0	0	3	0	5	5	3	0	0	0	0	0	13	8	0	0	0	0	12	0	0	1	0	0	0	161	120	GR
HR	1	0	0	0	0	10	0	3	16	1	0	14	3	0	0	0	2	0	0	0	0	4	0	0	1	0	0	0	402	318	HR
HU	0	1	0	0	0	27	0	34	27	2	0	5	22	0	0	1	10	0	0	0	0	1	0	0	0	0	0	0	441	386	HU
IE	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	64	64	IE
IS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	5	2	IS
IT	0	0	0	0	0	2	0	1	1	0	0	4	1	0	0	0	0	0	0	0	0	11	0	0	2	0	0	0	328	321	IT
KG	0	0	0	0	0	0	0	0	0	1	0	0	0	7	0	0	0	15	0	0	0	0	0	10	0	0	0	0	64	0	KG
KZ	0	0	0	0	0	0	0	0	0	14	0	0	0	1	1	0	3	4	0	0	0	0	0	6	0	0	0	0	61	1	KZ
LT	0	0	0	0	1	41	0	3	1	13	1	0	1	0	0	1	14	0	0	1	0	0	1	0	0	0	0	0	239	189	LT
LU	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	244	242	LU
LV	0	0	0	0	1	18	0	2	0	9	1	0	1	0	0	1	11	0	0	2	0	0	0	0	0	0	0	0	180	146	LV
MD	0	0	0	0	0	16	0	85	2	12	0	0	1	0	0	9	74	0	0	0	1	1	0	0	0	0	0	0	576	117	MD
ME	127	1	0	0	0	5	0	4	20	1	0	0	1	0	0	0	2	0	0	0	0	2	0	0	1	0	0	0	208	29	ME
MK	1	138	0	0	0	4	0	6	34	2	0	0	1	0	0	3	4	0	0	0	0	2	0	0	1	0	0	0	244	47	MK
MT	0	0	49	0	0	1	0	1	2	0	0	0	0	0	0	1	1	0	0	0	0	98	0	0	11	0	0	0	90	83	MT
NL	0	0	0	121	0	5	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	24	0	0	0	0	0	270	267	NL
NO	0	0	0	0	22	1	0	0	0	1	1	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	29	6	NO
PL	0	0	0	1	0	399	0	6	2	4	1	1	6	0	0	0	15	0	0	1	0	0	1	0	0	0	0	0	489	460	PL
PT	0	0	0	0	0	0	162	0	0	0	0	0	0	0	0	0	0	0	9	0	0	1	0	0	1	0	0	0	196	196	PT
RO	0	1	0	0	0	12	0	310	11	5	0	0	2	0	0	5	21	0	0	0	1	1	0	0	0	0	0	0	411	354	RO
RS	5	7	0	0	0	10	0	24	279	2	0	0	3	0	0	2	5	0	0	0	0	1	0	0	0	0	0	0	418	89	RS
RU	0	0	0	0	0	1	0	1	0	64	0	0	0	0	0	1	7	0	0	0	0	0	0	0	0	0	0	0	81	5	RU
SE	0	0	0	0	3	4	0	0	0	2	14	0	0	0	0	0	2	0	0	2	0	0	1	0	0	0	0	0	36	28	SE
SI	0	0	0	0	0	7	0	1	2	1	0	222	2	0	0	0	1	0	0	0	0	3	0	0	1	0	0	0	400	390	SI
SK	0	0	0	0	0	54	0	14	7	2	0	2	153	0	0	1	13	0	0	0	0	1	0	0	0	0	0	0	347	318	SK
TJ	0	0	0	0	0	0	0	0	0	1	0	0	0	114	1	1	0	16	0	0	0	0	0	26	0	0	0	0	136	0	TJ
TM	0	0	0	0	0	0	0	0	0	6	0	0	0	2	31	2	2	13	0	0	0	0	0	7	0	0	0	0	64	1	TM
TR	0	0	0	0	0	1	0	1	0	4	0	0	0	0	0	261	5	0	0	0	1	3	0	7	0	0	0	0	280	6	TR
UA	0	0	0	0	0	19	0	18	2	28	0	0	1	0	0	7	283	0	0	0	1	0	0	0	0	0	0	0	392	51	UA
UZ	0	0	0	0	0	0	0	0	0	6	0	0	0	14	7	1	2	82	0	0	0	0	0	3	0	0	0	0	125	1	UZ
ATL	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	8	7	ATL
BAS	0	0	0	1	1	22	0	1	0	7	6	0	0	0	0	0	4	0	0	13	0	0	1	0	0	0	0	0	84	67	BAS
BLS	0	0	0	0	0	4	0	10	1	33	0	0	0	0	0	89	50	0	0	0	13	2	0	1	0	0	0	0	215	23	BLS
MED	0	0	0	0	0	2	1	2	1	2	0	1	0	0	0	22	3	0	1	0	0	39	0	2	10	0	0	0	84	50	MED
NOS	0	0	0	3	3	3	0	0	0	1	0	0	0	0	0	0	1	0	2	1	0	0	16	0	0	0	0	0	59	54	NOS
AST	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1	8	1	1	0	0	0	0	0	214	0	0	0	0	18	1	AST
NOA	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	1	0	2	0	0	6	0	1	44	0	0	0	16	12	NOA
EXC	0	0	0	0	1	10	1	6	2	29	0	0	1	1	1	12	14	3	0	0	0	1	0	2	0	0	0	0	135	54	EXC
EU	0	0	0	2	1	35	4	19	2	2	2	2	3	0	0	1	4	0	1	1	0	2	1	0	1	0	0	0	219	204	EU
	ME	MK	MT	NL	NO	PL	PT	RO	RS	RU	SE	SI	SK	TJ	TM	TR	UA	UZ	ATL	BAS	BLS	MED	NOS	AST	NOA	BIC	DMS	VOL	EXC	EU	

APPENDIX E

Explanatory note on country reports for 2019

The country reports issued by EMEP MSC-W (Klein et al. 2021) focus on chemical species that are relevant to eutrophication, acidification and ground level ozone, but information on particulate matter is given as well. The country reports provide for each country:

- horizontal maps of emissions, and modelled air concentrations and depositions in 2019;
- emission trends for the years 2000 to 2019;
- modelled trends of air concentrations and depositions for the years 2000 to 2019;
- maps and charts on transboundary air pollution in 2019, visualizing the effect of the country on its surroundings, and vice versa;
- frequency analysis of air concentrations and depositions, based on measurements and model results for 2019, along with a statistical analysis of model performance;
- maps on the risk of damage from ozone and particulate matter in 2019.

EMEP MSC-W issues these country reports for 47 Parties to the Convention, and for Tajikistan, Turkmenistan and Uzbekistan. For the Russian Federation the country report includes only the territory which is within the EMEP domain (see Figure 1.1).

All 50 country reports are written in English. However, for the 12 EECCA countries, the reports are made available also in Russian. All country reports can be downloaded in pdf format from the MSC-W report page on the EMEP website:

`https://emep.int/mscw/mscw_publications.html#2021`

This year, the country reports are found under the header 'MSC-W Data Note 1/2021 Individual Country Reports'. The reports for each country can be selected from a drop-down menu.

References

Klein, H., Gauss, M., Tsyro, S., Nyiri, A., and Fagerli, H.: Transboundary air pollution by sulphur, nitrogen, ozone and particulate matter in 2019, Country Reports, Tech. Rep. EMEP MSC-W Note 1/2021 Individual Country Reports, The Norwegian Meteorological Institute, Oslo, Norway, available at www.emep.int/mscw/mscw_publications.html, 2021.

APPENDIX F

Model Evaluation

The EMEP MSC-W model is regularly evaluated against various kinds of measurements, including ground-based, airborne and satellite measurements. As the main application of the model within the LRTAP Convention is to assess the status of air quality on regional scales and to quantify long-range transboundary air pollution, the emphasis of the evaluation performed for the EMEP status reports has traditionally been put on the EMEP measurement sites.

However, a more detailed evaluation against measurements from both the EMEP network and the European Environment Agency's (EEA) Air Quality e-Reporting Database can now be found at the AeroVal webpage that has been developed recently for the evaluation of EMEP MSC-W model output:

`https://aeroval.met.no/evaluation.php?project=emep`

On this page, the user can select the set of measurement data, the station or country of interest, and view a large number of statistical parameters (bias, correlation, root mean square error, etc.). AeroVal is flexible and allows using all available observations, including irregular and non-standard-frequency measurements.
The web interface displays co-located observational and model datasets and contains:

- daily and monthly time series for each station, averaged per country, or the whole area covered by the model and the measurement network (labeled 'WORLD');
- statistics and scatter plots calculated for each station and country;
- an overall evaluation of the results using statistics calculated for each country or the whole area covered by the model and the measurement network (so-called Heatmaps and Taylor Diagrams).

Evaluation is made for O_3, $PM_{2.5}$, PM_{10}, SO_2, SO_4, NO_2, and several other nitrogen-containing species. The different types of visualization (bar charts, line charts, tables, etc.) are available both for viewing and for download.

Table F:1: Comparison of model results and observations for 2019. Annual averages over all EMEP sites with measurements. N_{stat}= number of stations, wd=wet deposition (integrated over the year and stations), cp= concentration in precipitation, Corr. = spatial correlation coefficient, RMSE = root mean square error, IOA = index of agreement. The requirement for being included is that at least 5 sites are available, that measurements be available for 75% of all days in 2019, except for the components marked with $\star$, where observational data covers the whole year of 2019, but with measurements 3-5 times a month. Note: daily (hourly for ozone) EMEP regular observations are used in this evaluation.

Component	N_{stat}	Obs.	Mod.	Bias (%)	RMSE	Corr.	IOA
NO_2 (μg(N) m^{-3})	73	1.56	1.44	-8	0.63	0.87	0.93
SO_2 (μg(S) m^{-3})	56	0.26	0.23	-12	0.22	0.50	0.68
SO_4^{2-}, sea salt corrected (μg(S) m^{-3})	24	0.34	0.18	-47	0.22	0.90	0.67
SO_4^{2-}, including sea salt (μg(S) m^{-3})	28	0.42	0.26	-39	0.22	0.86	0.71
NO_3^- (μg(N) m^{-3})	20	0.27	0.25	-9	0.08	0.90	0.94
HNO_3 (μg(N) m^{-3})	14	0.09	0.08	-18	0.08	0.45	0.57
NO_3^-+HNO_3 (μg(N) m^{-3})	32	0.39	0.40	3	0.09	0.91	0.95
NH_3 (μg(N) m^{-3})	18	0.46	0.56	22	0.29	0.91	0.92
NH_4^+ (μg(N) m^{-3})	24	0.43	0.38	-12	0.17	0.82	0.88
NH_3+NH_4^+ (μg(N) m^{-3})	30	1.22	1.29	6	0.86	0.77	0.83
SO_4^{2-} wd (mg(S)m^{-2})	50	8317	5649	-32	120	0.44	0.61
SO_4^{2-} cp (mg(S)l^{-1})	50	0.29	0.15	-49	0.43	0.51	0.36
NH_4^+ wd (mg(N)m^{-2})	49	11332	13534	19	112	0.90	0.92
NH_4^+ cp (mg(N)l^{-1})	49	0.33	0.36	9	0.17	0.67	0.81
NO_3^- wd (mg(N)m^{-2})	50	9109	9429	4	145	0.60	0.75
NO_3^- cp (mg(N)l^{-1})	50	0.27	0.24	-12	0.40	0.35	0.32
Precipitation (mm)	50	40898	45345	11	262	0.82	0.89
Ozone daily max (ppb)	114	41.75	41.44	-1	2.97	0.79	0.87
Ozone daily mean (ppb)	114	32.63	34.00	4	4.09	0.72	0.80
PM_{10} (μg m^{-3})	31	12.90	11.33	-12	3.65	0.60	0.76
$PM_{2.5}$ (μg m^{-3})	25	8.06	7.05	-13	2.63	0.72	0.82
SO_4^{2-}, including sea salt (μg m^{-3})	28	1.25	0.77	-39	0.65	0.86	0.71
SO_4^{2-}, sea salt corrected (μg m^{-3})	25	0.98	0.53	-46	0.66	0.90	0.68
SO_4^{2-} in PM_{10} (μg m^{-3})	13	1.56	0.97	-38	0.65	0.95	0.85
NO_3^- (μg m^{-3})	20	1.20	1.09	-9	0.36	0.90	0.94
NO_3^- in PM_{10} (μg m^{-3})	13	1.20	1.47	23	0.56	0.63	0.77
NH_4^+ (μg m^{-3})	24	0.55	0.49	-12	0.21	0.82	0.88
Na+ (μg m^{-3})	24	0.92	0.90	-2	0.48	0.89	0.94
Na+ in PM_{10} (μg m^{-3})	6	0.25	0.26	6	0.09	0.15	0.56

To allow for comparison of this year's model performance with earlier evaluation reports, Table F:1 summarizes common statistical measures of model performance, such as bias, root mean square error, temporal and spatial correlations and the index of agreement (see Chapter 1) against EMEP measurement stations within the whole model domain.

emep

Meteorological Synthesizing Centre – West
Norwegian Meteorological Institute
P.O.Box 43 – Blindern, NO-0313 Oslo, Norway

ccc
NILU
Norwegian Institute for Air Research
P.O. Box 100
NO-2027 Kjeller
Norway
Phone: +47 63 89 80 00
Fax: +47 63 89 80 50
E-mail: kjetil.torseth@nilu.no
Internet: www.nilu.no

ciam
International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1
A-2361 Laxenburg
Austria
Phone: +43 2236 807 0
Fax: +43 2236 71 313
E-mail: amann@iiasa.ac.at
Internet: www.iiasa.ac.at

ceip
Umweltbundesamt GmbH
Spittelauer Lände 5
1090 Vienna
Austria
Phone: +43-(0)1-313 04
Fax: +43-(0)1-313 04/5400
E-mail: emep.emissions@umweltbundesamt.at
Internet: http://www.umweltbundesamt.at/

msc-e
Meteorological Synthesizing Centre-East
2nd Roshchinsky proezd, 8/5, room 207
115419 Moscow
Russia
Phone +7 926 906 91 78
Fax: +7 495 956 19 44
E-mail: msce@msceast.org
Internet: www.msceast.org

msc-w
Norwegian Meteorological Institute (MET Norway)
P.O. Box 43 Blindern
NO-0313 OSLO
Norway
Phone: +47 22 96 30 00
Fax: +47 22 96 30 50
E-mail: emep.mscw@met.no
Internet: www.emep.int