MSC-W Data Note 1/2008
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METEOROLOGISK INSTITUTT
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Transboundary air pollution by main pollutants (S, N, O_3) and PM

Luxembourg

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Contents

1 Introduction

This note is one of a series of country-specific reports, complementary to the EMEP Status Report 1/2008. It presents overview information on transboundary pollution of main pollutants, ground level ozone and PM relevant for Luxembourg.

The transboundary contributions presented here are based on source-receptor calculations with the Unified EMEP model using meteorological and emission data for the year 2006. These source-receptor calculations are based on the same version of the Unified EMEP model as presented in the main report (rv 3.0.7).

Emissions The emissions for 2006 have been derived from the 2008 official data submissions to UN-ECE CLRTAP. The gridded distributions of the 2006 emissions have been provided by the EMEP Centre on Emission Inventories and Projections (CEIP). More detailed information on 2006 emission data is provided in the EEA/CEIP Report *'Inventory review 2008 stage1 and stage2 and review of gridded data'*. The emissions for 2005 have been derived by scaling with respect to gridded data distributions in year 2005 (Base 2005 V9). The emissions for 1990-2004 have been derived from the 2005 official data submissions to UN-ECE CLRTAP. The gridded distributions of these emissions have been derived by scaling with respect to gridded data distributions in year 2000 (Base 2000 V7). The gridded emission data are available on `http://www.emep-emissions.at/emission-data-webdab/`.

Trends Trends on depositions and air concentrations are presented for 1990 and from 1995 to 2006. The calculations are based on a consistent series of model runs, all using the same version of the Unified EMEP model (rv 3.0.7). This is an improvement with respect to previous trend calculations, and the use of this new model version explains changes in trends with respect to previous years' reports.

Transboundary data Data are presented in the form of maps, pies and bar-charts. The data are generated by source-receptor calculations, where emissions for each emitter of one or more precursors are reduced by 15%. For oxidised sulphur, oxidised nitrogen and reduced nitrogen, the results have been scaled to present data corresponding to all emissions from an emitter. For other components we choose to present the effect of a 15% reduction, as this is a more correct way of describing chemical non-linearities in atmospheric pollution.

The pie charts for depositions and PM give a picture of the relative contributions of the countries or regions to depositions and concentrations over Luxembourg.

For O_3 and related indicators bar charts are used because in some cases the effect of a reduction of emissions from a country can either increase or decrease O_3 levels elsewhere. The values in the bar charts for ozone indicators show the six most important contributors to AOT40, ozone fluxes and SOMO35 in Luxembourg. Since the contributions can be both positive or negative, the relative importance of the contributors has been determined by comparing the absolute value of the contributions.

To give more intuitive pictures on the effect of pollution from a given country, we use positive scales for pollution reductions throughout this note. Note then that negative values will mean increase of pollution levels.

Comparison with observations The map of monitoring stations shows all stations of Luxembourg in the EMEP measurement network with measurements in 2006 submitted to EMEP. The frequency analysis plots compare 2006 observation results with the model results. The measurement data are available from CCC: `http://www.nilu.no/projects/ccc/emepdata.html`. The table provides annual statistics of the comparison of model results with observations for each measured component.

Risks from ozone and PM The maps with ozone and PM values correspond to regional background levels and they are not representative of local point measurements, where these values can be much higher (i.e. in cities).

NOTE: This year, for the first time, country reports are presented for Kyrgyzstan, Uzbekistan, Turkmenistan and Tajikistan. Since no trends have been calculated for these countries, only 2006 data are presented.
For The Russian Federation and Kazakhstan, trends refer to the area of these countries inside the official EMEP grid. Results for 2006 are also presented for the extended EMEP area, now covering all of Kazakhstan's territory and a larger part of The Russian Federation.

Country Codes

Many tables and graphs in this report make use of codes to denote countries and regions in the EMEP area. Table 1 provides an overview of these codes and lists the countries and regions included in the present 2006 source-receptor calculations.

Code	Country/Region	Code	Country/Region
AL	Albania	IE	Ireland
AM	Armenia	IS	Iceland
ASI	Remaining Asian areas (official)	IT	Italy
AST	Remaining Asian areas (extended)	KG	Kyrgyzstan
AT	Austria	KZ	Kazakhstan (official)
ATL	Remaining N.-E. Atlantic Ocean	KZT	Kazakhstan (extended)
AZ	Azerbaijan	LT	Lithuania
BA	Bosnia and Herzegovina	LU	Luxembourg
BAS	Baltic Sea	LV	Latvia
BLS	Black Sea	MD	Republic of Moldova
BE	Belgium	ME	Montenegro
BG	Bulgaria	MED	Mediterranean Sea
BIC	Boundary and Initial Conditions	MK	The FYR of Macedonia
BY	Belarus	MT	Malta
CH	Switzerland	NL	Netherlands
CY	Cyprus	NO	Norway
CZ	Czech Republic	NOA	North Africa
DE	Germany	NOS	North Sea
DK	Denmark	PL	Poland
EE	Estonia	PT	Portugal
EMC	EMEP land areas (official)	RO	Romania
EXC	EMEP land areas (extended)	RS	Serbia
ES	Spain	RU	Russian Federation (official)
EU	European Community	RUE	Russian Federation (extended)
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

Table 1: Country/region codes used in the source-receptor calculations. ’official’ refers to the area of the country/region which is inside the official EMEP grid, while ’extended’ refers to the area of the country/region inside the extended EMEP grid.

The ’European Community’ includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria and Romania.

2 Definitions, statistics used

The following definitions and acronyms are used throughout this note:

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

PPM denotes primary particulate matter, originating directly from anthropogenic emissions. It is usually distinguished between fine primary particulate matter, $PPM_{2.5}$ with aerosol diameters below 2.5 μm and coarse primary particulate matter, PPM_{co} with aerosol diameters between 2.5μm and 10μm.

$PM_{2.5}$ denotes fine particulate matter, defined as the integrated mass of aerosol with diameter up to 2.5 μm. In the Unified EMEP model $PM_{2.5}$ is calculated as the sum: $PM_{2.5}$ = SO_4^{2-} + NO_3^-(fine) + NH_4^+ + $PPM_{2.5}$

PM_{10} denotes particulate matter, defined as the integrated mass of aerosol with diameter up to 10 μm. In the Unified EMEP model PM_{10} is calculated as the sum: PM_{10} = $PM_{2.5}$ + NO_3^-(coarse) + PPM_{co}

SOMO35 - The Sum of Ozone Means Over 35 ppb is the new 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:

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

where the $\max$ function ensures that only A_8^d values exceeding 35 ppb are included. The corresponding unit is ppb·days (abbreviated also as ppb·d).

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

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

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 for daytime only. The corresponding unit are ppb·hours (abbreviated to ppb·h).

Although the EMEP model now generates a number of AOT-related outputs, these country reports present results for two "practical" definitions:

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

AOT40$_c^{\mathbf{uc}}$ - 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 the UNECE Mapping Manual, but using a default growing season of May-July, and a default crop-height of 1 m.

AFstY - the accumulated stomatal ozone flux over a threshold Y nmol m^{-2} s^{-1}, i.e.:

$$\text{AFstY}_{gen} = \int \max(F_{st} - Y, 0)\, dt \tag{1}$$

where stomatal flux F_{st}, and threshold, Y, are in nmol m^{-2} s^{-1}, and the `max` function evaluates $\max(A - B, 0)$ to $A - B$ for $A > B$, or zero if $A \leq B$. 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* is applied, e.g. $\text{AF}_{\text{st}}1.6_{\text{gen-DF}}$ is used for deciduous forests.

3 Emissions

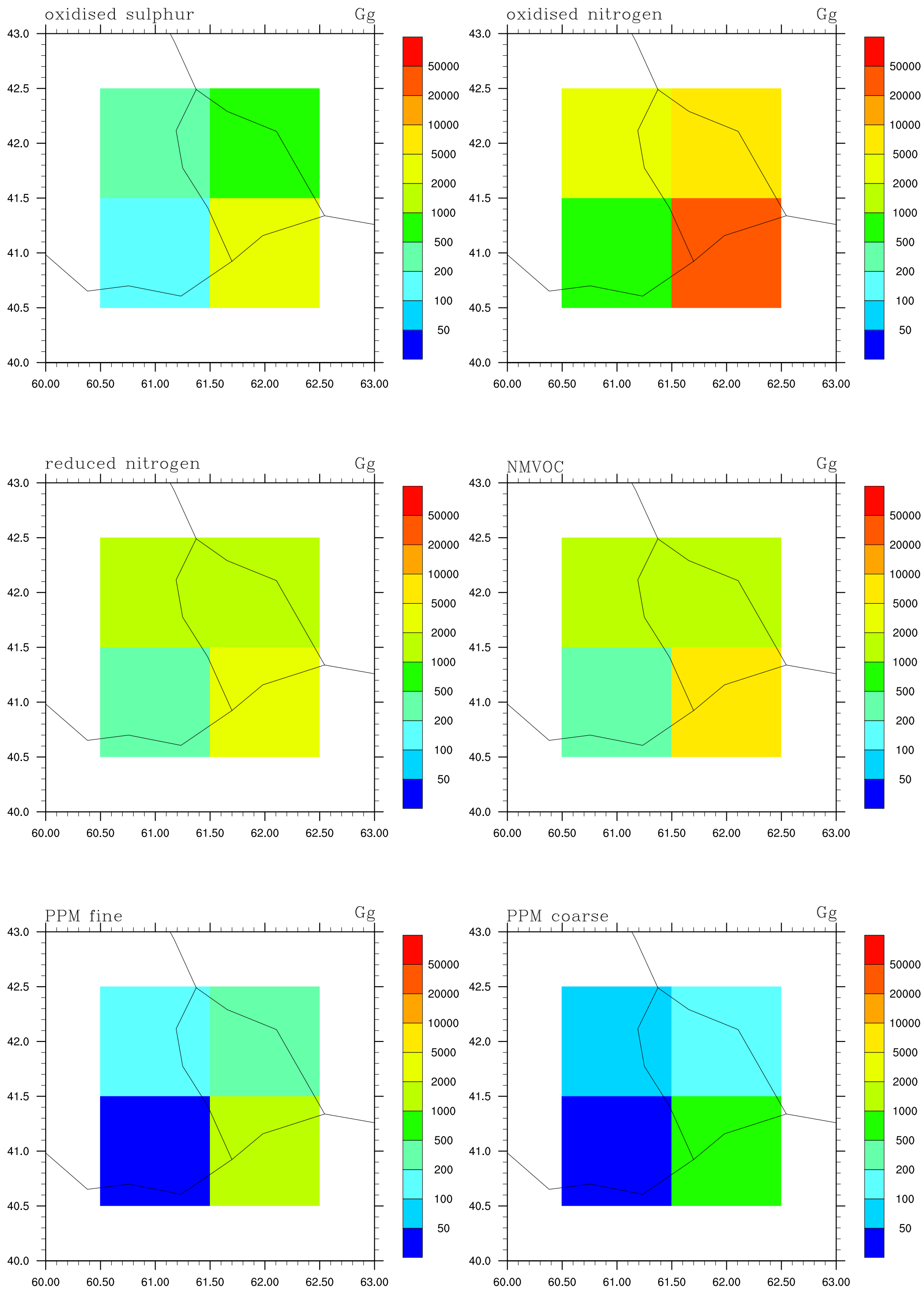

Figure 1: Spatial distribution of emissions from Luxembourg in 2006.

4 Trends

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
SO_x	26	7	7	6	6	5	4	4	4	4	4	4	4
NO_x	20	32	33	33	33	33	33	32	31	30	29	29	28
NH_3	7	7	7	7	7	7	7	7	7	7	7	7	7
NMVOC	16	22	20	18	17	15	13	12	11	11	10	10	9
CO	61	57	55	54	53	50	49	49	48	48	48	48	48
$PM_{2.5}$							3	3	3	3	3	3	2
PM_{10}							4	4	4	4	4	4	3

Table 2: Emissions from Luxembourg. Units: Gg.

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
S dep.	11	6	5	5	4	4	3	3	3	3	3	3	2
oxN dep.	3	3	3	2	2	2	2	2	2	2	2	2	2
redN dep.	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 3: Estimated deposition of Sulphur(S) and Nitrogen(N) in Luxembourg. Units: Gg(S) or Gg(N).

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
mean ozone	31	31	30	30	31	31	31	30	32	32	30	31	33
max ozone	44	43	41	41	42	42	42	40	42	43	41	42	44
$AOT40_f^{uc}$	29099	27656	20179	25527	18574	21192	20805	16886	21429	25572	17314	17282	23814
SOMO35	3953	3898	3183	3405	2950	3136	3099	2622	3206	3633	2794	2905	3474
$AF_{st}1.6_{gen\text{-}DF}$	29	27	26	30	25	29	27	25	28	26	25	24	26
$PM_{2.5}$ anthrop.							8	7	8	10	8	8	9
PM_{10} anthrop.							8	8	9	10	9	9	10

Table 4: Estimated yearly mean values of air quality indicators averaged over Luxembourg. Units: daily mean ozone (ppb), daily max ozone (ppb), $AOT40_f^{uc}$(ppb·h) SOMO35 (ppb·d), $AF_{st}1.6_{gen\text{-}DF}$ (mmol/m2); and $PM_{2.5}$ ($\mu g/m^3$) and PM_{10} ($\mu g/m^3$) from anthropogenic sources in the model.

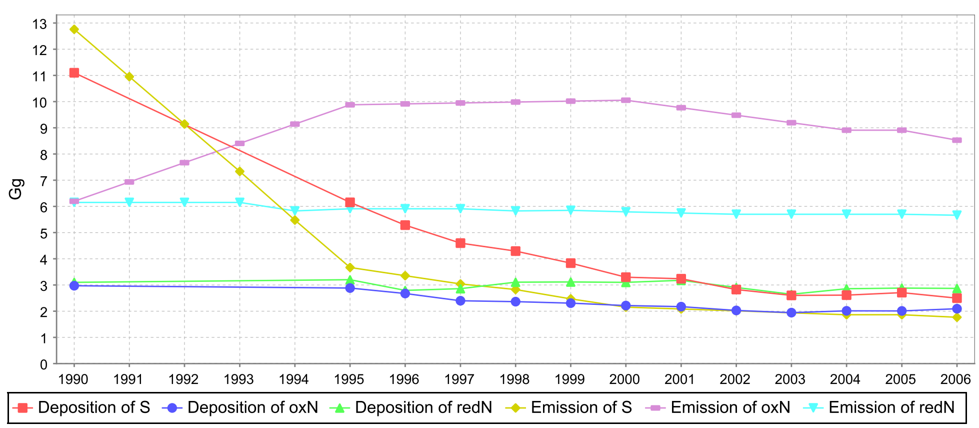

Figure 2: Trends in emissions and depositions of oxidised sulphur, oxidised nitrogen and reduced nitrogen. Units: Gg(S) or Gg(N).

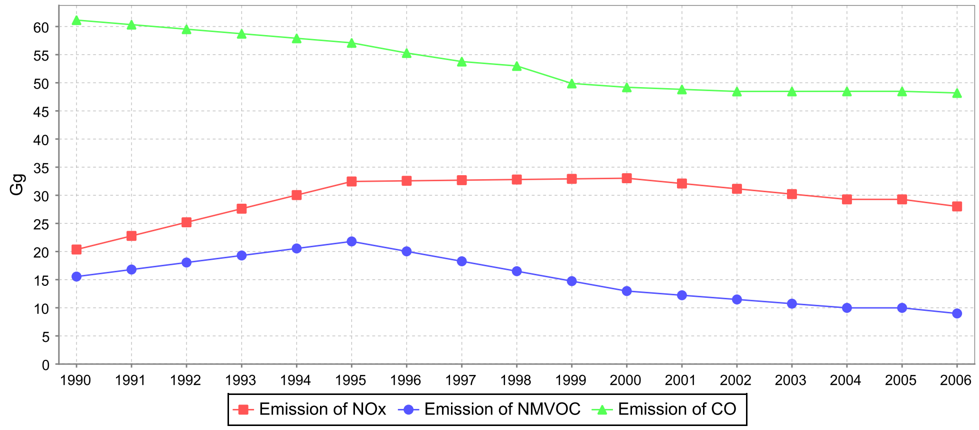

Figure 3: Trends in emissions of photo-oxidant pollution precursors. Units: Gg (note that NO_x is here as NO_2).

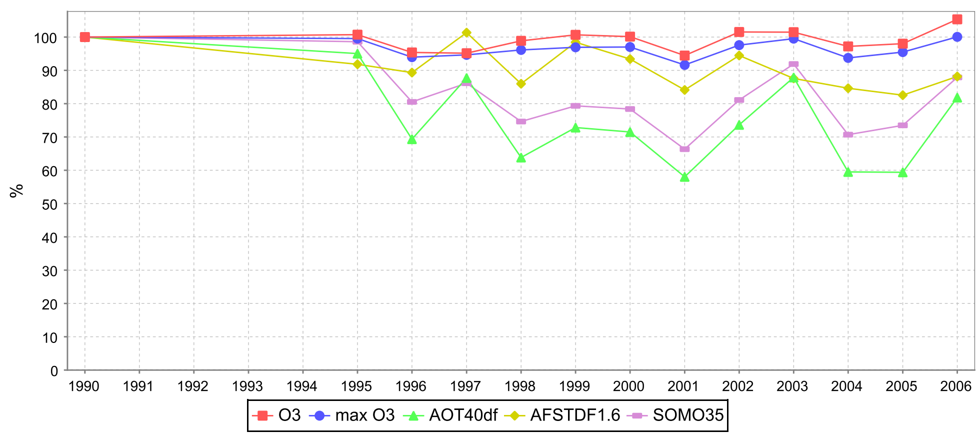

Figure 4: Changes in ozone related pollution relative to 1990. Units: %.

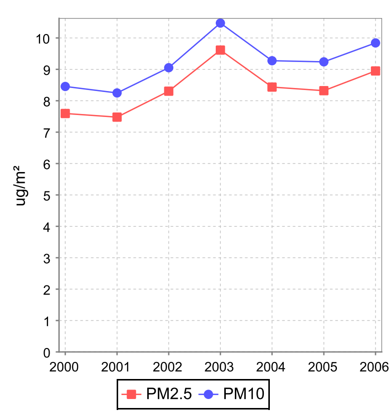

Figure 5: Trends in mean concentrations of particulates since 2000. Units: $\mu g/m^3$.

5 Transboundary fluxes in 2006

5.1 Oxidised sulphur deposition

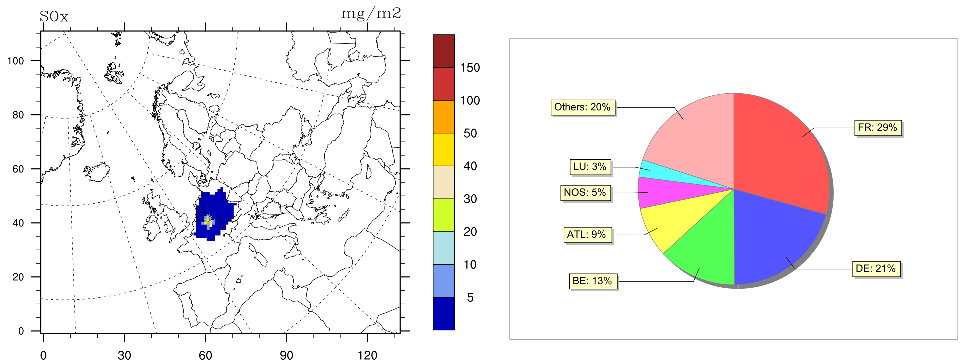

Figure 6: Contribution of emissions from Luxembourg to oxidised sulphur deposition in the EMEP domain. Units: mg(S)/m^2. The pie chart shows the six main receptor areas of oxidised sulphur deposition from Luxembourg. Units: (%).

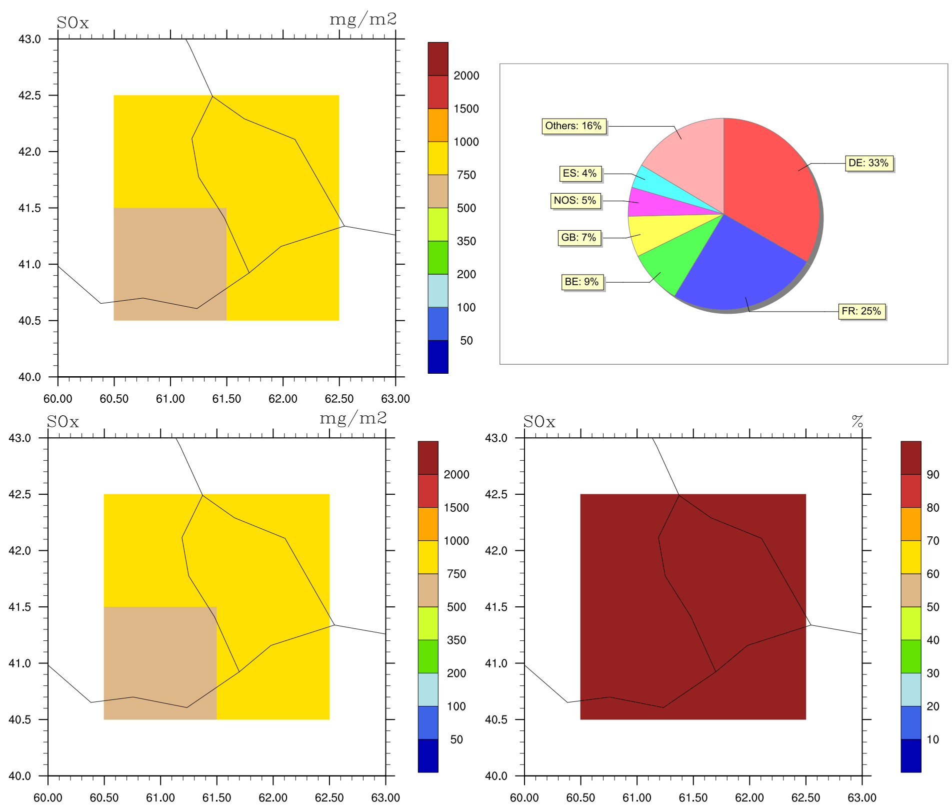

Figure 7: Oxidised sulphur deposition in Luxembourg (top left figure). Units: mg(S)/m^2. The pie chart shows the six main contributors to oxidised sulphur deposition in Luxembourg. Units: (%). Oxidised sulphur deposition from transboundary sources (lower left). Units: (mg(S)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

5.2 Oxidised nitrogen deposition

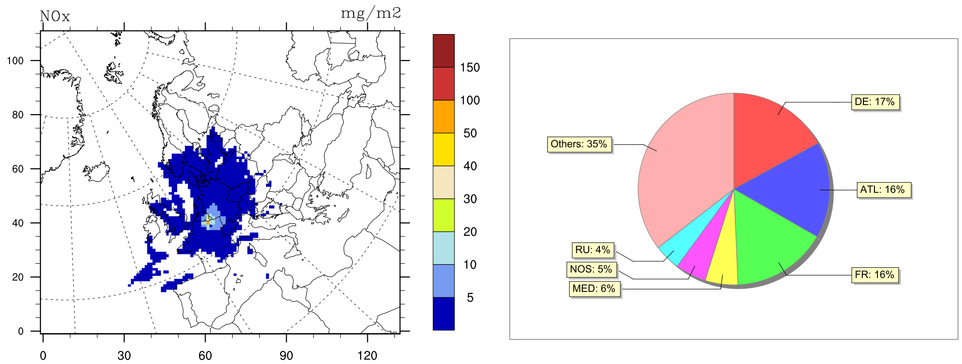

Figure 8: Contribution of emissions from Luxembourg to oxidised nitrogen deposition in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of oxidised nitrogen deposition from Luxembourg. Units: (%).

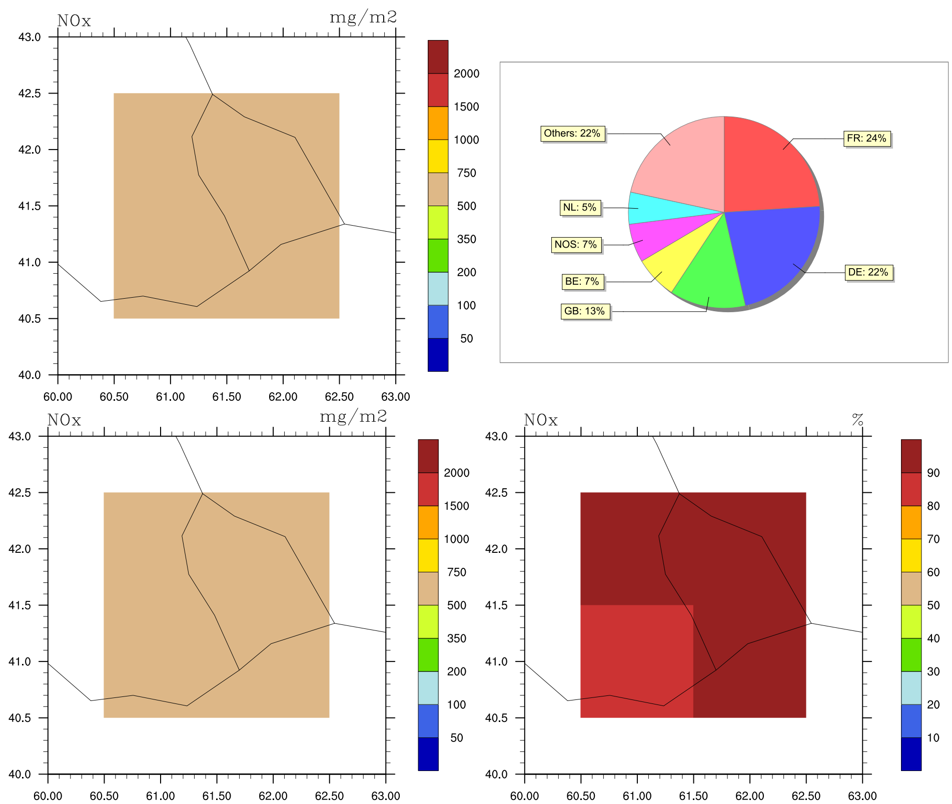

Figure 9: Oxidised nitrogen deposition in Luxembourg (top left figure). Units: mg(N)/m^2. The pie chart shows the six main contributors to oxidised nitrogen deposition in Luxembourg. Units: (%). Oxidised nitrogen deposition from transboundary sources (lower left). Units: (mg(N)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

5.3 Reduced nitrogen deposition

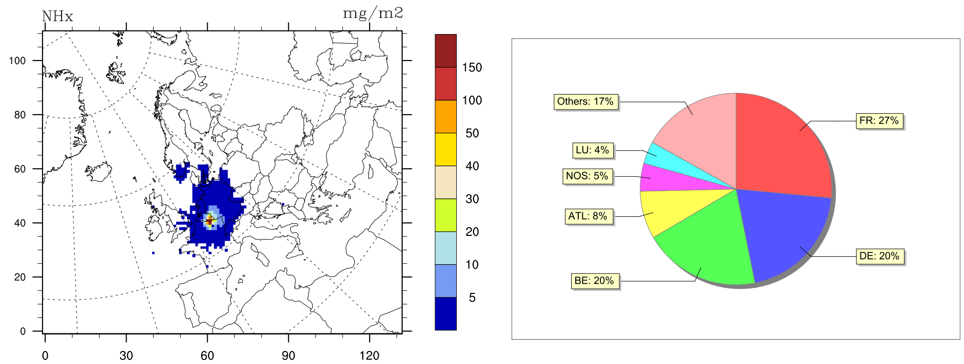

Figure 10: Contribution of emissions from Luxembourg to reduced nitrogen deposition in the EMEP domain. Units: mg(N)/m^2. The pie chart shows the six main receptor areas of reduced nitrogen deposition from Luxembourg. Units: (%).

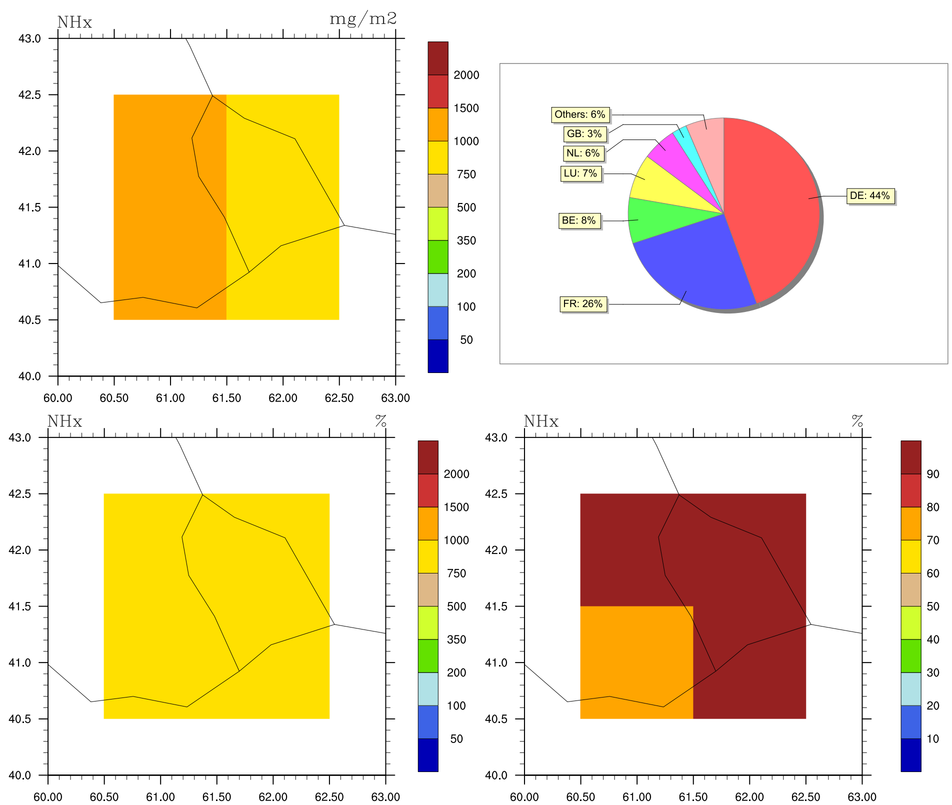

Figure 11: Reduced nitrogen deposition in Luxembourg (top left figure). Units: mg(N)/m^2. The pie chart shows the six main contributors to reduced nitrogen deposition in Luxembourg. Units: (%). Reduced nitrogen deposition from transboundary sources (lower left). Units: (mg(N)/m^2). Fraction from transboundary contribution to total deposition (lower right). Units: (%)

6 Transboundary ozone concentrations

6.1 AOT40$_f^{uc}$

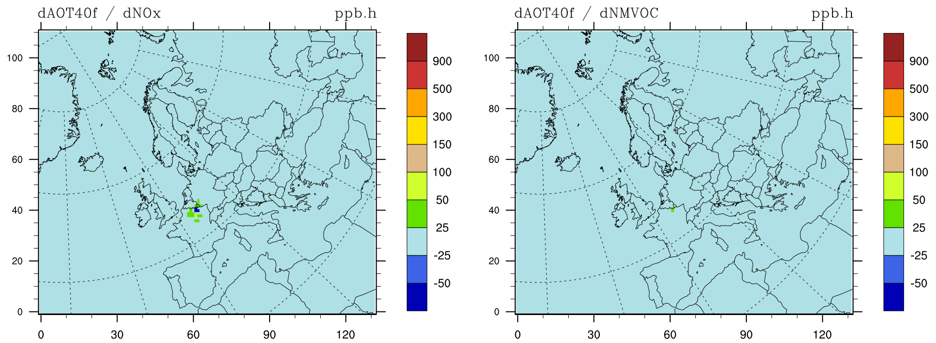

Figure 12: Reduction in AOT40$_f^{uc}$ due to 15% reduction in NO_x(left) and NMVOC (right) emissions from Luxembourg. Units: ppb·h

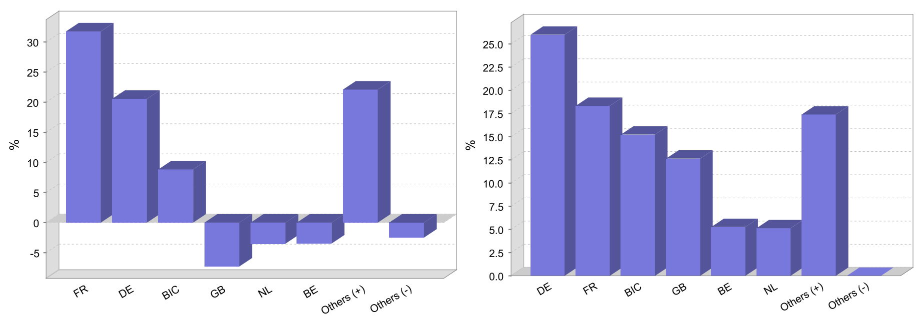

Figure 13: Six most important contributors to AOT40$_f^{uc}$ in Luxembourg by NO_x(left) and NMVOC (right) emission changes (15% reduction). Units: (%)

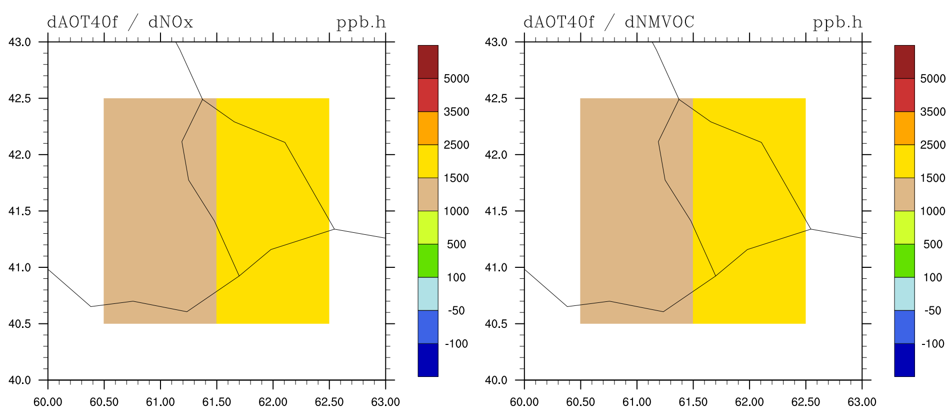

Figure 14: Reduction in AOT40$_f^{uc}$ due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·h

6.2 $AF_{st}1.6_{gen\text{-}DF}$ – Ozone fluxes to deciduous forests

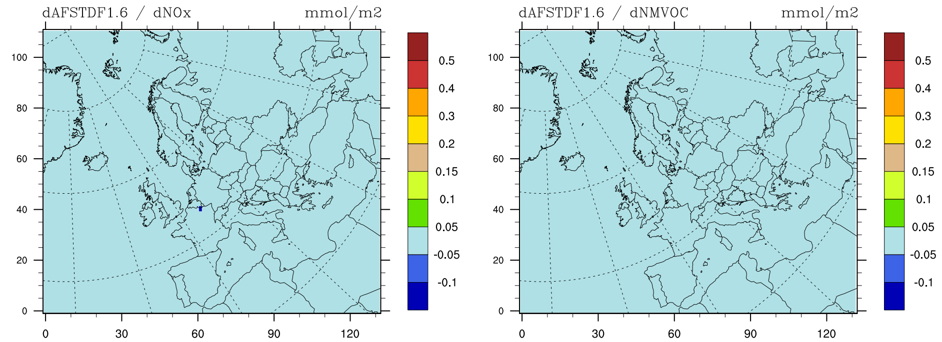

Figure 15: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to 15% reduction in NO_x(left) and NMVOC (right) emissions from Luxembourg. Units: mmol/m^2

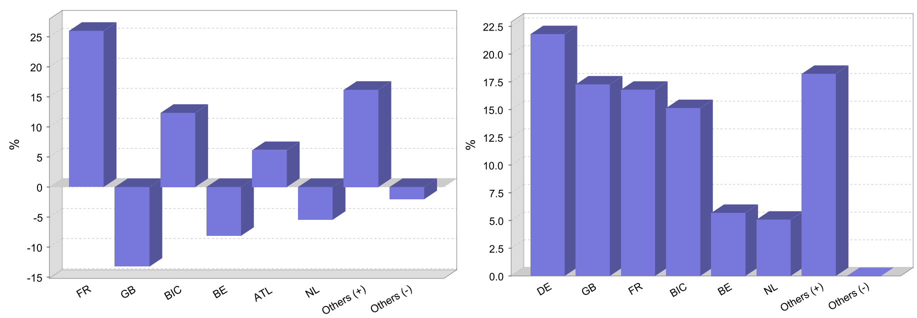

Figure 16: Six most important contributors to $AF_{st}1.6_{gen\text{-}DF}$ in Luxembourg by NO_x(left) and NMVOC (right) emissions (15% reduction)

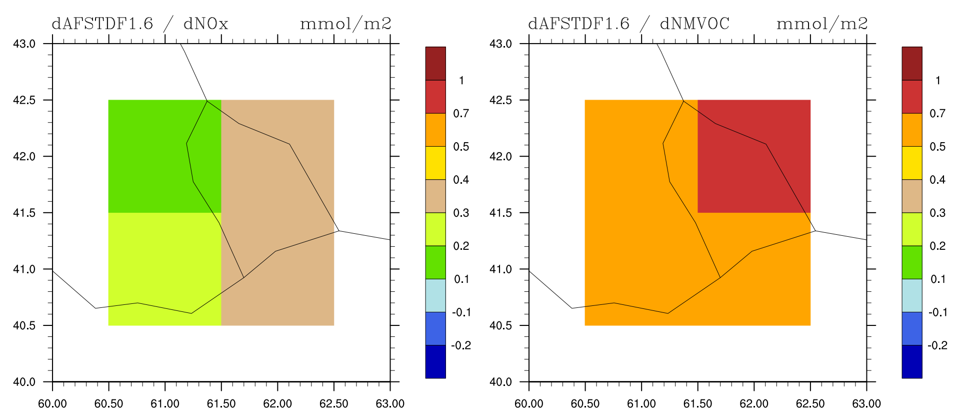

Figure 17: Reduction in $AF_{st}1.6_{gen\text{-}DF}$ due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: mmol/m^2

6.3 SOMO35 – Risk of ozone damages in human health

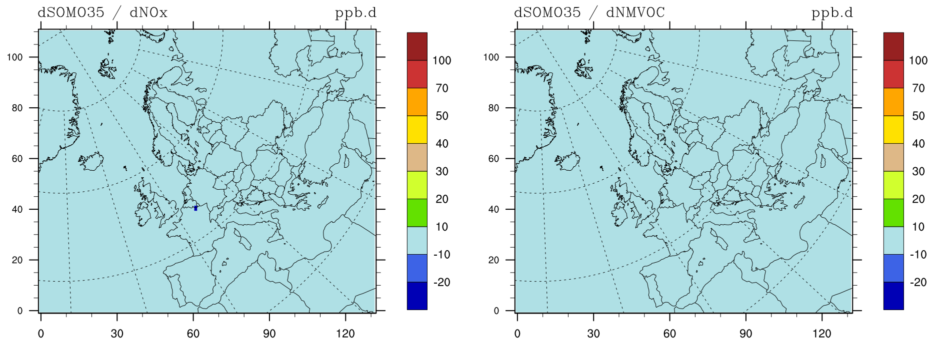

Figure 18: Reduction in SOMO35 due to 15% reduction in NO_x(left) and NMVOC (right) emissions from Luxembourg. Units: ppb·day

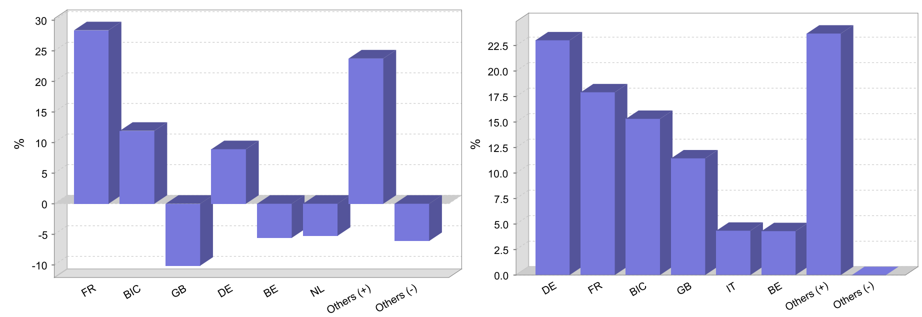

Figure 19: Six most important contributors to SOMO35 in Luxembourg by NO_x(left) and NMVOC (right) emissions (15% reduction)

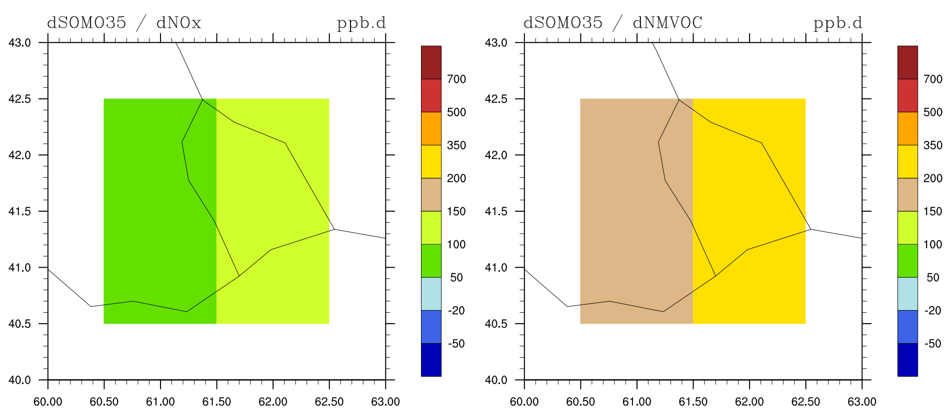

Figure 20: Reduction in SOMO35 due to 15% reduction in NO_x (left) and NMVOC emissions (right) from transboundary sources. Units: ppb·day

7 Transboundary concentrations of particulate matter

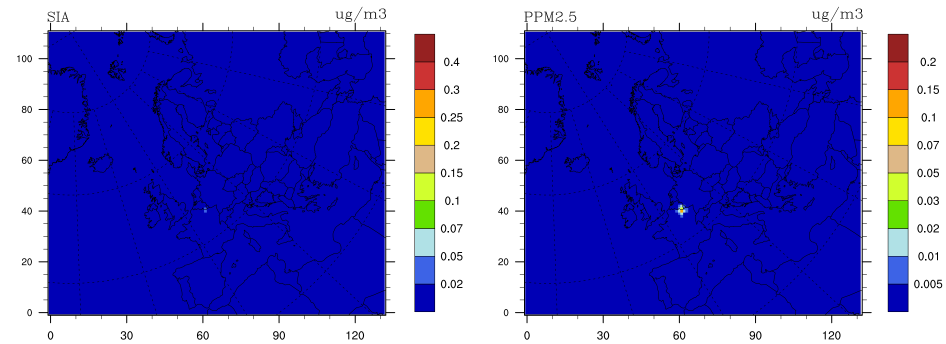

Figure 21: Reduction in SIA and PPM2.5 concentrations due to 15% emission reduction from Luxembourg. Units: μg/m^3. Note the difference in scales.

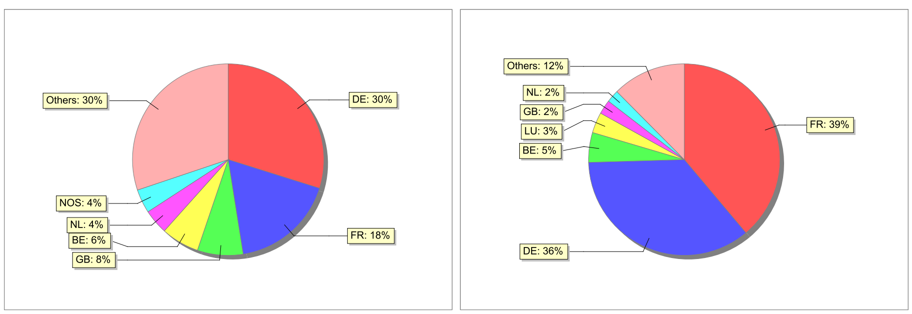

Figure 22: Main contributors to SIA (left) and PPM2.5 (right) concentrations in Luxembourg. Units: (%)

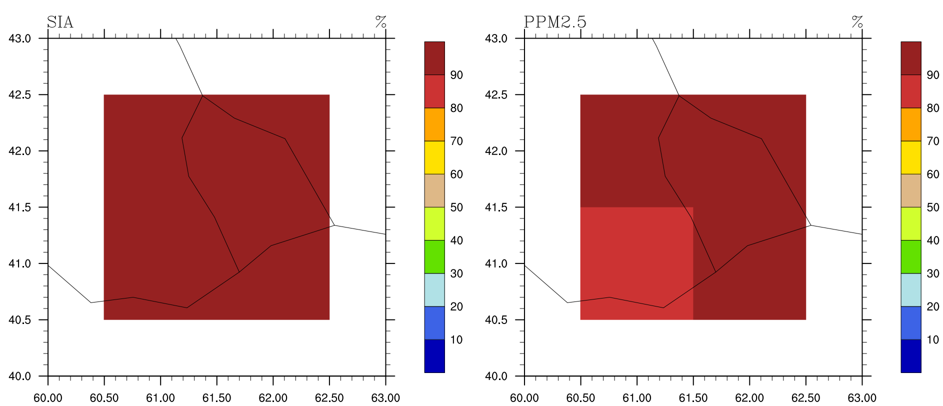

Figure 23: Reduction in SIA and PPM2.5 concentrations in Luxembourg due to 15% emission reductions from transboundary sources. Units: (%)

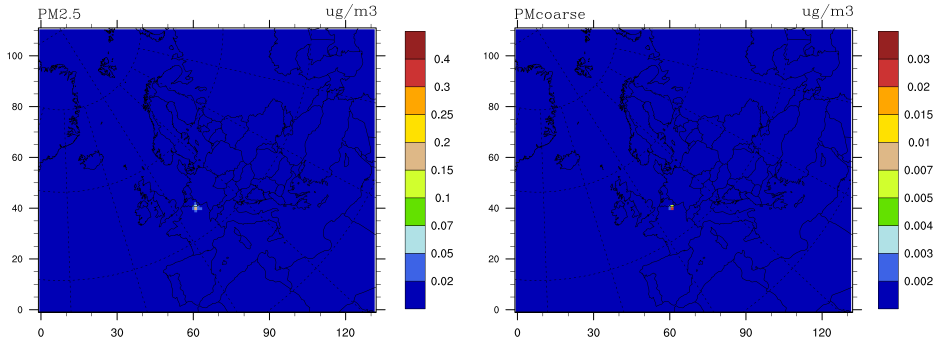

Figure 24: Reduction in PM2.5 and PMcoarse concentrations due to 15% emission reduction from Luxembourg. Units: μg/m^3. Note the difference in scales.

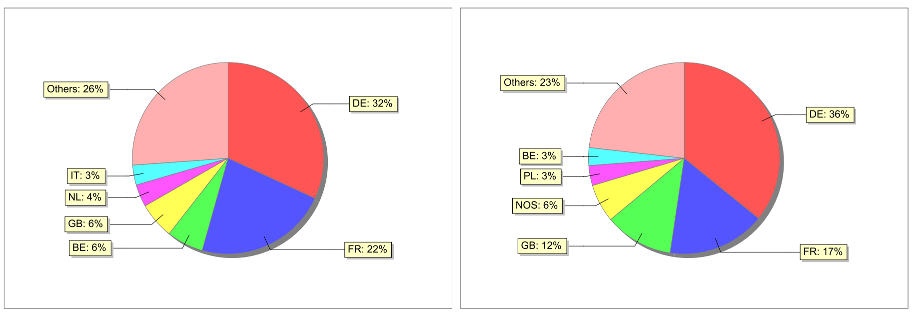

Figure 25: Main contributors to PM2.5 (left) and PMcoarse (right) concentrations in Luxembourg. Units: (%)

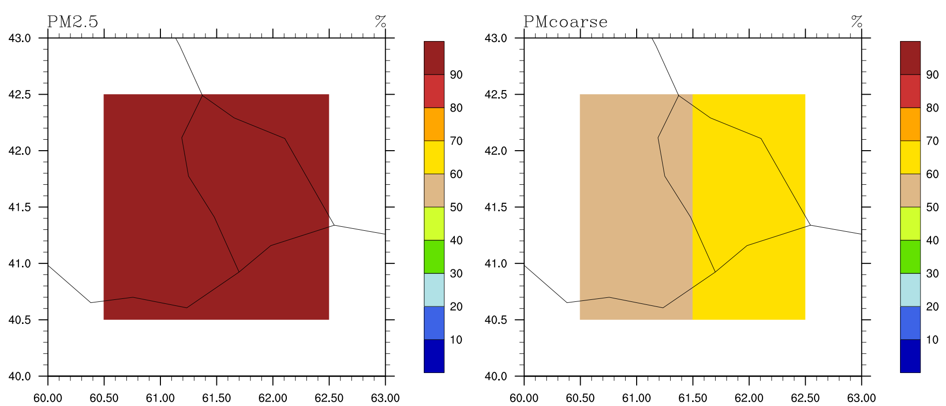

Figure 26: Reduction in PM2.5 and PMcoarse concentrations in Luxembourg due to 15% emission reductions from transboundary sources. Units: (%)

8 Comparison with observations

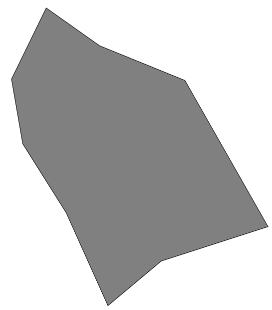

Figure 27: Location of stations in Luxembourg – No stations available

A sufficiently consistent set of daily ozone observations in LU for 2006 is not available for this analysis.

Figure 28: Frequency analysis of ozone in Luxembourg at the stations that reported O_3 in 2006 (Model, Observations)

A sufficiently consistent set of daily wet deposition observations in LU for 2006 is not available for this analysis.

Figure 29: Frequency analysis of depositions in precipitation in Luxembourg (Model, Observations)

A sufficiently consistent set of daily air concentration observations in LU for 2006 is not available for this analysis.

Figure 30: Frequency analysis of air concentrations in Luxembourg (Model, Observations)

Component	No.	Bias	Correlation	RMSE
SO2 in Air	0			
Sulfate in Air	0			
NO2 in Air	0			
Total Nitrate in Air	0			
NH3+NH4+ in Air	0			
Ozone daily max	0			
Ozone daily mean	0			
SO4 wet dep.	0			
Nitrate wet dep.	0			
Ammonium wet dep.	0			
Precipitation	0			

Table 5: Annual statistics of comparison of model results with observations in Luxembourg for stations with data available in weekly or higher time-resolution. Standard deviations provide variability ranges between stations.

9 Risk of damage from ozone and PM in Luxembourg in 2006

9.1 Ecosystem-specific AOT40 values

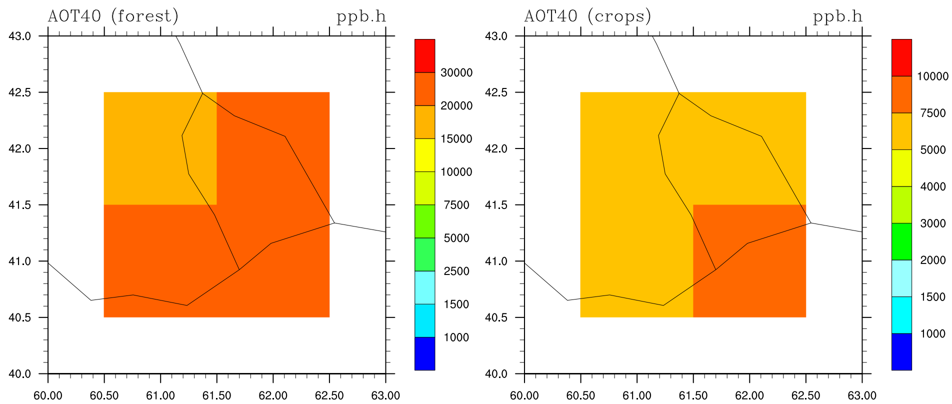

Figure 31: $AOT40_f^{uc}$ and $AOT40_c^{uc}$ in Luxembourg in 2006.

$AOT40_f^{uc}$(growing season: April-September): The critical level for forest damage is 5000 ppb·h.

$AOT40_c^{uc}$(growing season: May-July): The critical level for agricultural crops is 3000 ppb·h.

9.2 Ecosystem-specific ozone fluxes

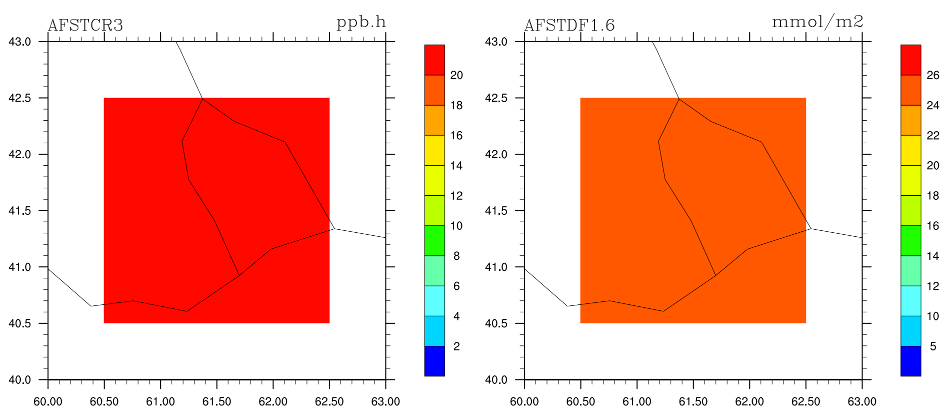

Figure 32: $AF_{st}3_{\text{gen-CR}}$ and $AF_{st}1.6_{\text{gen-DF}}$ in Luxembourg in 2006.

9.3 Health impacts from ozone and PM

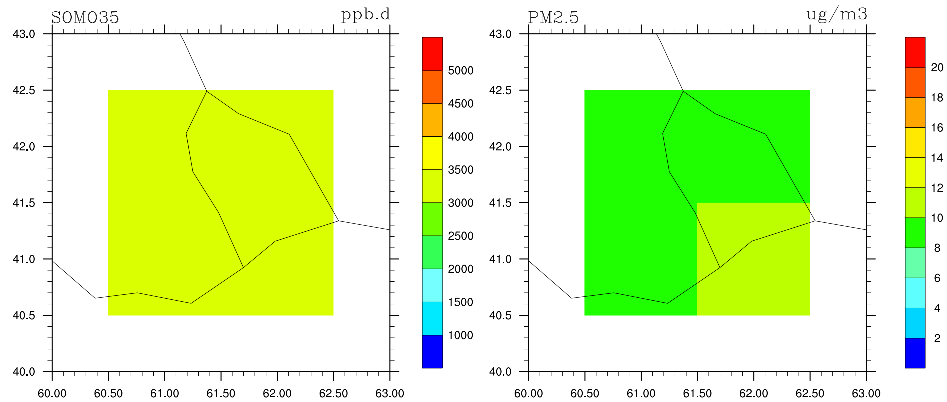

Figure 33: Regional scale SOMO35 and $PM_{2.5}$ in Luxembourg in 2006.