JRC Scientific and Technical Reports

EURODELTA: Evaluation of a sectoral Approach to Integrated Assessment Modelling – Second report

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EUR 24474 EN - 2010

JRC
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JRC59501

EUR 24474 EN
ISBN 978-92-79-16357-9
ISSN 1018-5593
doi:10.2788/40803

Luxembourg: Publications Office of the European Union

Printed in Italy

Acknowledgements

The Norwegian Meteorological Institute
The Institute for Meteorology of the Berlin Free University,
The Swedish Meteorological and Hydrological Institute,
TNO Built Environmet and Geosciences

would like to acknowledge financial support from CONCAWE (The Oil Companies' European Organization for Environment, Health and Safety), INERIS was funded by the French Ministry in charge of Ecology (MEEDAT).

Executive Summary

The EURODELTA II (ED II) project is a continuing collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) and five air quality modeling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden) in which the results from air quality model simulations are brought together in the JRC assessment toolkit and compared with each other and against data.

The second phase of Eurodelta (ED II) investigated how different models would represent the effect on pollutant impacts of applying, on a European scale, emission reductions to individual emission sectors. The reason for doing this was to test whether there are important sensitivities not captured by the sound science approach to air quality policy making on a European scale which is based on an integrated assessment (IA) approach and embodied in the IIASA RAINS/GAINS model.

The IA methodology is fundamentally based on a model of economic activity (power generation, industrial manufacture, transport, agriculture etc.) that gives rise to present, and by means of a scenario approach, future emissions. In RAINS mode abatement technology can be applied to reduce emissions and each abatement possibility has a cost, an effectiveness and a market penetration. To explore how future emissions may be reduced on a national scale and deliver targeted improvements in environmental quality these abatement possibilities are chosen in the most cost effective way, i.e. an optimum mix of controls is sought. In the GAINS mode this optimization can also include structural changes such as a change in fuel use that have to be treated as exogenous inputs when in RAINS mode.

As a consequence of this process the final assessment of a viable national emission ceiling implicitly contains a distribution of sectoral burdens. These, when disaggregated, will identify, out of all the emission reductions if it is possible to make, those which are least costly and thus “best” candidates for control. Such considerations should guide the making of enabling legislation, such as the large combustion plant directive (LCPD).

An essential part of the IA process is linking the effect of the emission reductions to pollutant impacts in such as way as to realize environmental improvement goals The pollutant impacts considered in current policy, for example as defined by the EU Thematic Strategy on Air Pollution and also in the revision of the Gothenburg Protocol, are manifold. They divide into:

- Damages to ecosystems, crops and forestry by acid deposition, eutrophication and ozone;
- Damages to human health (including both mortality and morbidity) through exposure to ozone and fine particle concentrations.

The IA process uses a source-receptor relationship (SRR) approach to relate emissions to their environmental and health impacts. The SRRs provide a country to grid mapping whereby the change in a national emission results in a calculated change in concentration and deposition at every grid square (50 x 50 km) in the model domain. The impact end-points for each square can then be calculated using indicators of risk to ecosystems and health developed by the environmental effects and health communities.

The relationships (SRR) presently used in Integrated Assessment are developed from a set of scenario calculations made with the EMEP air quality model. The model uses an emission inventory that is geographically accurate at model scale and so the distribution of base-case emissions is well represented as are the base impacts[1]. The SRR are developed by changing the national emissions from the base case and calculating the response in air concentrations and depositions. The change is applied to the emissions in each grid cell and is distributed over all the emission sources in proportion to their contribution.

As described above, it is highly unlikely that the cost optimization approach used in the IA process would distribute emission reductions in such an even manner across sectors. It is much more likely that the sectoral burdens will be different. This would mean that, in a future world, the emission reductions will take place with a different geographic pattern to that assumed in the IAM optimization process. This could lead in a policy context to a distorted view of sectoral emission contributions to environmental burdens and, in the worse case, formulation of policy that does not deliver intended benefits.

ED II therefore was set out to take a first look at whether there are differences in the size of effect of emission reductions applied to specific sectors compared to the case where they are applied across all sectors. As such ED II aims to assess whether introducing sectoral source receptor relationships into integrated assessment methodology would lead to significant gains in cost efficiency and deliver environmental improvements closer aligned with the policy targets.

In a first report (Thunis et al. 2008) sectoral emission reduction scenarios have been performed in four countries: France, Germany, Spain and UK and compared to the traditional approach in which emission reductions are proportionally distributed across sectors. The generality of the conclusions reached in this first report are tested here by extending the application of the emission reductions to new countries and regions: Italy, Northern Italy, Benelux and Poland. In total these 7 countries (and 1 region) account for 75% of the total EU-27 population.

Results from all of the models were collated and presented in a computer tool, the ED toolkit, developed and operated by the European Commission Joint Research Centre at Ispra (JRC). The toolkit allows detailed comparison (visual and numerical) of model results on a common grid basis.

It is not practical to present the full country-to-grid mapped source receptor relationship in a written report[2]. Therefore we have focused on aggregate measures representing the net country-to-self and the net country-to-domain mappings. The latter represents the main European policy target of ensuring that national emission ceilings are chosen to the overall benefit of the European Community. The former

[1] The EMEP model generates concentrations and deposition rates. Damage functions are subsequently applied to calculate effects on crops, ecosystems and health and these calculations constitute an additional step.
[2] The toolkit and all detailed results are available on request.

represents, for these countries, the largest impact and, for the country itself, the most useful information on the efficacy of the sectoral controls it might choose to enforce. Because the policy metric is a function of the concentration/deposition in each cell and might be an environmental or a human health impact we have represented results on both a population weighted and on a area-weighted basis to see if the receptor distribution affects the results. We have, for reasons of practicality, not been able to go further and include an urban uplift[3] to concentrations to account for city conditions (which would likely enhance sector 2 and sector 7 contributions) or to incorporate the detailed land-use and critical load databases to provide quantified acidification and eutrophication results.

The results are expressed as a response to a change in emission and so an effectiveness (pollutant reduction per kilo-ton of pollutant abated) measure is derived. The expression "emission potency" is also used to describe differences in effectiveness. Thus if one of two reduction measures is said to have a greater potency the effectiveness is higher.

A key finding of the study is the high level of agreement between models across all the scenarios studied regarding the effectiveness of sectoral reductions. This consistency in results is encouraging as it is strong evidence that the conclusions of this report are robust.

In the findings below the "ALL" scenario refers to the case where emissions are reduced proportionately across all sectors. This is the current policy modeling assumption.

Regarding particulate matter concentrations:

- All the models agree that there are differences in effectiveness of emission reductions between sectors. This is broadly consistent with a physical interpretation that the more effective reductions are for sectors where proximity of emission to people is greatest. Thus, higher effectiveness is seen from sectors emitting at low level and distributed according to population and lower effectiveness is seen for sectors emitting from large point sources as these are fewer in number, emissions are released from great height (taking plume rise into account) and generally the association with populated areas is smaller. Note that NHx is also contributing to PM2.5; but we did not investigate the sectoral efficiency since it is almost only emitted from agriculture

- The differences between sectors is greater for population weighted compared with non-weighted concentrations.

- The above is true whether the impact is assessed EU wide or in the country in which the emission control takes place.

[3] The "CityDelta" correction of regional model results used in CAFE is currently being improved as part of the EC4MACS project.

- All models show that the ‘ALL’ scenario gives a significantly different effectiveness to the sectoral effectiveness and this applies to all the pollutants contributing to PM2.5 concentrations (NOx, SOx, PPM2.5).

- The sectoral response is not the same in all countries and is different for each pollutant and in particular the potency of ammonia emissions as they affect PM2.5 is much larger (by a factor of two) in the UK and the Benelux than for other countries.

- A full sectoral analysis would be beyond the means of current policy tools. Scenarios have therefore been carried out to see if simplifications can be made. In these, sectors have been grouped according to a low/high classification of their release height in the atmosphere. These low and high sector group scenarios are found to accurately represent the average behavior of the individual sectors within these groups and would therefore represent one alternative to generating SR relationships for each individual sector

These results can be quantified by looking at the ratio of sector effectiveness to the ‘ALL’ scenario effectiveness for PM2.5 concentrations. The table below provides an overview of these ratio effectiveness averaged both on models and countries. A value of 1 indicates parity with the current policy approach. A value less than 1 means that the current policy approach is over-estimating gains of emission controls and a value greater than 1 means the current policy approach underestimates gains.

PM2.5			SNAP Sectors					
			1	2	3	4	7	8
Area-W	Country	PPM2.5	0.29	0.96	0.37	0.96	1.31	
		SO2	0.77	1.30	0.70			1.25
		Nox	0.63	0.80	0.71		1.23	
	EU-all	PPM2.5	0.42	0.98	0.47	0.95	1.18	
		SO2	0.94	1.05	0.80			1.10
		Nox	0.79	0.89	0.84		1.10	
Popul-W	Country	PPM2.5	0.25	1.04	0.33	0.92	1.45	
		SO2	0.72	1.28	0.67			1.39
		Nox	0.61	0.69	0.69		1.28	
	EU-all	PPM2.5	0.37	1.04	0.44	0.95	1.33	
		SO2	0.88	1.02	0.77			1.20
		Nox	0.76	0.75	0.82		1.15	

Table 1: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the ‘ALL’ scenario effectiveness) for PM2.5 concentrations. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (PPM2.5, NOx and VOC).

Regarding ozone (as measured by SOMO35)

- There are considerable country differences in the response of SOMO35 to NOx reductions, especially in the sectors 1 and 3 which mostly correspond to point source emissions. Sector 1 controls in France and sector 2 controls in all countries considered in the scenarios (Italy, Po-Valley, Benelux and Poland) have less effect than the 'ALL' scenario. Large model variability is seen especially for controls in Sector 1 and 3, possibly indicating sensitivity to how models describe the vertical structure of the atmosphere and implement these high emitting sources. In the Benelux and in the UK SOMO35 is predicted to increase rather than decrease with NOx reductions. Unfortunately it is not possible to fully assess the response of the grouped scenarios since not all of the individual sectoral scenarios comprising the group were performed for ozone.

- There are considerable model differences in the response of SOMO35 to VOC reductions for all sectors and countries considered. VOC emission reductions in the traffic sector are more effective in Spain (only country considered for this traffic scenario) whereas reductions in sector 4 are generally less effective than the "ALL" scenario for all countries.

The table below provides an overview of the ratio effectiveness (Sectoral/ALL) averaged both on models and countries.

SOMO35			Sectors					
			1	2	3	4	6	7
Area-W	Country	NOx	0.82	0.45	1.01			1.15
		VOC				0.42	1.00	1.27
	EU-all	NOx	0.84	0.55	1.13			1.06
		VOC				0.18	0.83	1.08
Popul-W	Country	NOx	0.67	0.33	0.84			1.25
		VOC				0.28	1.00	1.56
	EU-all	NOx	0.14	0.45	0.89			1.21
		VOC				0.25	1.07	1.38

Table 2: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the 'ALL' scenario effectiveness) for SOMO35. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (NOx and VOC).

Regarding deposition:

- Differences in sectoral efficiency were more varied for the deposition of oxidized Sulphur than for oxidized Nitrogen. The previous work found little difference.

- Deposition of nitrogen in the country of emission change was generally less than that of Sulphur indicating greater transboundary transport of Nitrates. The amount of Sulphur and Nitrate retained on land in the whole domain was generally about twice that retained in the country of emission. If retention in the entire domain

(EU-all) was considered, only about half of the change in Nitrogen and Sulphur emission is accounted for by deposition to land within the domain.

- For Sulphur, all models predicted that emission reductions in sectors 1 and 3 were less effective in changing deposition than the ALL scenario. For Nitrogen, this was the case for sectors 1, 2 and 3. Emissions reductions in sector 7 were generally more effective than the 'ALL' scenario both for Nitrogen and Sulphur. This is consistent with a longer range transport of emissions from large point sources that characterize sector 1 and part of sector 3.

- Sectoral differences were less marked when looking at the whole domain than when looking at individual country results.

- Reduced nitrogen deposition is dominated by the agriculture sector and so no comparison with other sectors is possible. Dispersion was of much shorter range than for oxidized nitrogen and Sulphur with much more retained in the domain.

- A useful extension of this work would be to include information on detailed ecosystem impacts (critical loads, forest, crops and ecosystem locations) as weighting factors for the deposition calculations.

The table below provides an overview of the ratio effectiveness (Sectoral/ALL) averaged both on models and countries.

Deposition			Sectors				
			1	2	3	7	8
Area-W	Country	Nox	0.66	0.66	0.78	1.25	
		SO2	0.71	1.22	0.65		1.53
	EU-all	NOx	0.83	0.79	0.91	1.13	
		SO2	0.87	1.11	0.78		1.25

Table 3: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the 'ALL' scenario effectiveness) for deposition. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (NOx and So2).

This study has shown that there are important differences between sectors in the amount of concentration (deposition) reduction obtained by changing a pollutant emission. It is possible that the sectoral effect would be much stronger if the full ecosystem impact assessment were made due to the specific geographic distribution of key sensitive areas. This difference is not accounted for in the present process used to evaluate future national emissions ceiling reductions for both beneficial effect and cost-effectiveness. This raises the possibility that, when national bodies consider how to implement an emission ceiling taking account of the information used in deriving that ceiling, choices might be made that are less effective than expected.

It is recommended that, at minimum, validation calculations are carried out as part of the NEC process to examine if the implied sectoral reductions are able to deliver the intended benefits. If sectoral weights could be incorporated into the integrated assessment itself then this may lead to an overall better recommendation for emission ceilings.

Table of contents

1. Introduction

European Air Quality policy needs have been very well met by an Integrated Assessment (IA) approach which informs on the most cost-effective means to reduce national emissions in order to mitigate transboundary pollutant impacts and achieve environmental improvement targets. Emission reductions also benefit the country in which they take place and so the focus of policy is now to improve the total European condition rather than target specific transboundary influences.

The inputs to the IA model that are used to calculate emissions and the cost and potential for abatement, operate at a sectoral level. However, the effects module, through which the benefits of emission reductions are calculated, does not. It uses a set of source-receptor relationships that represent a country-to-grid-cell mapping such that the effect of change in a national emission produces a change in pollutant concentrations (or deposition) in all grid cells. These changes may then be multiplied by a weighting factor, for example population in each cell, and summed to produce an environmental damage measure. Examples are human exposure to PM or the number of ecosystems above critical load. Because the IA method produces detailed sectoral information, especially information about where the largest emission reductions can be made at least cost, it is highly likely that any controls put in place to meet an emission ceiling will require different emission reductions from different sectors. It is therefore important to establish whether such reductions would actually have the intended effect. This is especially important as the system that was originally developed for eco-system protection is being expanded to account for the mitigation of health and climate effects as well. This project was carried out to provide the first information on whether a sectoral approach to emissions reduction and a national approach to emissions reduction would provide the same benefits in terms of the amount of benefit achieved per unit emission reduction which we will call effectiveness or potency.

It is important to note that, even if differences are found, there are several factors to be considered before the overall effect on policy decisions is known. For example the emission from an individual sector might not be large even if a reduction were very effective so the total benefit might be small. Similarly an effective but very costly reduction might not be achievable. A cause for concern would be the finding that an emission that is large and cost-effective to control would be found to have a lower effectiveness than assessed using a non-sectoral approach. This could lead either to policy targets not being met or the final costs of control to meet targets being underestimated.

EURODELTA is a continuing collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) and five air quality modeling teams at Ineris (France), the Free University of Berlin (Germany), met.no (Norway), TNO (Netherlands) and SMHI (Sweden) in which the results from air quality model simulations are brought together in an assessment toolkit that allows model predictions to be compared with each other and against data.

In a first stage, sectoral emission reductions have been tested in 4 countries (UK, Germany, France and Spain) with a total of 50 different land-based scenario calculations (Thunis et al. 2008). In this report an additional series of scenarios with emission reductions in Italy, Poland and in the Benelux is discussed. The main objective of this additional series of 70 scenarios is to increase the robustness and representativeness of the findings described in the previous report.

For reasons of space and policy relevance the only pollutants discussed in this report are fine particulate matter (PM2.5), SOMO35 (which is a count of cumulative daily ozone hours exceeding 35 ppb and is the currently accepted human health metric for ozone impacts), sulphur and reduced nitrogen deposition (which represents acidic deposition) and deposition of oxidized nitrogen and ammonia which are both eutrophying and acidifying pollutants.

2. Input data

2.1. Emission inventory

Each participating model used its native grid and the common overlap area of grid defines the geographic scope which runs from approximately 10 degrees west to 24 degrees east and between 36 and 57 degrees north. Four of the models have larger domains. The overlap area (also named EU-all in the following) does encompass most countries of the European Union: the United Kingdom (except northernmost Scotland), France, Germany, Spain, Italy, the Benelux and Poland in which the sectoral emission reductions are tested, are well within the domain. The total population covered is approximately 75% of the EU.

The model common input data was co-ordinated, quality checked and distributed by JRC via the EuroDelta website (http://aqm.jrc.it/eurodelta). JRC collected and processed all of the modeling results on a common EMEP projection grid basis to facilitate the inter-comparison. Anthropogenic inputs were fixed and provided by the JRC but there are inevitably some variations in biogenic inputs and in boundary conditions. A meteorological year (1999) has been imposed for all simulations, but each modeling group used its own meteorological driver to produce the required input data for its air quality model.

The base case emission inventory for 2020 for the land based sources was the current legislation scenario consistent with that used for the CAFE program. Sectors that were investigated follow the SNAP97 designation:

Sector 1	COMBUSTION IN ENERGY AND TRANSFORMATION INDUSTRIES	Large combustion plant sources (stationary) with emissions from tall stacks. The sources are not uniformly distributed around the country-side but are concentrated into industrial areas
Sector 2	NON-INDUSTRIAL COMBUSTION PLANTS	This sector includes domestic combustion (stationary). Sources are low level and distributed more inline with population density.
Sector 3	COMBUSTION IN MANUFACTURING	Contains a mixture of high and low level sources (stationary) in mostly industrial

	INDUSTRY	areas
Sector 4	PRODUCTION PROCESSES	Contains mostly low level sources in industrial area (stationary)
Sector 5	EXTRACTION AND DIST. OF FOSSIL FUELS AND GEOTHERMAL ENERGY	Contains mostly low level sources in industrial area (stationary)
Sector 6	SOLVENT AND OTHER PRODUCT USE	Widely distributed low level sources of volatile organic compounds from both industrial and domestic activity
Sector 7	ROAD TRANSPORT	Low level sources, distributed widely in both populated and non-populated areas in the case of main highways
Sector 8	OTHER MOBILE SOURCES AND MACHINERY	Low level sources including national shipping emissions.
Sector 9	WASTE TREATMET AND DISPOSAL	Mostly high level sources
Sector 10	AGRICULTURE	Widely distributed low level source of mainly ammonia

Table 4: SNAP sector description

A set of heights was agreed for the different emission sectors with the definitive source height distribution being set by the EMEP model which included a consideration of plume rise. The other groups allocated emissions to the nearest compatible vertical layer in their models. The final classification of the emissions as function of their release height is provided in the table below.

Snap sector	Vertical layer mean height (m)					
	0-90m	90-170m	170-310m	310-470m	470-710m	710-990m
1			8%	46%	29%	17%
2	50%	50%				
3		4%	19%	41%	30%	6%
4	90%	10%				
5	90%	10%				
6	Lowest layer					
7	Lowest layer					
8	Lowest layer					
9	10%	15%	40%	35%		
10	Lowest layer					

Table 5: Emission distribution height for modelled emissions in terms of the SNAP sectors

2.2. Emission scenarios

The time-line for most of the scenarios is 2020 to be consistent with the EU CAFE study and the NECD review. To be realistic the emission reduction scenarios used in this simulation must consider what emissions are available in each sector in each country so it is not realistic to impose a constant emission reduction across all countries. For each country and for the main pollutants NOx, SO2, NH3, VOC, and primary PM2.5 we have set an absolute reduction amount. The base case for each country has this reduction distributed across the emissions from each sector in proportion to their contribution. This is referred to as the “ALL” scenario and best represents the country reduction used in CAFE studies. Next we look at how that same amount of reduction could be achieved by making an explicit reduction in each of the major emitting sectors for that pollutant. These are sector specific reductions.

Since the generation of source-receptor relationships for each individual sector would be too CPU time consuming, a series of scenarios has been carried out in which sectors have been grouped according to a low/high classification of their release height in the atmosphere. Low emissions were considered as those mostly emitted in the first model layer (i.e. sector 2, 4, 7 or 8) whereas high emissions mostly included emissions from sectors 1, 3 and 9.

The scenario reductions are listed in Table 6. As the number of permutations is large there was some pair-wise matching on the assumption that some emission reductions have an independent effect on pollutant concentrations. PM2.5 comprises primary and secondary particles and is affected by emission changes to primary particles (PPM), as well as the precursors to secondary PM which are SO2, NOx and NH3. To minimize the number of model simulation runs we made some assumptions:

- That NOx and PPM emission reductions can be paired on the basis that PPM does not affect the ozone dependence on NOx and that PPM reductions do not affect the secondary particulate matter dependence on NOx and vice versa.

- That SO2 and VOC emission reductions can be paired and SO2 reduction changes do not affect the ozone dependence on VOC and that the VOC changes do not affect the secondary particulate matter dependence on SO2 (secondary organic aerosols being neglected). But as discussed in the first ED-II report this assumption that the SO2 emission effects on ozone was negligible compared with that of VOC emissions may not be completely correct.

None of the models in this project calculated secondary organic aerosol because the uncertainties in the formation rates are too large. Hence there is no direct link between VOC emissions and particulate matter.

In addition to the country specific emission reductions, a series of scenarios focuses on the Po-Valley in Northern Italy to investigate how important the spatial extension of the emission area is in the definition of the source receptor relationships. Emission scenarios over the PO-Valley are defined in a similar manner to the other countries with the exception of the grouped sectors scenarios which are not simulated.

Country/Area	Sectors	Pollutant(s)	Emissions Reductions in ktonnes/year with Percent of Total 2020 Emissions Remaining Shown in Parenthesis				
			NOx	PM2.5	SOx	VOC	NH3
BASE CASE 2020 CLE							
France	All	NOx+PM2.5	230 (71.9%)	62 (61.2%)			
	All	SOx+VOC			110 (68.1%)	150 (83.8%)	
	S1	NOx+PM2.5	40 (95.1%)	3 (98.1)			
	S1/4	SOx+VOC			40 (88.4%)	30 (96.8%)	
	S2	PM2.5		45 (71.8%)			
	S3	NOx+PM2.5	100 (87.8%)	2 (98.7%)			
	S3/6	SOx+VOC			70 (79.7%)	120 (87.0%)	
	S4	PM2.5		10 (93.7%)			
	S7	NOx+PM2.5	90 (89.0%)	2 (98.7%)			
	S10	NH3					250 (64.4%)
Spain	All	NOx+PM2.5	200 (70.6%)	25 (71.1%)			
	All	SOx+VOC			97 (71.0%)	180 (74.3%)	
	S1	NOx+PM2.5	50 (92.7%)	3 (96.5%)			
	S1/4	SOx+VOC			40 (88.1%)	70 (90.0%)	
	S2	PM2.5		12 (86.1%)			
	S3	NOx+PM2.5	90 (86.8%)	1 (98.8%)			
	S3/6	SOx+VOC			40 (88.1%)	100 (85.7%)	
	S4	PM2.5		8 (90.8%)			
	S7	NOx+PM2.5	60 (91.2%)	1 (98.8%)			
	S8/7	SOx+VOC			17 (94.9%)	10 (98.6%)	
	S10	NH3					125 (66.2%)
Germany	All	NOx+PM2.5	150 (81.4%)	25 (78.0%)			
	All	SOx+VOC			60 (81.9%)	120 (84.6%)	
	S1	NOx+PM2.5	50 (93.8%)	4 (96.5%)			
	S1/4	SOx+VOC			50 (84.9%)	20 (97.4%)	
	S2	PM2.5		8 (93.0%)			
	S3	NOx+PM2.5	50 (93.8%)	4 (96.5%)			
	S3/6	SOx+VOC			10 (97.0%)	100 (87.1%)	
	S4	PM2.5		8 (93.0%)			
	S7	NOx+PM2.5	50 (93.8%)	1 (99.1%)			
	S10	NH3					125 (79.3%)
UK	All	NOx+PM2.5	250 (69.4%)	13 (79.3%)			
	All	SOx+VOC			65 (68.9%)	90 (89.8%)	
	S1	NOx+PM2.5	100 (87.8%)	2 (96.8)			
	S1/4	SOx+VOC			30 (85.6%)	10 (98.9%)	
	S2	PM2.5		4 (93.6%)			
	S3	NOx+PM2.5	90 (89.0%)	2 (96.8%)			
	S3/6	SOx+VOC			35 (83.2%)	80 (90.9%)	
	S4	PM2.5		4 (93.6%)			
	S7	NOx+PM2.5	60 (92.7%)	1 (98.4%)			
	S10	NH3					90 (71.0%)
Belgium	All	NOx+PM2.5	58 (69.5%)	4.1 (81.1%)			
	All	SOx			31.4 (62.2%)		
	S1	NOx+PM2.5	13 (69.5%)	0.3 (17.1%)			
	S1	SOx			4 (72.4%)		
	S2	NOx + PM2.5	6 (73.2%)	1.2 (42.8%)			
	S3	NOx+PM2.5	24 (54.7%)	2.5 (47.2%)			
	S3	SOx			18 (50.6%)		
	S7	NOx+PM2.5	11 (82.9%)	0.25 (91.3%)			
	S8	SOx			2 (36.0%)		
	S2+4+7+8	NOx+PM2.5	6/0/11/4 (73.2/100/82.9/79.8 %)	1.2/1/0.25/4 (42.8/85.2/91.3/81 %)			
	S2+4+7+8	SOx			4/3/.4/2 (49.8/85.4/29.8/36 %)		
	S1+S3+S9	NOx+PM2.5	13/24/0 (69.5/54.7/100%)	0.3/2.5/0.3 (17.1/47.2/81%)			
	S1+S3+S9	SOx			4/18/0 (72.4/50.6/100%)		
	S10	NH3					26 (63.6%)
Luxembourg	All	NOx+PM2.5	5 (71.9%)	0.45 (79.2%)			
	All	SOx			1.3 (39%)		
	S1	NOx+PM2.5	0.5 (29.8%)	0 (100%)			
	S1	SOx			0.1 (28%)		
	S2	NOx + PM2.5	0.5 (61.5%)	0.05 (47.4%)			
	S3	NOx+PM2.5	2 (40.7%)	0 (100%)			
	S3	SOx			0.9 (34%)		
	S7	NOx+PM2.5	2 (83.1%)	0 (100%)			
	S8	SOx			0 (100%)		
	S2+4+7+8	NOx+PM2.5	05/0/2/4 (29.8/100/83.1/79.8 %)	0.05/0.4/0/0 (47.4/60.6/100/100 %)			
	S2+4+7+8	SOx			0.3/05/0/0 (38/100/100/100%)		
	S1+S3+S9	NOx+PM2.5	0.5/2/0 (29.8/40.7/100%)	0/0/0 (100/100/100%)			
	S1+S3+S9	SOx			0.1/0.9/0 (28/34/100%)		
	S10	NH3					1.3 (64.9%)

Netherlands	All	NOx+PM2.5	57 (76.3%)	6.7 (74.7%)			
	All	SOx			16.1 (75.1%)		
	S1	NOx+PM2.5	20 (54.8%)	0.25 (55.6%)			
	S1	SOx			0 (100%)		
	S2	NOx + PM2.5	1 (94.7%)	3 (37.2%)			
	S3	NOx+PM2.5	7 (58.1%)	0.25 (84%)			
	S3	SOx			1.8 (67%)		
	S7	NOx+PM2.5	18 (77.2%)	0.5 (87%)			
	S8	SOx			14 (22.9%)		
	S2+4+7+8	NOx+PM2.5	20/0/18/11 (94.7/100/77.2/86.2 %)	3/2/0.5/0 (37.2/65/87/100)			
	S2+4+7+8	SOx			0.3/7/0/14 (69/77/100/22.9%)		
	S1+S3+S9	NOx+PM2.5	20/7/0 (54.8/58.1/100%)	0.25/0.25/0.4 (55.6/84/85%)			
	S1+S3+S9	SOx			0/1.8/0 (100/67/100%)		
	S10	NH3					33 (73.9%)
Italy	All	NOx+PM2.5	222 (66.6%)	30.5 (67.9%)			
	All	SOx			161 (42.8%)		
	S1	NOx+PM2.5	40 (58.4%)	2 (34.8%)			
	S1	SOx			25 (63.7%)		
	S2	NOx + PM2.5	14 (76.7%)	12 (40.9%)			
	S3	NOx+PM2.5	60 (52.7%)	3 (77.4%)			
	S3	SOx			35 (50.9%)		
	S4	NOx+PM2.5	7 (52.3%)	8 (70.1%)			
	S7	NOx+PM2.5	40 (79.5%)	1 (91.4%)			
	S8	NOx+PM2.5	4 (64.5%)	1 (92.7%)			
	S9	NOx+PM2.5	.5 (23.7%)	3 (70.1%)			
	S8	SOx			70 (16.9%)		
	S2+4+7+8	NOx+PM2.5	14/7/40/4 (76.7/52.3/79.5/64.5 %)	12/8/1/1 (40.9/57.4/91.4/92.7 %)			
	S2+4+7+8	SOx			2/29/0/70 (72.8/40.4/100/16.9 %)		
	S1+S3+S9	NOx+PM2.5	40/60/.5 (58.4/52.7/23.7%)	2/3/3 (34.8/77.4/70.1%)			
	S1+S3+S9	SOx			25/35/0 (63.7/50.9/100%)		
	S10	NH3					122 (67.6%)
Po-Valley	All	NOx+PM2.5	66.60%	67.90%			
	All	SOx			42.80%		
	S1	NOx+PM2.5	58.40%	34.80%			
	S1	SOx			63.70%		
	S2	NOx + PM2.5	76.70%	40.90%			
	S3	NOx+PM2.5	52.70%	77.40%			
	S3	SOx			50.90%		
	S7	NOx+PM2.5	79.50%	91.40%			
	S8	SOx			16.90%		
	S10	NH3					67.60%
Poland	All	NOx+PM2.5	104 (71.5%)	55.5 (44.9%)			
	All	SOx			340 (38.6%)		
	S1	NOx+PM2.5	40 (65.7%)	4 (65.3%)			
	S1	SOx			200 (31.3%)		
	S2	NOx + PM2.5	10 (79.2%)	40 (27.9%)			
	S2	SOx			14.5 (68.3%)		
	S3	NOx+PM2.5	40 (52.8%)	3 (61.5%)			
	S3	SOx			125 (25.9%)		
	S7	NOx+PM2.5	14 (80%)	1 (73.6%)			
	S2+4+7+8	NOx+PM2.5	10/3/14/5 (79.4/47.5/80/86.9 %)	40/4/1/0 (27.9/48.4/73.6/100 %)			
	S2+4+7+8	SOx			14.5/34/0/.25 (68.3/26.8/100/54%)		
	S1+S3+S9	NOx+PM2.5	40/40/.5 (65.7/52.8/16.8%)	4/3/2.5 (65.3/61.5/63.6%)			
	S1+S3+S9	SOx			200/125/0 (31.3/25.9/100%)		
	S10	NH3					140 (54.8%)

Table 6: Emission scenario reference list. The columns indicate which precursor emissions have been reduced and in which amount (in parentheses the remaining percentage of emissions after reduction)

3. Methodology

The objective of the study is to evaluate whether sectoral emission reductions would result in different SR relationships to those currently used in policy. It is difficult to compare SR relationships directly because they are defined as a country to grid mapping and thus comprise very large matrices. It is necessary to aggregate the results. For example EMEP regularly publishes “blame” matrices in its annual status reports that reflect the change in concentration of a pollutant in one country for a 15% reduction of precursor emission in another country. In this work a normalized measure is used which is the sum of the response of all of the grid cells in one receptor area (see definitions below) divided by the magnitude of the emission change. This is a measure of effectiveness or “potency”. If it is zero then making an emission change has no effect, if it is positive then making an emission reduction produces a benefit. Depending on the relevant policy endpoint the grid cell response can be weighted.

In the following the potency of sectoral emission changes on PM2.5 concentrations, on SOMO35 and on deposition are compared using the following normalized formula:

$$POT_{P,S,C}^{V,D,M} = \left. \frac{\sum_{i,j \in D} \delta_{P,S,C}^{V,[i,j],M} F_{i,j}}{F_{tot}} \middle/ E_{P,S,C} \right. \qquad (1)$$

Where:

- $POT_{P,S,C}^{V,D,M}$ is the normalized potency of a precursor (P) emission reduction in sector (or group of sectors) S and country C on a given end point variable V over the receptor area D and for a given model M.

- $\delta_{P,S,C}^{V,[i,j],M}$ is the yearly averaged delta resulting from a precursor (P) emission reduction in sector (or group of sectors) S and country C on a given end point variable V in the EMEP grid cell (i,j) for a given model M. This yearly averaged delta ($\delta_{P,S,C}^{V,[i,j],M}$) is expressed either in µg/m3 (for PM2.5), in tons/km2 (for depositions) or in ppb*days (for SOMO35). It is obtained as the difference between the base case (CLE) and the chosen sectoral (S) emission reduction scenario values. The convention used in this report for expressing the delta is that the first scenario is the base case CLE; the second scenario is an emission reduction scenario. As the reduction scenario generally leads to lower concentrations the difference is positive. Thus a positive value is a decrease in the respective quantity and a negative value is an increase.

- $E_{P,S,C}$ represents the total emission reduction of precursor P in a given sector S (or group of sectors) in country C. For air concentrations of pollutants the normalization uses the actual precursor emission with the exception of NOx which is treated as a NO2 equivalent in the usual way. For deposition results are expressed in mass units of sulphur or nitrogen.

- F_{ij} represents either the EMEP cell areas (in the case of area weighting) or population within this cell (in the case of population weighting) whereas F_{tot} stands for the total area or population of the selected receptor, respectively. Population weighting is used to describe the PM2.5 and SOMO35 responses because the concern with PM2.5 and O3 is the effect on human health. It is thus sensible to give more weight to grid cells in populated areas.

- D is the receptor domain. In this report the potency for each emission reduction scenario is analyzed in terms of two different receptor areas. The first is the country itself, in which emissions are being reduced whereas the second (named EU-all) is defined as the common intersection between the different models.

The structure of the report is as follows. We first briefly examine the main characteristics of the country emissions in terms of their sectoral distribution and degree of correlation with population to provide elements useful for the interpretation of the country and sectoral potencies presented in this report. The potency results are then presented on both a population weighted and a non-population weighted basis to give some indication of how population distribution may influence the results. We examine the response of PM2.5 which is influenced by emissions of SO2, NOx, NH3 and primary PM2.5. Then we look at the response of SOMO35 which is influenced by NOx and VOC emissions. The deposition of oxidized Sulphur and oxidized Nitrogen is then examined. For completeness the reduced nitrogen results are also presented but, as agriculture is the overwhelming source of ammonia there is no useful sectoral information

4. Country emission characteristics

4.1. Country sectoral emission distribution

Before presenting the main results of the Eurodelta modeling exercise we briefly provide some information on the characteristics of the sectoral emission distribution for each of the countries considered. This information is helpful for interpreting the differences in potencies obtained across sectors between the sectoral and proportional approaches. And it is also helpful for understanding the differences obtained in potencies between the two approaches across countries. Indeed the larger the contribution of one particular sector to the emission total is, the smaller the difference between the sectoral potency of this sector and the proportional approach will be. In the limit, the proportional and sectoral approaches will become identical if all emissions are contained in a single sector. The different sectoral emission distribution in one given country and the country-to-country differences in this distribution therefore constitute key elements which are presented here for each of the countries considered in the study.

In Figure 1 the sectoral distribution is provided for each country. A few points are worth noting:

- For PPM2.5 emissions the contribution of the high level sources to the emission total is on the order of 20% and does not vary significantly among countries, with France having the lowest and UK the largest percentages. The same is true for the low-level sources group (sectors 2, 4, 7 and 8) with a contribution around 60% and again France and UK having the outlying percentages. Note however that the distribution among sectors in the low level sources may be quite different among countries. It is the case of Poland and France where the sector 2 emissions are a factor 2 larger than in other countries. This may be due to different domestic fuel choices.

- For SOx emissions the proportion of the low (2-4-7-8) and high level (1-3-9) sources grouping to the emission total is approximately equivalent for all countries with a 45-55% split with the exception of Poland which shows a much larger fraction of its emission belonging to the high-level group. Larger variations are visible in individual sectors.

- For NOx the situation is more homogeneous. With the exception of Poland, high level sources contribute to approximately 30% of the total. The emission distribution is quite homogeneous among countries for individual sectors. Poland exhibit however a larger fraction of high level sources (especially from sector 1).

- Differences between Italy and the Po-Valley in terms of emission distribution are relatively moderate.

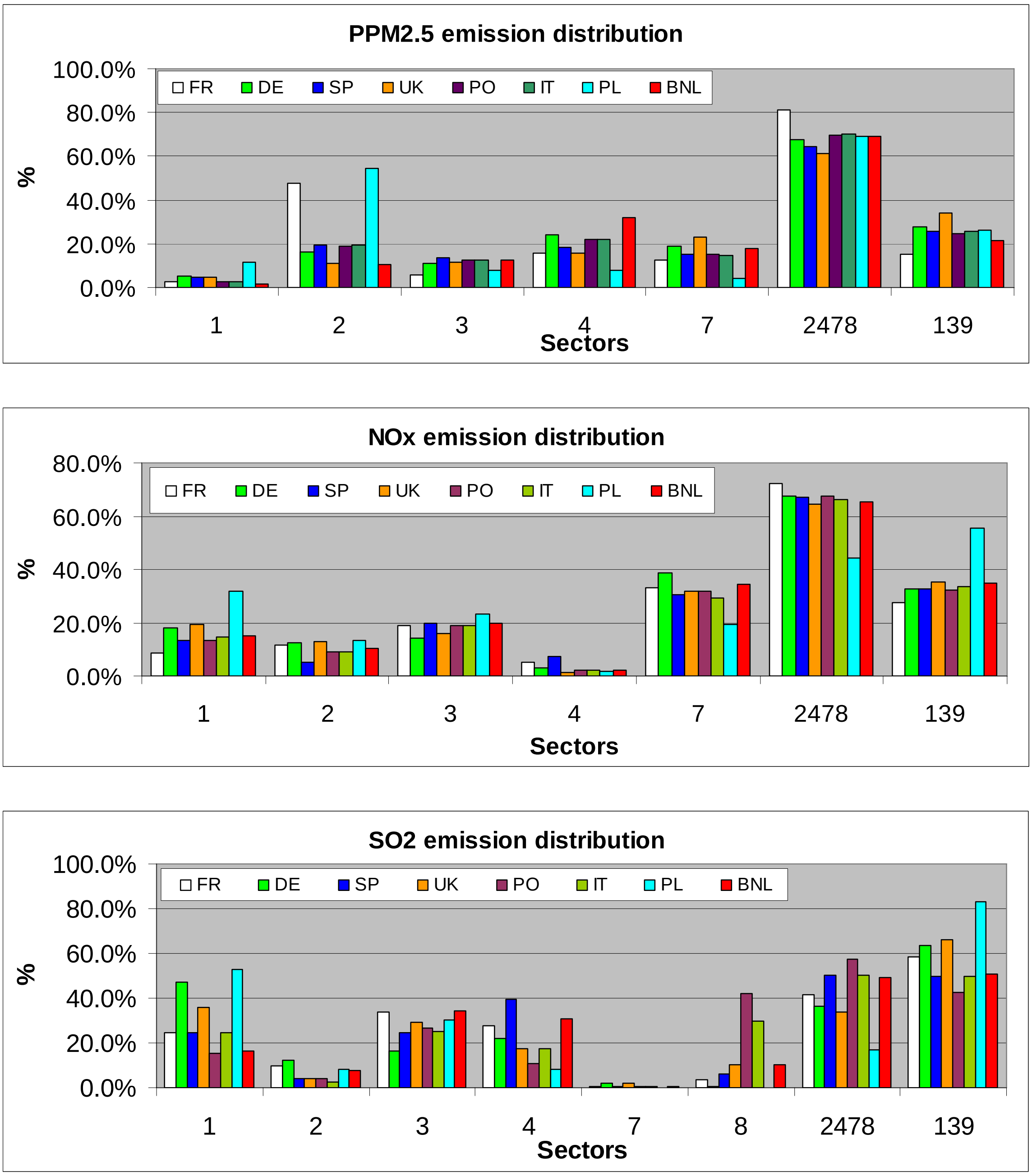
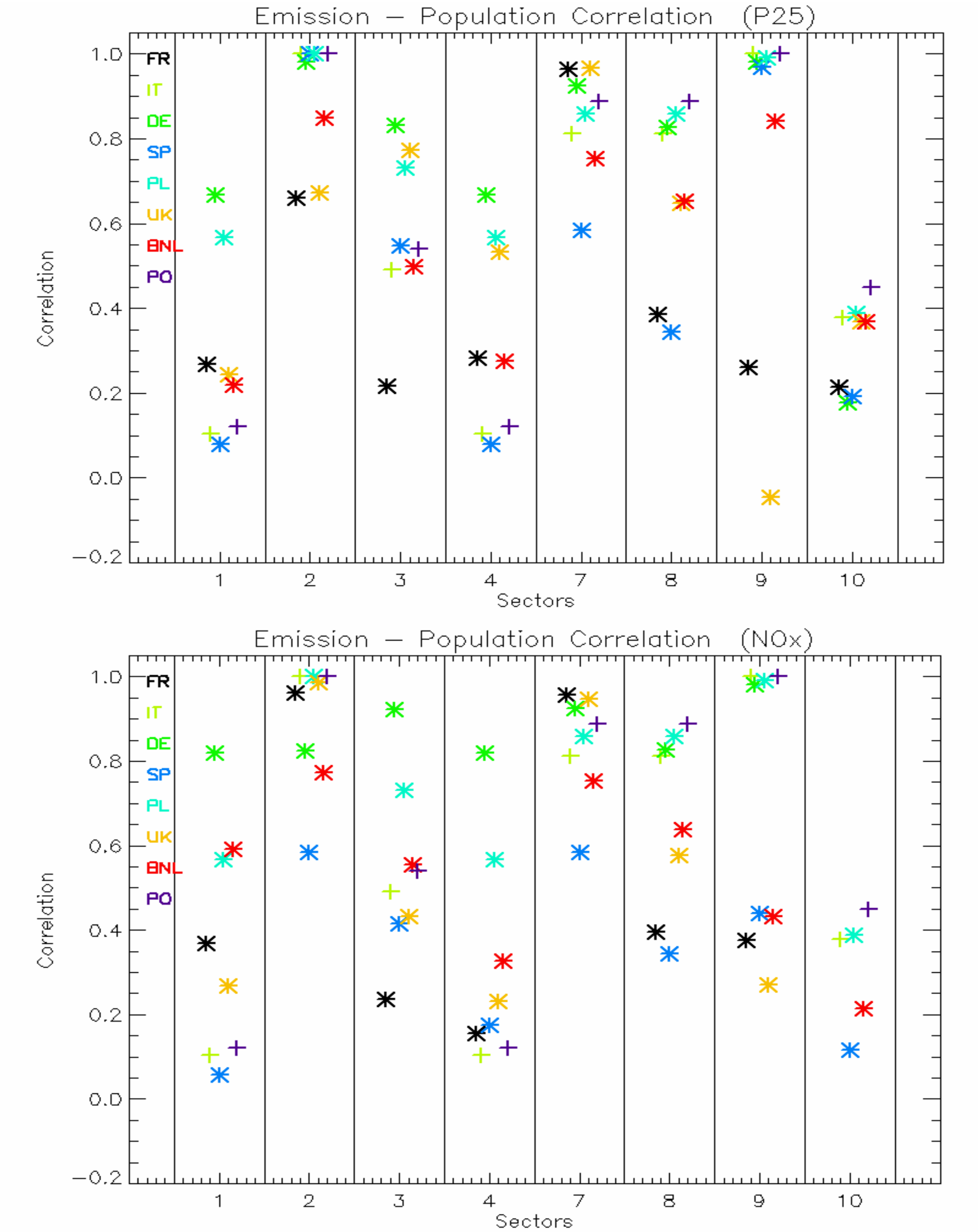


Figure 1: Sectoral emission distribution per country for PPM2.5 (a), NOx (b) and SO2 (c). The column heights indicate the percentage emission fraction with respect to the total emissions (all sectors). Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors

4.2. Emission – population correlations

In the formulation of the potency (formula 1) two different weighting factors are possible in the numerator: area or population. In the case a population weighting factor is selected the potency will depend on how well concentration deltas are spatially correlated with population.

Although the link between emissions and concentrations is not a direct one, especially for secondary pollutants such as PM and O3, it is interesting to consider the spatial correlation between emission source and population for the sectors and countries considered in this study. Figure 2 shows the correlations between PPM2.5, SO2 and NOx emissions and population for each individual SNAP sector.



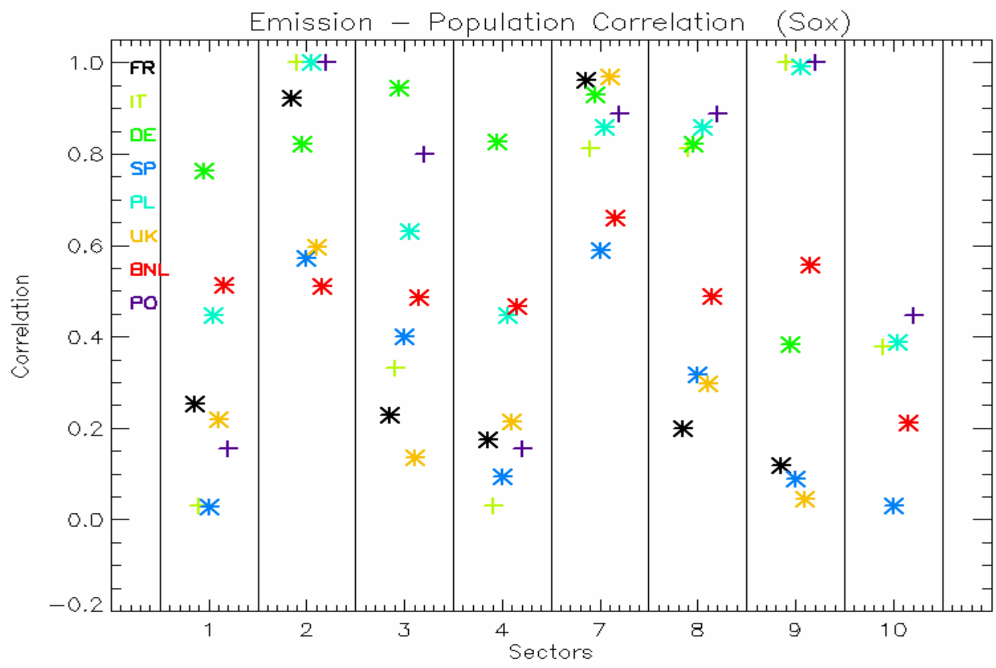


Figure 2: Correlations between emissions and population (on an EMEP grid-cell basis) are given in terms of the SNAP sector (abscissa) for each of the countries (color code indicated on the side of each figure). Data are provided for PPM2.5 (top), NOx (middle) and SO2 (bottom).

In general large differences are seen among sectors and/or countries regarding the emission – population correlations. In particular we note the following:

- Sectors 2 and 7 for NOx, SO2 and PPM2.5 are highly correlated with population with the highest correlations (close to 1) for France and UK and the lowest for Spain (around 0.6). Sectors 4 and 8 are generally less correlated with population and show large variations across countries.

- For high level sources (mostly sectors 1 and 3) the degree of correlation with population is extremely diverse among countries (for all pollutants). Values range from 0 to 0.8, the highest values generally been found for Germany and the lowest for Spain and France

- Italy, the Po valley and Poland show correlation coefficients close to 1 for sector 9 for all precursors whereas for countries like UK it is close to zero.

- Italy and the Po valley are very close to each other with the exception of sector 3 for SO2 where much larger correlations are observed for the Po-Valley.

Apart from the degree of correlation between emissions and population, another factor which impacts the calculation of the population-weighted potencies is the way population is distributed in the country. If a large fraction of the population resides in the high emissions area then the population-weighted potency will increase accordingly. Different population distribution patterns can then result in different population-weighted potencies although their degree of correlation between population and emission is similar.

In Figure 3Figure 2 the population degree of concentration is shown for the different countries (and Po-Valley). We see that both the Po Valley and Spain have a high fraction of their population concentrated in only a few EMEP grid cells (about 20% of the population lies in only grid cells coinciding with the main city areas and therefore with the highest emission density cells) whereas UK and Germany need 5 times more space to accommodate the same population number.

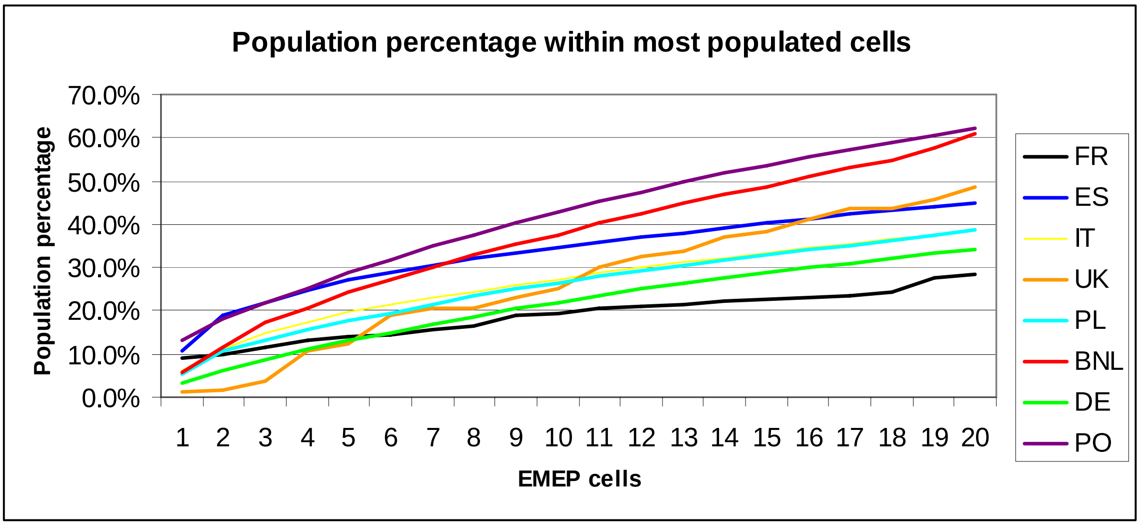


Figure 3: Population cumulative curves for each country in terms of EMEP grid-cells. Ordinate indicates population percentage (with respect to the country total population).

5. Evaluation of sectoral approaches

5.1. Procedure

In this section we compare the potencies of various emission scenarios in a systematic manner. For a given end-point (e.g. PM2.5, O3…) the analysis is made in a two-step approach distinguishing between population and area weighted results. For each of these steps figures are presented showing the results obtained for different sizes of the receptor area. Two receptor sizes are selected: the country and the common intersection of all modeling areas (named EU-all). Each figure is itself composed of different sub-figures illustrating and comparing the potencies of emission scenarios across sectors, countries, emission precursors and/or models. Detailed information on each of these possible bases for comparing the results is made below.

Relative Potency (or efficiency): To compare the potency of sectoral emission scenarios with the traditional approach used to build SRR we use the following ratio:

$$\text{Relative Potency} = POT_{P,S,C}^{V,D,M} \,/\, POT_{P,All,C}^{V,D,M} \qquad (2)$$

where the numerator represents the change in a given end point per unit change in emission resulting from a scenario in which emissions are changed only in a single sector (or a group of sectors) and the denominator represents a similar quantity for the “ALL” scenario in which emissions are reduced proportionately to each emitting sector. If the ratio is one then an emission control on this sector would be as effective as expected by a current policy assumption. If the ratio is less than one then emission control on that sector would deliver less than expected by current policy. If the ratio is greater than one then emission control on that sector would deliver more than expected by current policy methods.

In addition to a sectoral comparison, potencies ($POT_{P,S,C}^{V,D,M}$) can also be compared in terms of precursor emissions ($P = \text{Nox, Sox, VOC, NH3 and/or PPM2.5}$), countries ($C = Germany, France, UK, ...$), receptor ($D = \text{country or EU} - \text{all...}$) or model ($M = CHIMERE, LOTOS...$)

The comparison in terms of precursor emissions (for the "ALL" emission reduction scenario) is systematically proposed in the lower section of each figure

5.2. General comments

1. In general terms the potency of an emission change on a given end-point variable will depend on the following factors:

   a. <u>The spatial distribution of the emissions</u>: If emissions for a given sector are localized in vicinity of the boundaries of the selected receptor area, it is likely that a significant part of the emission change will not be accounted for due to transboundary transport. For small countries this factor becomes significant if the selected size of the receptor is the country itself. As the selected receptor area becomes larger (e.g. EU-all) differences in potencies will tend to be less significant across countries.

   b. <u>The vertical distribution of the emissions</u>: Point source emissions are emitted at higher heights and are less likely to affect the surface layer where concentration changes (and therefore potencies) are monitored. In addition, these emissions probably travel longer distance and are more sensitive to the size of the receptor area. As the selected receptor area becomes larger differences in potencies will tend to be less significant across sectors.

   c. <u>Meteorological conditions</u>: The average prevailing atmospheric dispersion will determine the extent of the vertical mixing and the degree of dilution of the concentration change. The greater atmospheric dispersion is the smaller the concentration change (and related potencies) monitored within the surface layer will be.

2. Comparison of sectoral emission scenario potencies with the "ALL" scenario approach largely depends on the sectoral composition of the emissions in each country. If one specific sector largely contributes to the overall emission total the ratio defined by Equation 2 will tend to be closer to one. The country sectoral composition of the emissions must therefore be considered when analyzing country to country differences (see section 4).

3. For population weighted deltas, the differences will tend to be reinforced when the correlation between the given sectoral emissions and the population is high. In addition for a similar degree of correlation between population and emissions the

degree of concentration of the population in the highest emitting cells also plays a significant role and will tend to further strengthen the differences across countries.

5.3. Response of PM2.5 to changes in precursor emissions

In this section we analyze the response on PM2.5 levels of an emission reduction of the following precursors: NOx, SO2, PPM2.5 and NH3. All figures follow the same rule: the ratio of the sectoral to ALL potencies (Equation 2) for PPM2.5 (top left), SO2 (top right) and NOx (bottom left) precursor emissions is presented in terms of the emission scenarios (abscissa) over one of the two receptors (referenced at the bottom of each figure). Model results (when available for a given emission scenario) are indicated with a * symbol (or + symbol for the EMEP model) while a vertical line joins the minimum and maximum model responses for each country and scenario. The bottom right figure provides a comparison of the reduction potential of the different precursors for the "all" scenario.

Note that:

- PM2.5 concentrations are affected by both NOx and primary PM emissions. In the combined NOx and PPM scenarios the effects are taken as additive. The PPM effect was calculated first and then the NOx effect was calculated using: $(\Delta PM_{2.5} - \Delta PPM_{2.5}) / \Delta NO_x$ to avoid double counting.

- Secondary PM2.5 is not necessarily equal to the total secondary inorganic fraction as some models can promote secondary particles to a size range greater than PM2.5. This is true for nitrates in the EMEP model and for all secondary inorganic aerosols in the CHIMERE model.

- Some model results were unphysical (presumably a data processing error) and have been excluded from the analysis.

<u>The impact of emission reductions on surface weighted PM2.5 shows the following (Figures 4 to 7)</u>:

- Although some variability in the model results is visible, models do generally behave in a very consistent manner.

- Regardless of model and country, at the country scale, PPM2.5 emission reductions in the traffic (S7) and residential (S2) sectors are 4 and 3 times more potent than similar reductions in the point source sectors (1 & 3), respectively. At the European scale (EU-all) these numbers reduce to 3 and 2, respectively. NOx and SO2 emission reductions in the traffic sector (S7 or S8) are 2 times more potent than similar reductions in the point source sectors (1 & 3) at the country scale and reduce to a factor 1 to 1.5 for the EU-all receptor.

- Differences in sectoral potency ratios (Equation 2) are generally smaller (ratios closer to 1) for precursor emission reductions acting on secondary PM2.5 than on primary PM2.5.

- As the size of the receptor area gets larger differences among the sectoral potencies ratios (Equation 2) become less significant. This is explained by the reduced impact of the country size, and by the spatial and sectoral distribution of the emissions within the countries. This is especially valid for potencies related to PPM2.5 emission reductions.

- Some differences among countries, e.g. the Benelux response to PPM2.5 emission reductions in sector 2 (or the Poland response to NOx emission reductions in sector 1) might partly be explained by the lower (larger) contribution of the emission arising from these particular sectors to the total emissions for this country (see Figure 1, top).

- In terms of absolute impacts, as the size of the receptor area increases potencies tend to be more uniform across countries and pollutants. In particular the differences in potency between emission reductions of precursors acting on primary and secondary PM become smaller (e.g. the Benelux ratio between the PPM2.5 and NOx potencies moves from around 20 at the country scale to around 5 at the EU-all scale). Although this is true especially for small countries, it remains significant for larger countries as well.

- Reducing primary particle emissions directly has a much larger direct effect on concentrations but it must be remembered that overall emissions are quite small compared to those of the precursors for secondary particles. Thus the overall total abatement potential is more limited than for precursor emissions for secondary particles if the policy driver is to reduce all particles without regard to potential differences in health end-point.

- The effect of population weighting is to increase the overall absolute impacts, as seen from the comparison of the lower left parts of Figure 4 (5) and Figure 6 (7), and to emphasize differences among countries according to the degree of correlation between population and emission. Regarding relative potencies (top and bottom left figures) population weighting tends to increase the difference between sectoral potencies. This reflects the importance of the close proximity of ground level sources to population. But with the exception of a few cases (e.g. PPM2.5 emission reductions in sector 2 for Spain and the Po-Valley, PPM2.5 emission reductions in sector 4 for Spain and Germany or PPM2.5 emission reductions in sector 7 for France) differences between population and area weighted potencies are minor.

- As mentioned earlier, the generation of SRR for each individual sector would be too CPU time consuming. Scenarios have therefore been carried out in which sectors have been grouped according to a low/high classification of their release height in the atmosphere. These low (2, 4, 7 and 8) and high (1, 3 and 9) sector group scenarios accurately represent the average behavior of the individual sectors within the groups, although the differences obtained between individual sectors are slightly smoothed out. Note that these grouped scenario have been carried out for Italy, Benelux and Poland but not all individual sectoral scenarios have been completed for these three countries (for example the sector 9 scenario is missing for Benelux).

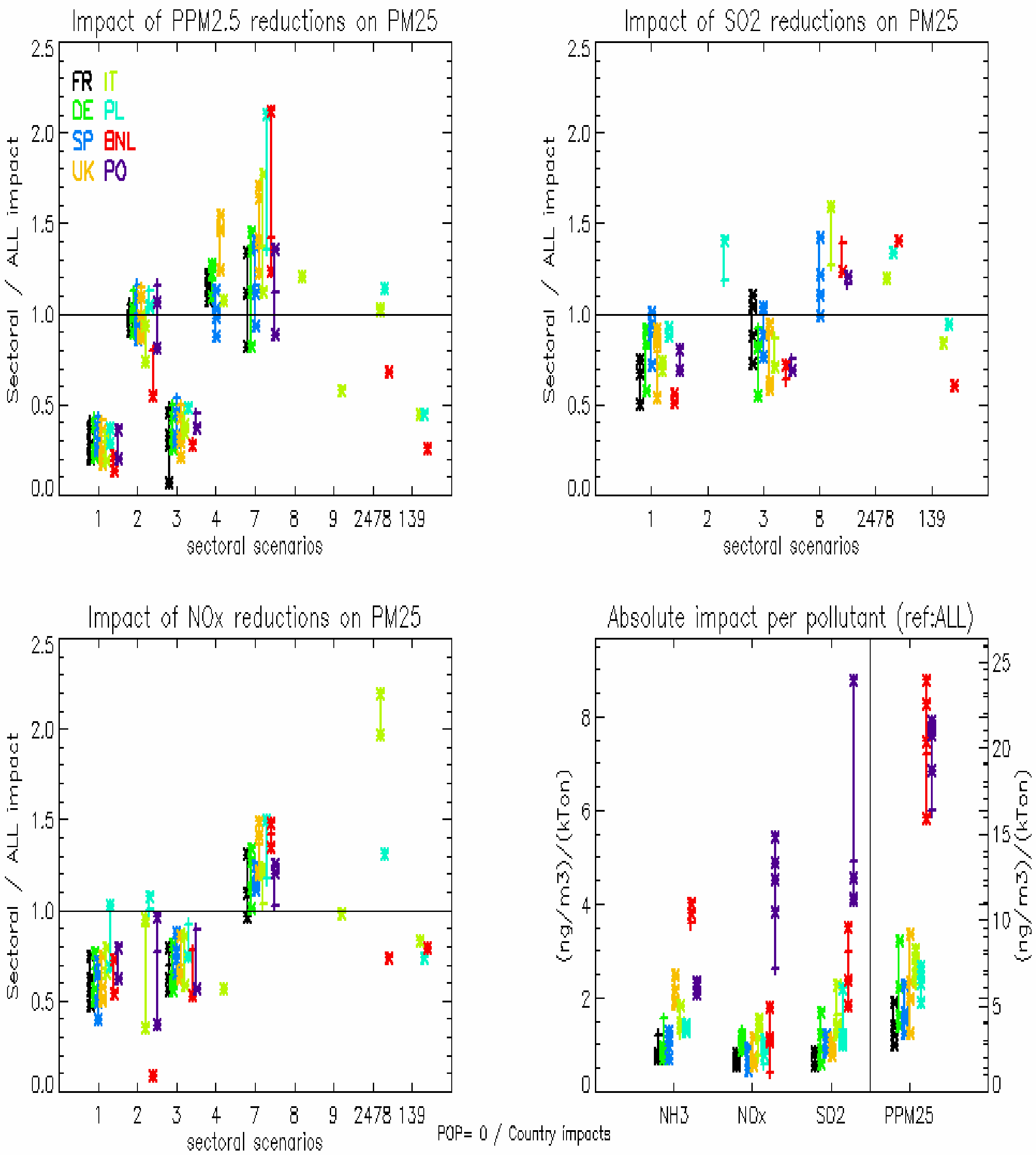


Figure 4: Comparison of sectoral to "ALL" potencies on PM2.5 concentrations for emission reductions in PPM2.5 (a), NOx (b) and SO2 (c) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower right figure provides model results for the absolute potency for different precursor emissions. The vertical black line separates the variables which are scaled on the left axis (NH3, NOx and SO2) from those to be read on the right axis (PPM2.5). Potencies are area weighted at the country scale.

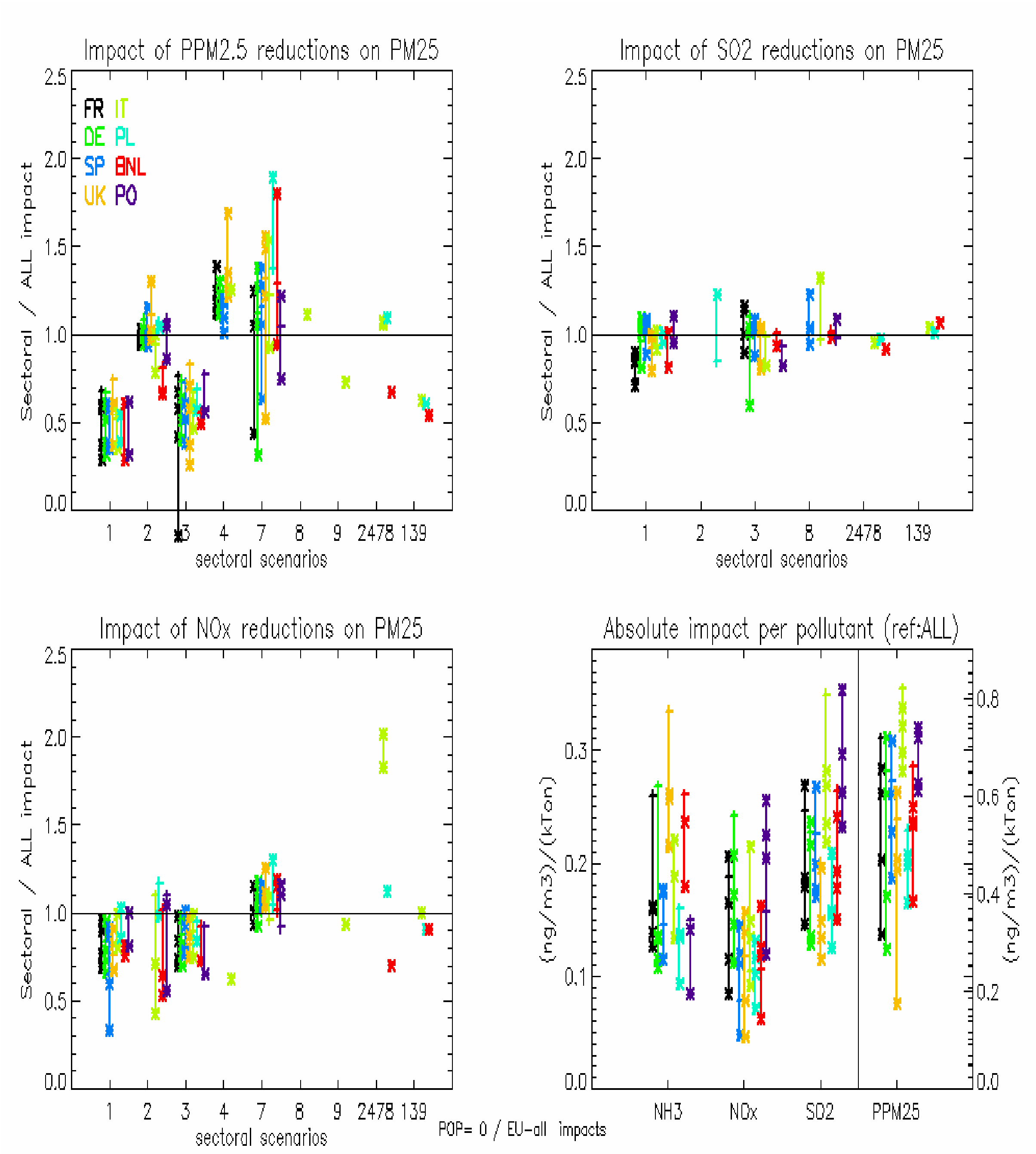


Figure 5: Comparison of sectoral to "ALL" potencies on PM2.5 concentrations for emission reductions in PPM2.5 (a), NOx (b) and SO2 (c) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower right figure provides model results for the absolute potency for different precursor emissions. The vertical black line separates the variables which are scaled on the left axis (NH3, NOx and SO2) from those to be read on the right axis (PPM2.5). Potencies are area weighted at the EU-all scale.

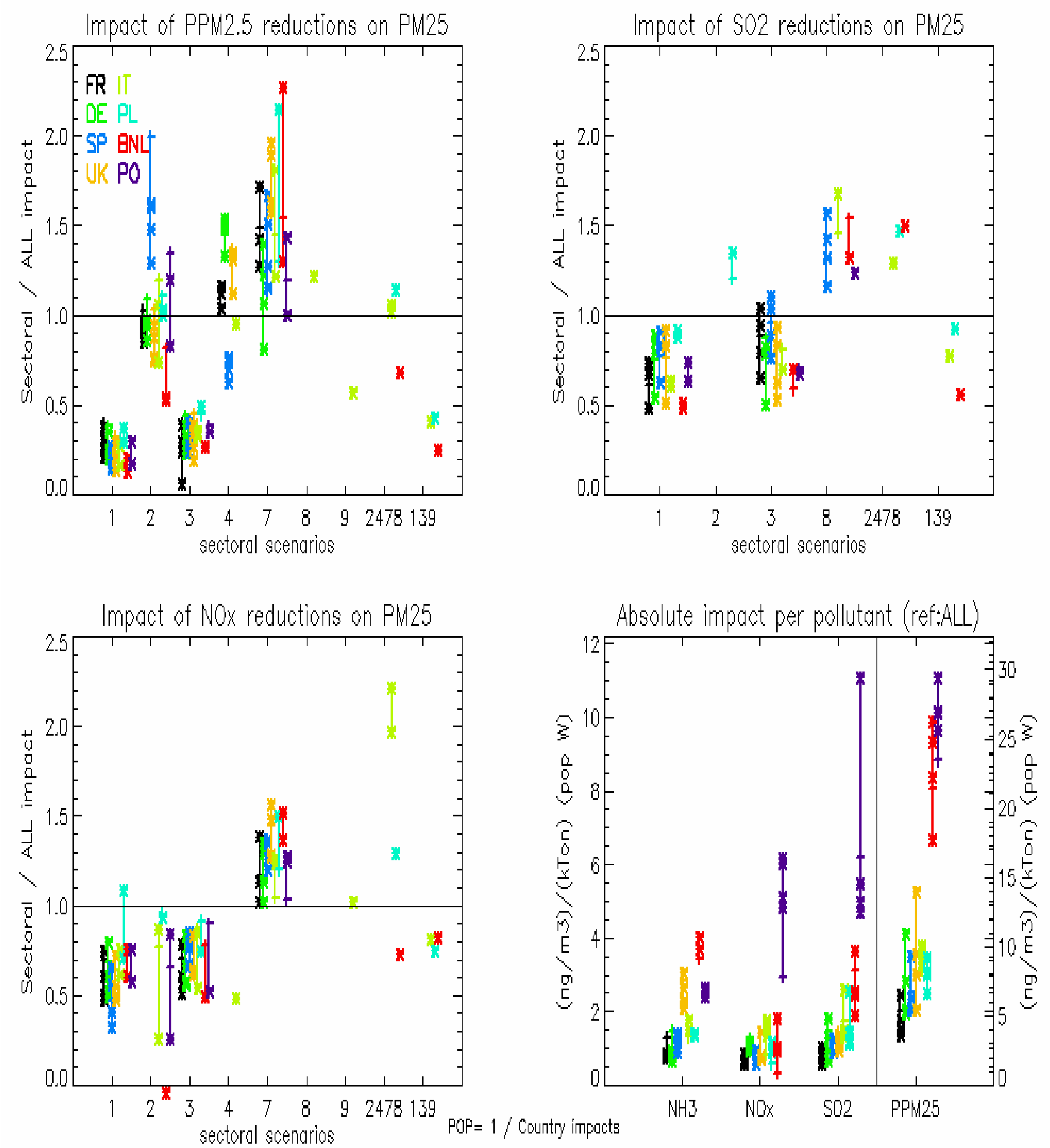


Figure 6: Comparison of sectoral to "ALL" potencies on PM2.5 concentrations for emission reductions in PPM2.5 (a), NOx (b) and SO2 (c) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower right figure provides model results for the absolute potency for different precursor emissions. The vertical black line separates the variables which are scaled on the left axis (NH3, NOx and SO2) from those to be read on the right axis (PPM2.5). Potencies are population weighted at the country scale.

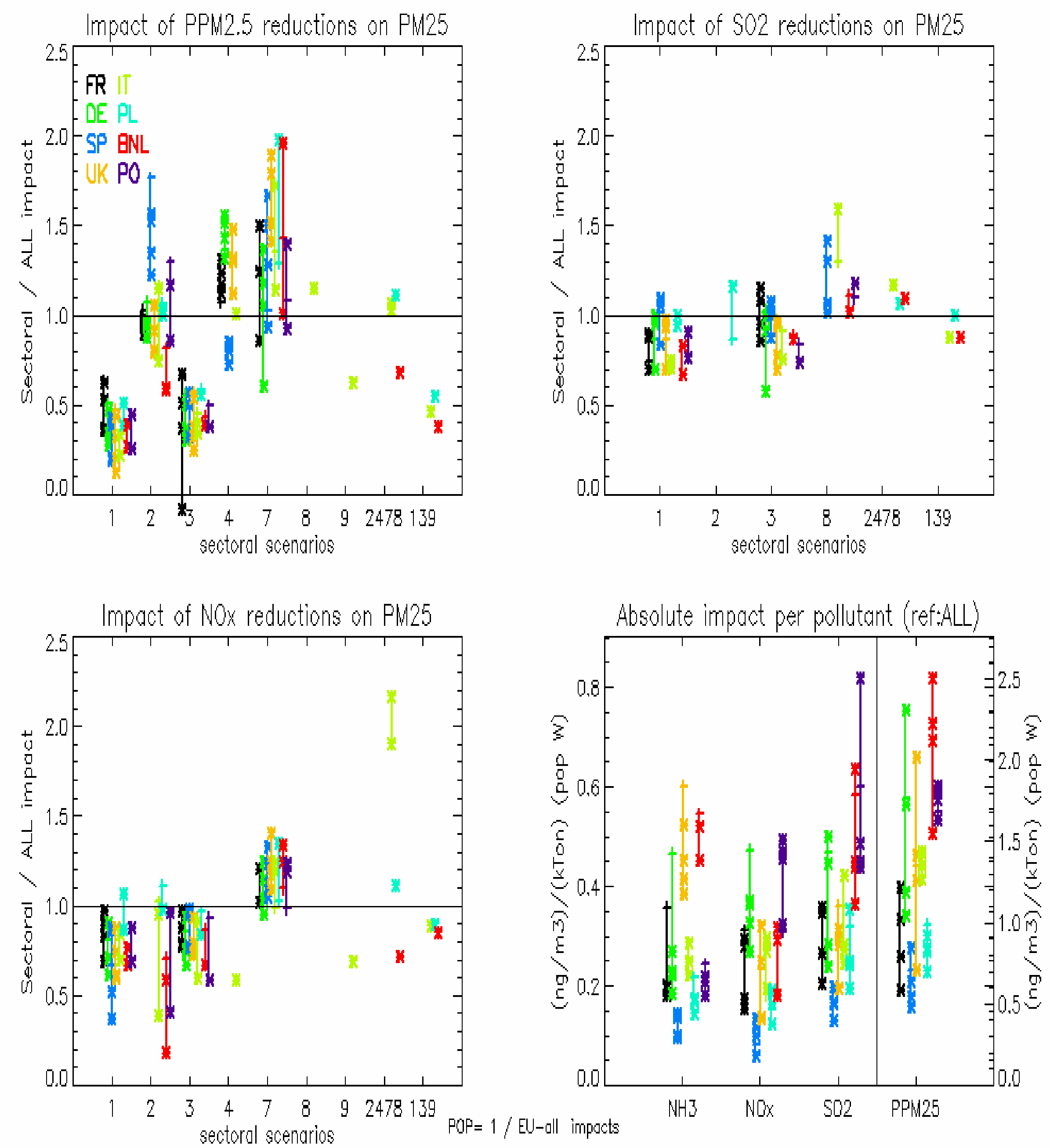


Figure 7: Comparison of sectoral to "ALL" potencies on PM2.5 concentrations for emission reductions in PPM2.5 (a), NOx (b) and SO2 (c) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower right figure provides model results for the absolute potency for different precursor emissions. The vertical black line separates the variables which are scaled on the left axis (NH3, NOx and SO2) from those to be read on the right axis (PPM2.5). Potencies are population weighted at the EU-all scale.

5.4. Response of SOMO35 to changes in precursor emissions

Figure 8 and Figure 9 show the effect on SOMO35 of reducing NOx and VOC emissions over the two receptor areas (country and EU-all).

For the relative response the “ALL” scenario (top left and top right in Figure 8Figure 8 and Figure 9) is compared with controls on sectors 1, 2, 3 and 7 for NOx and with controls on sectors 4, 6 and 7 for VOC through the usual ratio defined in Equation 2. The effect of combining sectors 2, 4, 7, and 8 on one hand and sectors 1, 3 and 9 on the other is also shown for available model results.

The absolute potency of the “ALL” approach for NOx and VOC emission reductions is shown in the bottom part of the figures. The differences among countries are very large for NOx emission reductions and very small for VOC emission reductions. This might partly due to the generally low impact of changes of VOC-emissions on O3 and partly due to the large differences in background O3 (and NOx) levels between the different countries.

The sectoral responses to NOx emission reductions show strong differences among countries especially in sectors 1 and 3 mostly composed of point source emissions. For most countries with the exception of UK and the Benelux the sector 1 potency is lower than that of the traffic sector. This is marked in France where the potency is about 3-5 times less than that of sector 7 which has the highest potency. In Germany and Spain there is very little difference between any of the sectors. In the UK the potency is small and varies between having a beneficial and a negative effect.

The model variability in the sectoral potency ratios is very large for NOx control in UK and in the Benelux and for VOC controls in Spain, Italy and France whereas the model variability in terms of absolute potencies is rather contained and is similar for all countries. This high variability observed for the relative potencies might be explained by the low (close to zero) absolute potencies obtained for these countries.

At the country scale all models agree that the strongest overall response to NOx reductions (see bottom left figure) is in the Po valley followed by Spain and Italy whereas for the Benelux and in a less measure UK some models predict a net increase in SOMO35.

If we consider a larger receptor size (EU-all), the country ranking in terms of absolute potency to NOx emission reductions is modified. Italy and Spain show the highest potencies, UK, Benelux and Germany the lowest. For VOC controls, all models agree with similar and very low potencies across all countries.

Results for population weighted potencies are shown in Figures 10 and 11 and are very similar to the surface weighted ones. The area weighted potency is in general smaller than the population weighted potency although some exception occurs. For example Spain where the correlation between emission and population is quite low in all sectors (excepted for PPM2.5 emissions in sector 2) shows lower potencies for population weighting.

It was assumed at the outset of the work that the coupling between SO2 chemistry and ozone production would be much weaker than the effect of VOC's on ozone. Furthermore, because SO2 and VOC emission sources are not strongly correlated (and we do not study secondary organic aerosols) there was a mindset that the two pollutants could be treated as independent. As a consequence the SO2 and VOC reduction scenarios were paired. No VOC only reduction scenarios were carried out to test the assumption of independence. It is therefore not possible to be entirely sure that the values reported below are all attributable to VOC. Furthermore, because ozone concentrations can go up or down in response to emission changes depending on several factors and with high spatial variability there may not be a consistent direction of effect on integrated measures such as country averaged SOMO35. The results regarding the potencies to VOC controls should therefore be considered preliminary.

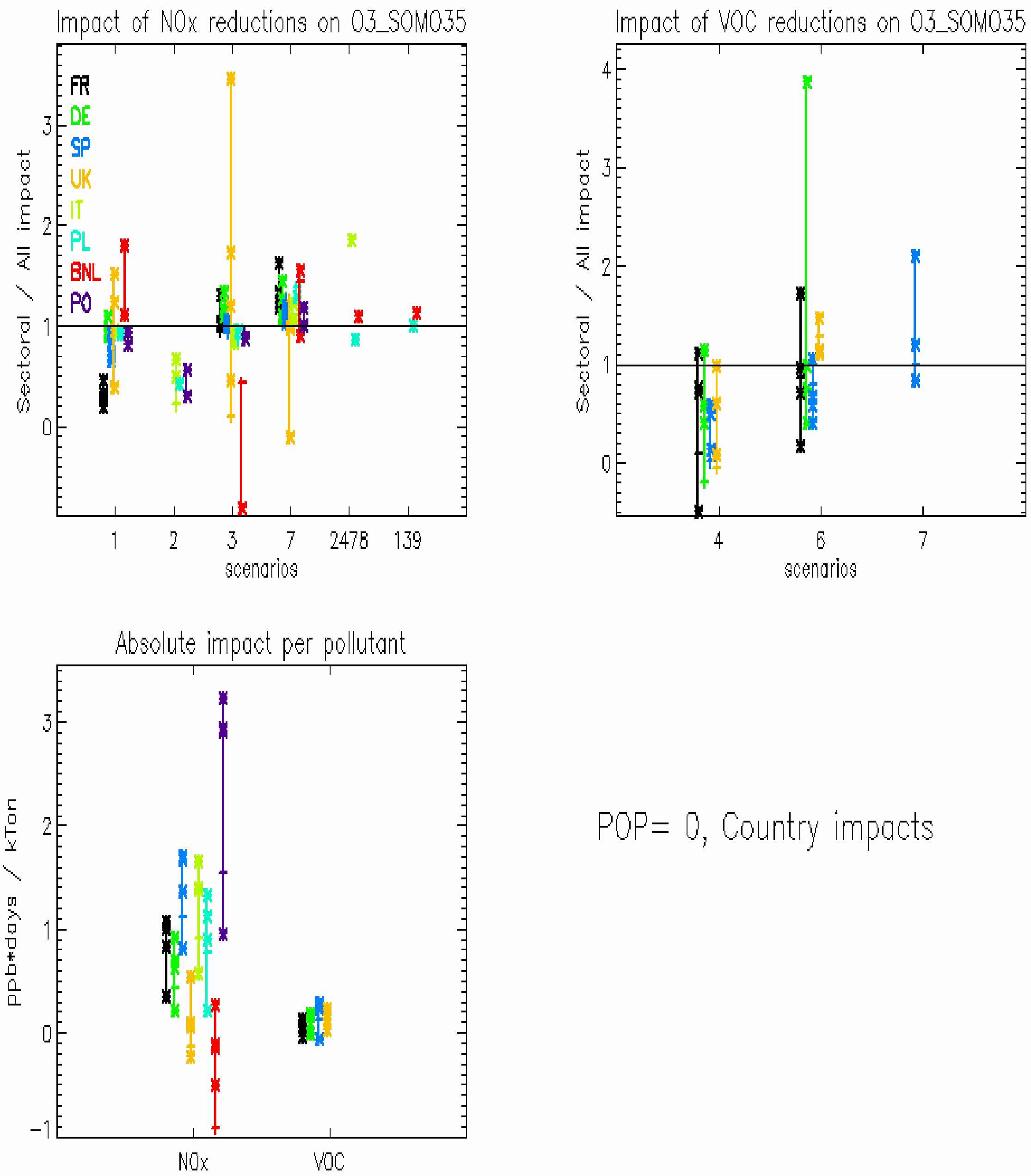


Figure 8: Comparison of sectoral to “ALL” potencies on SOMO35 levels for emission reductions in NOx (a) and VOC (b) precursors. Indications “2478” and “139” indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Potencies are area weighted at the country scale.

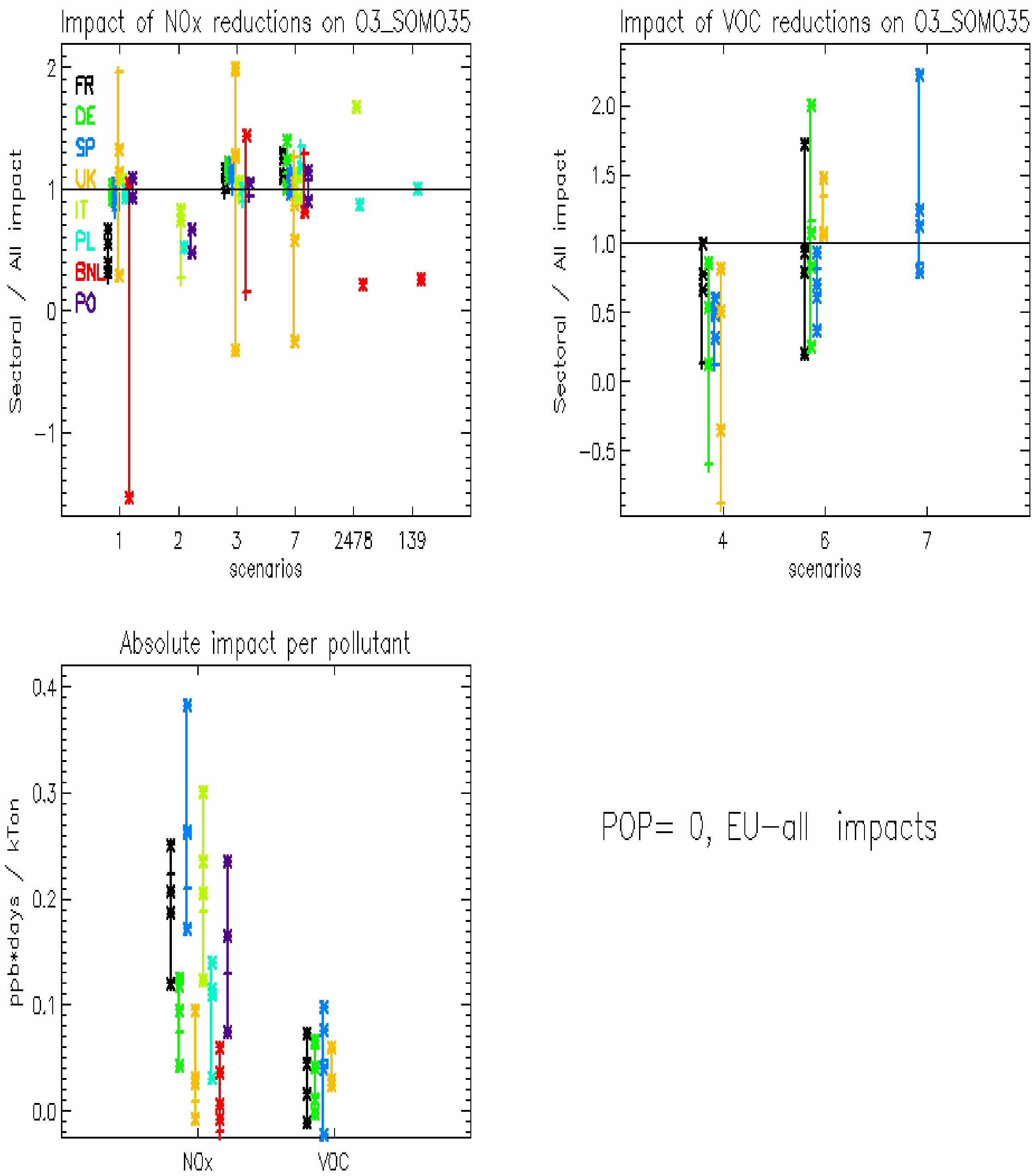


Figure 9: Comparison of sectoral to "ALL" potencies on SOMO35 levels for emission reductions in NOx (a) and VOC (b) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Potencies are area weighted at the EU-all scale.

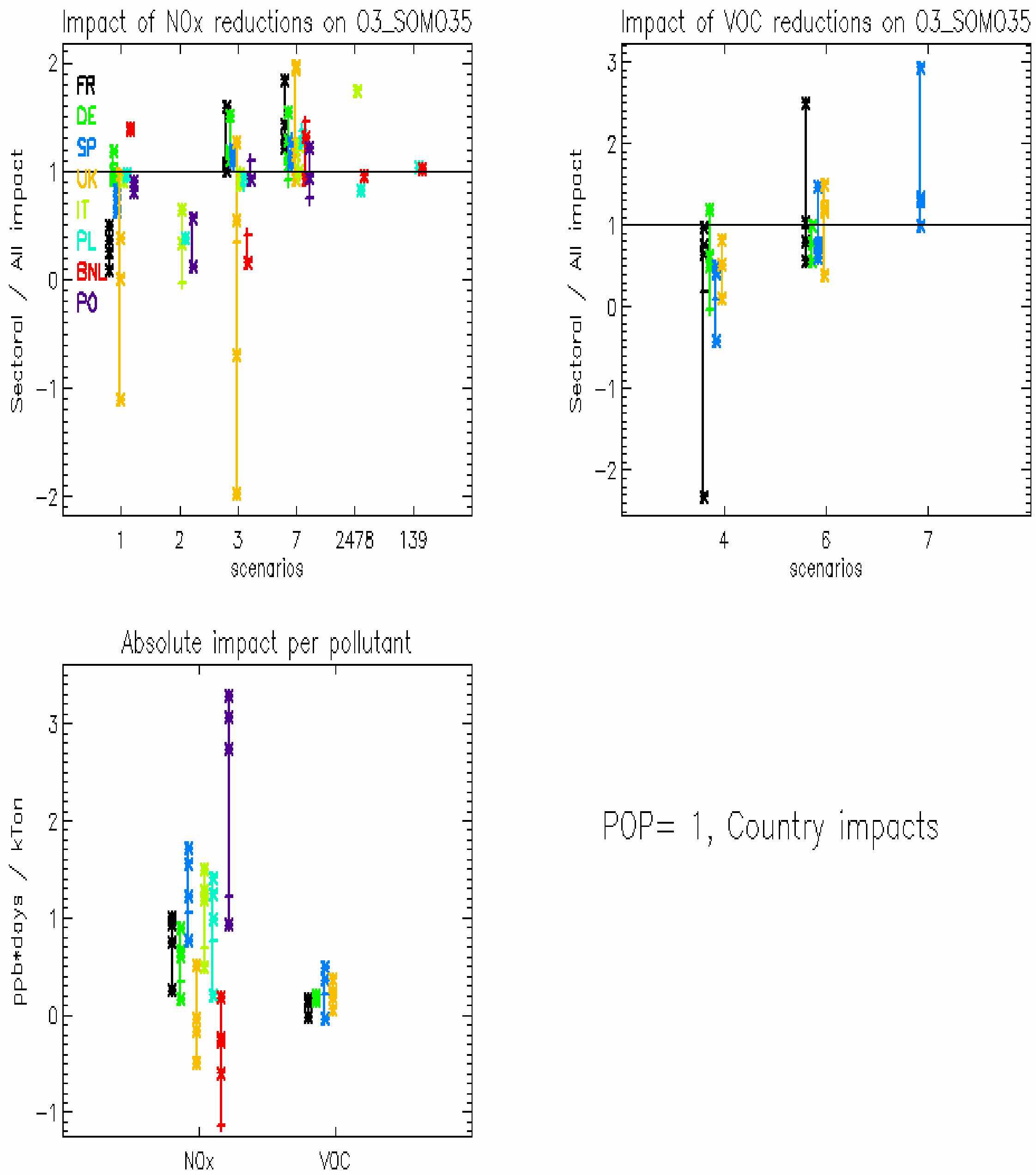


Figure 10: Comparison of sectoral to "ALL" potencies on SOMO35 levels for emission reductions in NOx (a) and VOC (b) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Potencies are population weighted at the country scale.

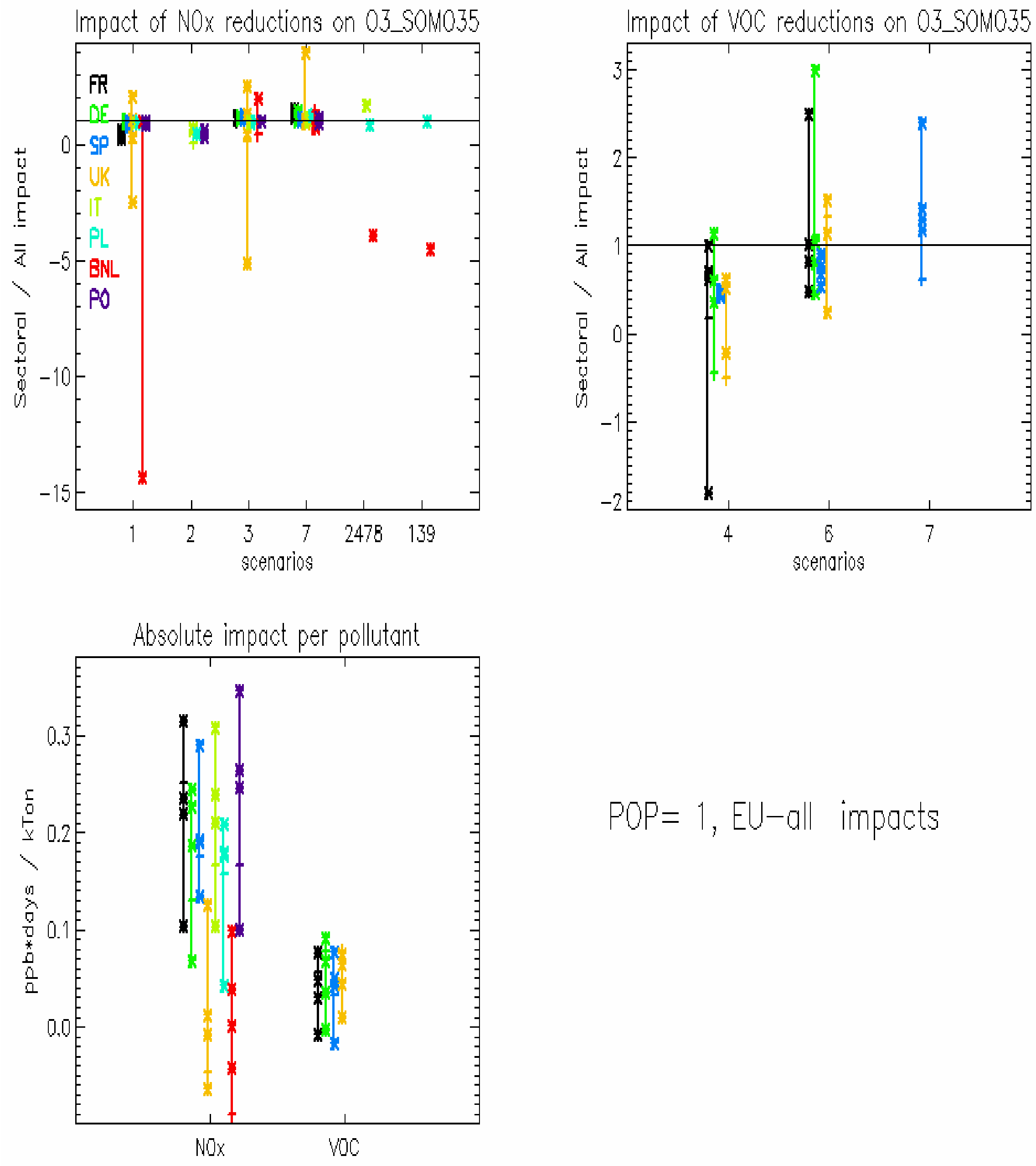


Figure 11: Comparison of sectoral to "ALL" potencies on SOMO35 levels for emission reductions in NOx (a) and VOC (b) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Potencies are population weighted at the EU-all scale.

5.5. Response of depositions to changes in precursor emissions

Figures 12 to 13 show the change in deposition density of oxidized Nitrogen and Sulphur deposited in the two receptor areas defined previously. The top (nitrogen) and middle (sulfur) figures show the sectoral potencies as compared to the “ALL” scenario (see Equation 2) whereas the bottom figure compares the change in deposition density per unit of emission for emission reductions in the three precursors NOx, SO2 and NH3.

For NOx emission reductions, deposition amounts are a factor 2 larger for traffic than for sector 1, 2 or 3 at the country scale. This is consistent with a greater proportion of emissions from tall stacks contributing more to transboundary transport. However it is a bit surprising that the sector 2 results show a reduced potency compared to “ALL” but it is difficult to draw conclusions since sector 2 scenarios have been performed only for Poland which stands relatively close to the border of the EU-all domain included in the study. When increasing the size of the receptor area differences among sectoral potencies decrease significantly and the factor 2 found at the country scale becomes close to 1 at the EU-all scale as would be expected. At the EU-all scale, differences across models and countries are limited.

For SO2 controls the conclusions drawn for NOx controls remain valid except for sector 2 which now shows a higher efficiency than the “ALL” approach as obtained for all other end-point variables (PM2.5 and SOMO35).

The bottom parts of figures 12 and 13 provides a comparison of the deposition amount corresponding to emission reductions for the “ALL” scenario for the three precursors: NOx, NH3 and SO2. Results are visualized in terms of integrated delta (obtained by multiplying the deposition densities by the area of the selected receptor) which allows visualizing the amount of the emission which deposits in the selected receptor area. Results are therefore expressed in tons deposited per emitted ton.

As seen from Figure 12 and 13 (bottom parts):

- Deposition of nitrogen in the country of emission change is generally less than that of Sulphur indicating greater transboundary transport of Nitrates.

- The amount of Sulphur and Nitrate retained on land in the whole domain is approximately twice that retained in the country of emission (excepted for the Benelux and the UK where this ratio is closer to 3).

- Only about half of all Nitrogen emission reduction is accounted for by deposition to land within the EU-all domain.

- Dispersion is of much shorter range for reduced than for oxidized nitrogen with much more retained in the domain. This is explained by the fact that reduced nitrogen is only released as a surface source and has a very high deposition velocity already in the NH3-form while NOx is partly released from higher stacks and also need to be oxidized to be efficiently deposited.

Figures 14 and 15 examine the dry and wet deposition contributions to total deposition. It can be seen that the sectoral differences lie in the dry deposition contribution. The wet deposition is governed by the pattern of precipitation and affects all source sectors equally.

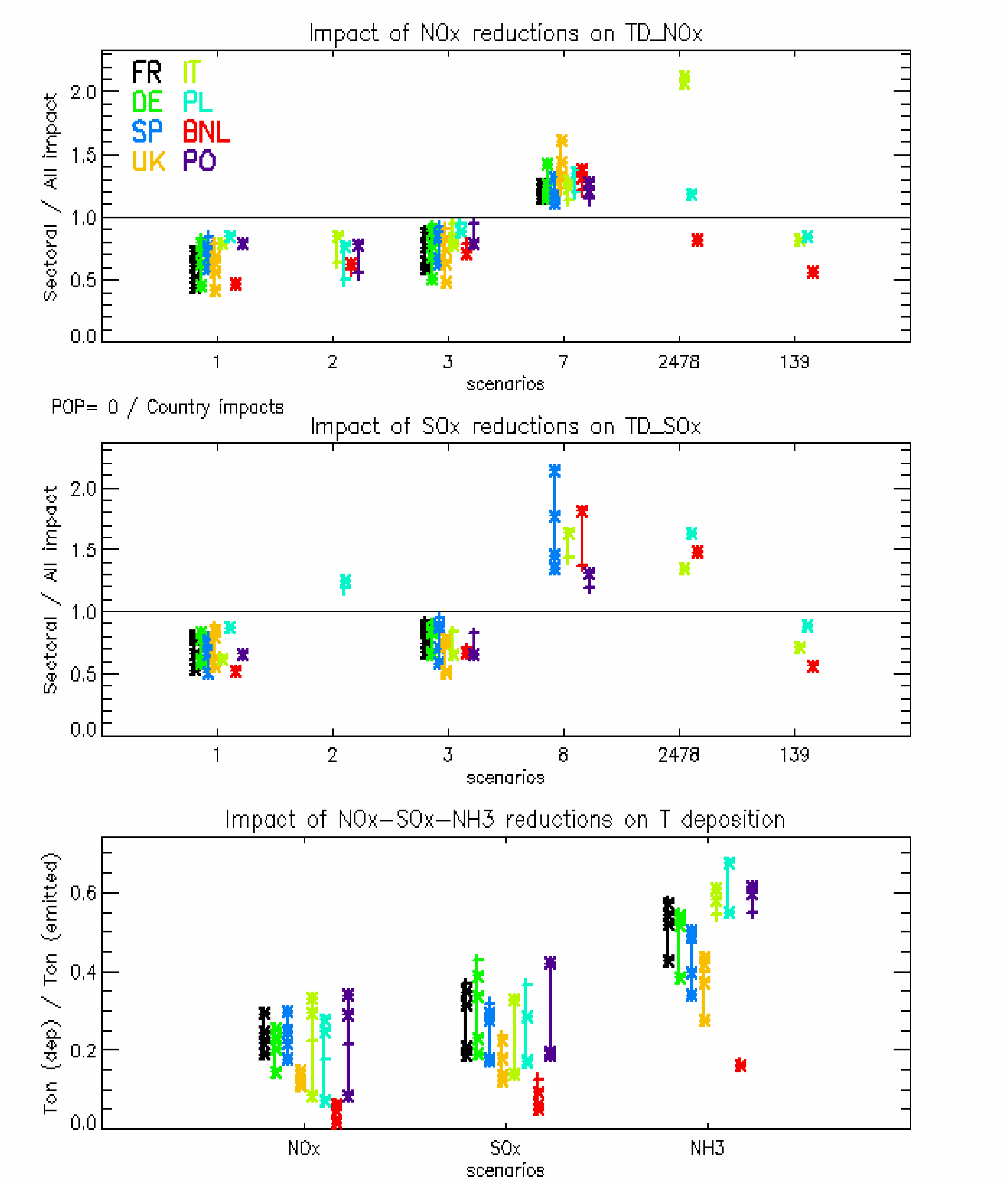


Figure 12: Comparison of sectoral to "ALL" potencies on oxidized nitrogen and sulfur total depositions levels for emission reductions in NOx (a) and SO2 (b) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Results are expressed in tons deposited per emitted ton. Potencies are expressed at the country scale.

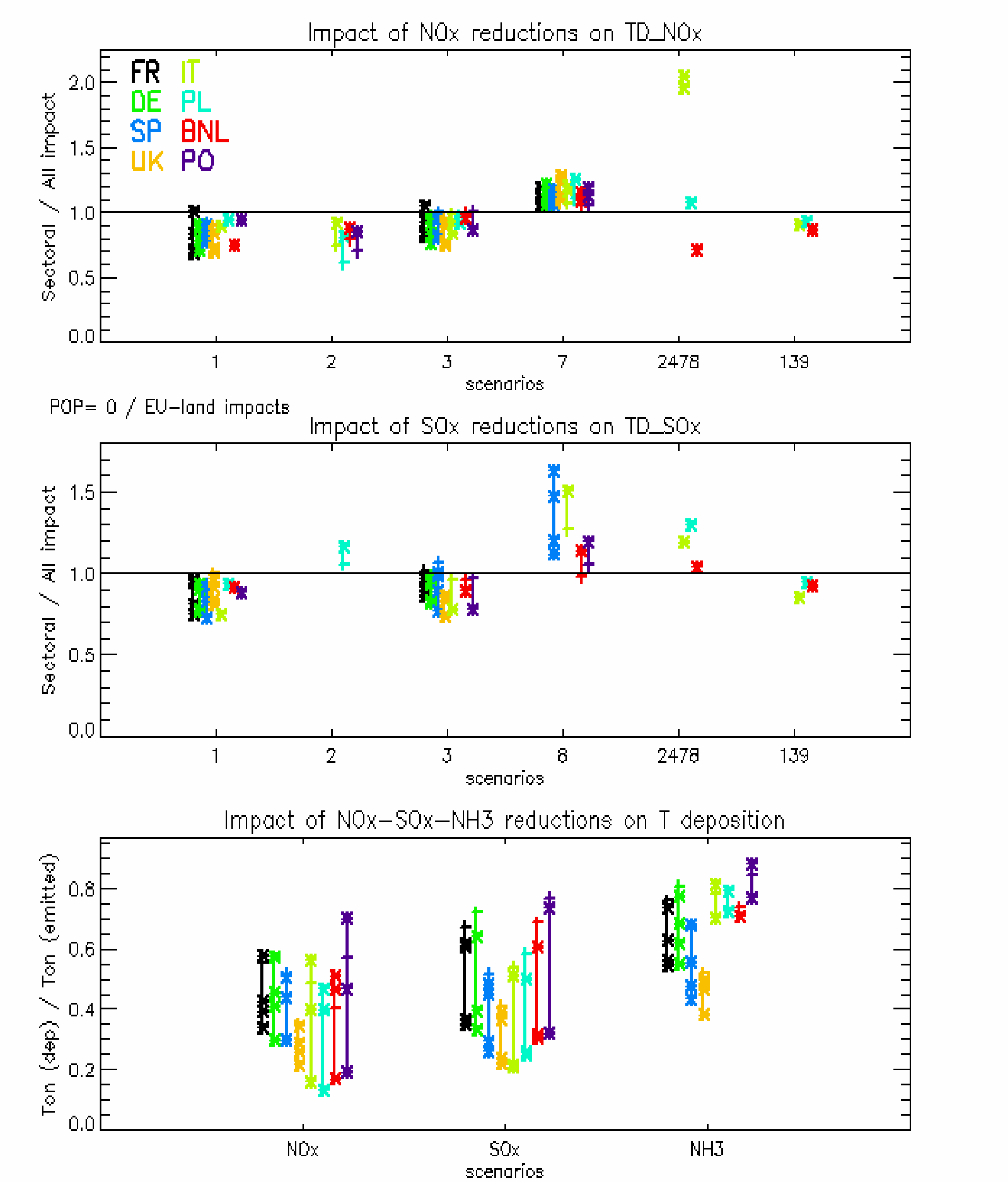


Figure 13: Comparison of sectoral to "ALL" potencies on oxidized nitrogen and sulfur total depositions levels for emission reductions in NOx (a) and SO2 (b) precursors. Indications "2478" and "139" indicate scenarios where emission reductions are operated on a group of sectors. Each vertical line links the model results available for the given scenario with a + and * to represent the EMEP and any other model, respectively. The lower figure provides model results for the absolute potency for different precursor emissions. Results are expressed in tons deposited per emitted ton. Potencies are expressed at the EU-all scale

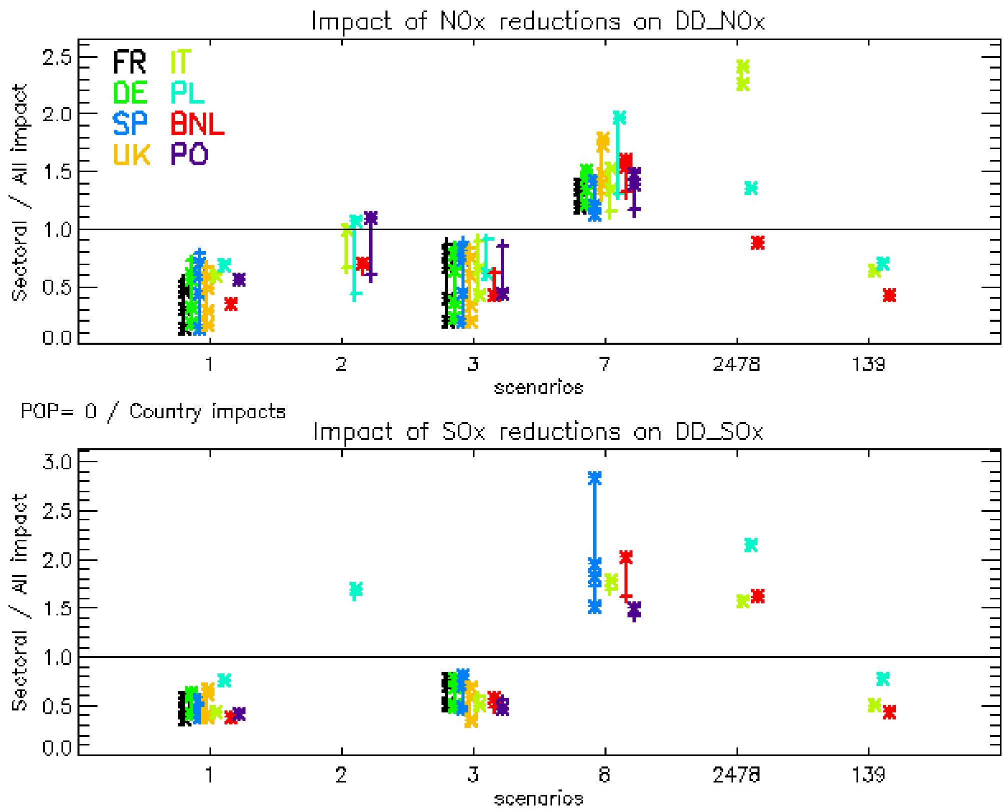


Figure 14: Same as figure 13 (a and b) but for dry deposition. Potencies are expressed at the country scale.

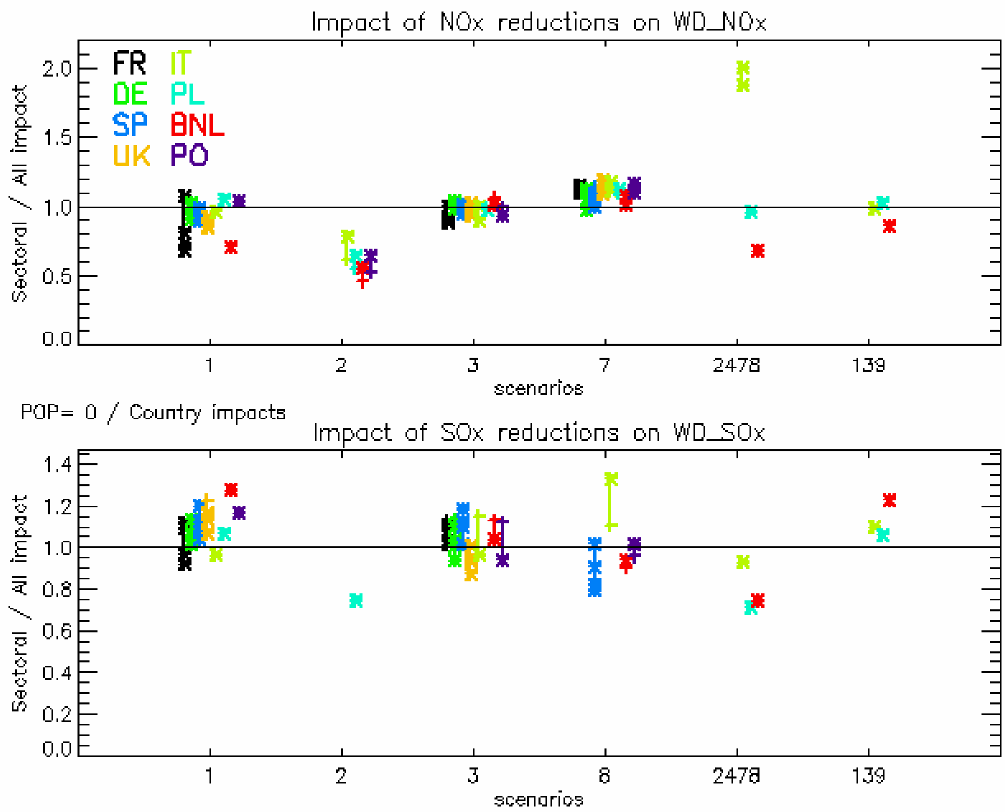


Figure 15: Same as figure 14 but for wet deposition. Potencies are expressed at the country scale.

6. Conclusions and recommendations

The Joint Research Centre of the European Commission working with five internationally recognized air quality modeling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden) has developed the EuroDelta II project toolkit. The modeling teams have explored about 100 emission scenarios to explore how environmental impacts (depositions and concentrations) depend on land-based sectoral emission changes.

This report has summarized some of the results that can be derived from the toolkit. We have examined deposition, both of oxidized and reduced nitrogen; the concentration of fine particulate matter and SOMO35; an ozone measure relevant to human health effects. Aggregate measures have been used to express the effect of an emission change on conditions within the country of change and within the whole modeling domain.

The domain approximates the EU-27 and includes most countries of the European Union. The United Kingdom (except Northern Scotland), France, Germany, the Benelux, Italy, Poland and Spain, in which the sectoral emission reductions are tested, are well within the domain. These seven countries account for 75% of the total EU-27 population.

The EuroDelta II project was motivated by interest in whether emission reductions in different industrial sectors would necessarily have the same effectiveness in reducing environmental impacts across Europe. Here effectiveness is measured by the change in impact per change in emission.

The SR relationships used to determine how country wide emissions contribute to impacts in individual EMEP grid squares are derived by perturbing national emissions, and in so doing, assigning emission reductions proportionately across all sectors. On the other hand, when designing policy on a cost-effectiveness basis which is at the heart of integrated assessment methods, controls on those sectors where sufficient emission reductions can be achieved at least cost are likely to be preferred.
If there is a mismatch in the assessed effectiveness of sectoral emission reductions, particularly if a sectoral reduction is less effective than thought, this could lead to either underachievement in the ambition to meet an environmental improvement target or an underestimate of the cost of achieving it. Either of these would have serious consequences for a country making choices as to how to achieve its national emission ceiling.

We summarize below the main findings of the Eurodelta II study:

<u>Regarding particulate matter</u>:

- All the models agree that there are differences in effectiveness of emission reductions between sectors. This is broadly consistent with a physical interpretation that the more effective reductions are for sectors where proximity of emission to people is greatest. Thus, higher effectiveness is seen from sectors emitting at low level and distributed according to population and lower effectiveness is seen for sectors emitting from large point sources as these are fewer in number, emissions are released from great height (taking plume rise into account) and generally the association with populated areas is lower.

- The differences between sectors are greater for population weighted compared with non-weighted concentrations.

- The above is true whether the impact is assessed EU wide or in the country in which the emission controls take place.

- All models show that the 'ALL' scenario gives a significantly different effectiveness to the sectoral effectiveness and this applies to all the pollutants contributing to PM2.5 concentrations (NOx, SOx, PPM2.5).

- The sectoral response is not the same in all countries and is different for each pollutant and in particular the potency of ammonia emissions as they affect PM2.5 is much larger (by a factor of two) in the UK and the Benelux than for other countries.

A table summarizing the country-model average ratio (of the sectoral to "ALL" potencies) is provided in the table below.

PM2.5			Sectors					
			1	2	3	4	7	8
Area-W	Country	PPM2.5	0.29	0.96	0.37	0.96	1.31	
		SO2	0.77	1.30	0.70			1.25
		Nox	0.63	0.80	0.71		1.23	
	EU-all	PPM2.5	0.42	0.98	0.47	0.95	1.18	
		SO2	0.94	1.05	0.80			1.10
		Nox	0.79	0.89	0.84		1.10	
Popul-W	Country	PPM2.5	0.25	1.04	0.33	0.92	1.45	
		SO2	0.72	1.28	0.67			1.39
		Nox	0.61	0.69	0.69		1.28	
	EU-all	PPM2.5	0.37	1.04	0.44	0.95	1.33	
		SO2	0.88	1.02	0.77			1.20
		Nox	0.76	0.75	0.82		1.15	

Table 7: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the 'ALL' scenario effectiveness) for PM2.5 concentrations. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (PPM2.5, NOx and VOC).

<u>Regarding ozone (as measured by SOMO35)</u>

- There are considerable country differences in the response of SOMO35 to NOx reductions, especially in the sectors 1 and 3 which correspond to point source emissions. Sector 1 controls in France and sector 2 controls in all countries (Italy, Po-Valley, Benelux and Poland) have less effect than the 'ALL' scenario. A large model variability is visible especially for controls in Sector 1 and 3. In the Benelux and in the UK SOMO35 is predicted to increase rather than decrease with

NOx reductions. Unfortunately it is not possible to fully assess the response of the grouped scenarios since not all individual sectoral scenarios composing the group have been performed.

- There are considerable model differences in the response of SOMO35 to VOC reductions for all sectors and countries considered. VOC emission reductions in the traffic sector are more effective in Spain (only country considered for this traffic scenario) than the "ALL" scenario whereas reductions in sector 4 are generally less effective than the "ALL" scenario for all countries.

A table summarizing the country-model average ratio (of the sectoral to "ALL" potencies) is provided here below.

SOMO35			Sectors					
			1	2	3	4	6	7
Area-W	Country	NOx	0.82	0.45	1.01			1.15
		VOC				0.42	1.00	1.27
	EU-all	NOx	0.84	0.55	1.13			1.06
		VOC				0.18	0.83	1.08
Popul-W	Country	NOx	0.67	0.33	0.84			1.25
		VOC				0.28	1.00	1.56
	EU-all	NOx	0.14	0.45	0.89			1.21
		VOC				0.25	1.07	1.38

Table 8: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the 'ALL' scenario effectiveness) for SOMO35. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (NOx and VOC).

Regarding deposition:

- Differences in sectoral efficiency were more varied for oxidized Sulfur deposition than for oxidized Nitrogen deposition. The previous study found less difference..

- Deposition of nitrogen in the country of emission change was generally less than that of Sulphur indicating greater transboundary transport of Nitrates. The amount of Sulphur and Nitrate retained on land in the whole domain was generally about twice that retained in the country of emission. If retention in the entire domain (EU-all) was considered only about half of all Nitrogen and Sulphur emission reduction is accounted for by deposition to land within the domain. Sectoral differences are driven by dry deposition. Precipitation patterns determine wet deposition.

- For Sulphur, all models predicted that emission reductions in sectors 1 and 3 were less effective than the ALL scenario. For Nitrogen, this was the case for sectors 1, 2 and 3. Emissions reductions in sector 7 were generally more effective than the 'ALL' scenario both for Nitrogen and Sulphur.

- Sectoral differences were less marked when looking at the whole domain than when looking at individual country results.

- Reduced nitrogen deposition is dominated by the agriculture sector and so relative efficiencies do not apply. Dispersion was of much shorter range than for oxidized nitrogen and Sulphur with much more retained in the domain.

- A useful extension of this work would be to include information on detailed ecosystem impacts (critical loads, forest, crops and ecosystem locations) as weighting factors for the deposition calculations.

A table summarizing the country-model average ratio (of the sectoral to "ALL" potencies) is provided here below.

Deposition			Sectors				
			1	2	3	7	8
Area-W	Country	Nox	0.66	0.66	0.78	1.25	
		SO2	0.71	1.22	0.65		1.53
	EU-all	NOx	0.83	0.79	0.91	1.13	
		SO2	0.87	1.11	0.78		1.25

Table 9: overview of the relative effectiveness ratios (sector scenario effectiveness divided by the 'ALL' scenario effectiveness) for deposition. Results are classified in terms of weighting (area vs. population), spatial averaging scale (country vs. EU-all) and reduced precursor emissions (NOx and SO2).

This study has shown that there are important differences between sectors in the amount of concentration (deposition) reduction obtained by changing a pollutant emission. This difference is not accounted for in the present process used to evaluate future national emissions ceiling reductions for both beneficial effect and cost-effectiveness. This raises the possibility that, when national bodies consider how to implement an emission ceiling taking account of the current policy information used in deriving that ceiling, choices might be made that are less effective than expected in delivering the sought-for environmental improvements.

These findings are very significant. They suggest that sectoral emission reduction burden may be being incorrectly calculated. It is therefore recommended that, at a minimum, validation calculations are carried out as part of the NEC process to examine if the implied sectoral reductions are able to deliver the intended benefits.

Recommendations for emission ceilings should carry a qualifier describing the sectoral share of reductions that is necessary to meet the intended environmental goals.

If sectoral weights could be incorporated into the integrated assessment itself then this may lead to not only a an overall better recommendation for emission ceilings but greater environmental gains for the same cost of controls.

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ANNEX: MODELS DESCRIPTION

	RCG	MATCH	EUROS-LOTOS	EMEP	CHIMERE
Reference	Free University of Berlin Stern et al. 2006 Beekmann et al.,2007 Stern et al. 2007	Swedish Meteorological and Hydrological Institute Gidhagen et al., 2005 Andersson et al., 2007 Langner et al., 2005 Langner et al., 1998a.	TNO Schaap et al.. 2005, 2008	Norwegian Meteorological Institute Simpson et al. 2003 Fagerli et al. 2004	INERIS Schmidt et al. 2001 Vautard et al. 2001 Vautard et al. 2003 Bessagnet et al. 2004
Model Configuration	- grid resol: 05x0.25 deg - Grid config: 80x123x5 - 1st vertical level: 20m - vertical extent: 3000m	- grid resol: 0.4x0.4 deg - Grid config: 84x106x14 - 1st vertical level: 60m - vertical extent: ca 5500 m	- grid resol:: 0.50x0.25 deg - Grid config: 100x140x4 - 1st vertical level: 25m - vertical extent: 3500 m (V1.2)	- grid resol: ca 50 x 50 km - Grid config: 132x111x 20 - 1st vertical level: 90m - vertical extent: ~16000m	- grid resol: 0.5x0.5 deg - Grid config: 70x44x8 - 1st vertical level: ca 20 m - vertical extent: 500 hPa
Meteorology	Diagnostic meteorological analysis system based on optimum interpolation on isentropic surfaces (TRAMPER).	numerical weather prediction (NWP) model HIRLAM	Diagnostic meteorological analysis system based on optimum interpolation on isentropic surfaces (TRAMPER).	3-h resolution meteo data from PARLAM-PS. This is a dedicated version of the HIRLAM numerical weather prediction (NWP) model, with parallel architecture and same resolution as the CTM EMEP model	1°x1°(ECMWF) data refined by MM5 simulations (36 km in resolution)
BC	Based on observations at background locations, for O3 based on Logan's O3 climatology	Partly based on observations at background locations and partly on large-scale model calculations	For O3, based on Logan database. For PM and its components based on observations	For O3, 3D fields are specified from observations from Logan and then adjusted to ensure consistency. For other components, interpolation based on observations.	_For gas phase_, monthly average values of the LMDzINCA climatological simulations. _For particulate_, monthly averaged GOCART model simulation for dusts, organic and black carbon, and sulfate.
	Addition of 3 ppb for 2020 background ozone				
	RCG	**MATCH**	**EUROS-LOTOS**	**EMEP**	**CHIMERE**
Emissions					
VOC Split	Mass-based, source group dependent NMVOC profiles	Mass-based, source group dependent NMVOC profiles	Mass-based, source group dependent NMVOC profiles	Mass-reactivity weighting of real emission following Middleton et al.	- AEAT speciation (AEAT, 2002. - Mass-reactivity weighting of real emission following

				(1990)	Middleton et al. (1990)
PM Split	For PM2.5 and coarse PM: PM2.5 divide into mineral dust, EC and primary OC. For the OC and EC fractions in PM2.5 see Stern et al. 2008	PPM emissions split into three size bins (Aitken, accumulation and coarse mode). 5% of the anthropogenic SOx-emissions are assumed to be sulphate	PPM2.5 and PPM10-2.5. Of all Sox emissions 2% is assumed to be sulphate	Only primary split into two modes (PM2.5 and PM10)	Only primary split into two modes (PM2.5 and PM10)
Biogenic	- E94 emission factors for isoprene and OVOC - Other VOCs as in Simpson et al. (1995). - Terpene emission factors taken from CORINAIR - Light intensity and temperature dependencies considered.	- E94 emissions factors for isoprene - Oceanic sulphur treated as SO2. - Volcanic sulphur split into 89% SO2, 2.2% sulphate and rest unreactive	- isoprene emissions are calculated following Veldt (1991)	Isoprene and alpha-pinene computed according to Simpson et al. (1995), -Volcanic Sulfur as SO2. -DMS from oceans from Tarrason et al. (1995)	- computed according to Simpson et al. (1995), for alpha-pinene, NO and isoprene - Volcanic Sulfur: 99% SO2, 1% sulfate
Soil NO	- function of fertilizer input and temperature (Simpson et al., 1995).	None	None	Not included	- function of fertilizer input and temperature (Simpson et al., 1995).
Other	No NOx from ligthning			Nox emissions from lightning from Kohler et al. 1995	No Nox from lightning. HONO emission set to 13% of NO2
Temporal factors	As specified from Eurodelta Web page				
Height releases					
	RCG	**MATCH**	**EUROS-LOTOS**	**EMEP**	**CHIMERE**
Gas Chemistry					
Scheme	- updated CBM-4 - Carter's 1-Product Isoprene scheme - Homogeneous and heterogeneous conversion of NO2 to HNO3 - Aq. phase conversion of SO2 to H2SO4, through oxid. by H2O2 and O3. - Equilibrium concentrations for	- Simpson et al. (1993) - Carter's 1-Product Isoprene scheme. - Aqueous phase conversion of SO2 to H2SO4, through oxidation by H2O2 and O3. -Equilibrium concentrations for SO2, H2O2 and ozone from Henry	TNO CBM-IV scheme (Schaap et al., 2005) Heterogeneous formation of sulphate represented by an effective first order rate constant depending on RH and cloud cover. (Schaap et al. 2004a)	EMEP/MSC-W scheme (Andresson-Skold and Simpson, 1997, 1999)	MELCHIOR-2 -(lattuati, 1997, based on the EMEP mechanism) -Heterogeneous reactions for HNO3 formation. -Acqueous phase conversion of SO2 to H2So4 through oxidation by H2O2 and O3 (pH in the range [5-6].

	SO2, H2O2 and ozone from Henry constants and assuming progressive cloud cover for relative humidity above 80%. - Effective rate constants for aqueous phase reactions SO2+H2O2 and SO2+O3 calculated for an average pH of 5 using acid / base equilibrium and kinetic data from Seinfeld and Pandis (1998).	constants using NWP cloud cover and cloud water content. Effective rate constants for aqueous phase reactions SO2+H2O2 and SO2+O3 calculated for an average pH of 5	N2O5 oxidation on aerosols explicitly calculated (Schaap et al. 2004a)		-Isoprene and terpene chemistry
Numerics	QSSA solver with variable time step	Rosenbrock solver, "RODAS-3" (Sandu et al. 1997)	TWOSTEP	TWOSTEP	TWOSTEP
Species & reactions	42 species, 96 reactions	130 reactions and 61 chemical components.	28 species and 66 reactions	71 species and 130 reactions	44 gas-phase species
	RCG	**MATCH**	**EUROS-LOTOS**	**EMEP**	**CHIMERE**
Aerosol Chemistry					
Species	PM10, PMcoarse, PPM2.5, EC, OCprim , SOA, SO4, NO3, NH4, Na+, Cl-	PPMcoarse, PPM2.5, EC, OCprim , SO4, NO3, NH4	*SO_4, NO_3, NH_4, SOA from terpenes,* PM2.5, PMC, BC, sea salt	SO4, NO3, NH4, sea salt, PM2.5, PMcoarse, PPM2.5, PPMcoarse	Sulfate, Nitrate, Ammonium, SOA, PPM, water, wind blown dusts
Approach	Bulk approach		Bulk approach	Bulk approach	Sectional approach
Bin number		3 size bins for PPM	Fine and coarse	Fine and coarse	4 bins betw. 40 nm and 10 um.
Equilibrium module	ISORROPIA	NH4NO3 ←→NH3+HNO3 RH & T dependent equilibrium constant (Mozurkewich, 1993)	ISORROPIA	EQSAM (Metzger et al. 2002) or alternatively RH & T dependent equilibrium constant (Mozurkewich, 1993)	ISORROPIA
SOA	SORGAM module + terpenes, pinene, limonene.	Not included	Not used in this study	Not used in this study	Included for both anthropogenic and biogenic
Resuspension	- function of friction velocity and soil nature for mineral aerosol. - both direct and indirect entrainment of	None	Not used in this study	Not used in this study	Telluric dusts from local erosion or from boundaries and resuspended particles are included

	small particles - saltation is accounted				
Sea-salt	function of size and wind speed (Gong et al., 1997)	Not used in this study	Not used in this study	Not used in this study	not included
Other		- Only few chemical reactions for ammonia-ammonium conversion - No aerosol dynamics included (except deposition and hygroscopic growth).		No aerosol dynamics included, no chemical speciation of primary aerosol included in this study	
Coarse SIA	No coarse SIA, all SIA components are assigned to PM2.5	All SIA components are assigned to PM2.5	All SIA components are assigned to PM2.5	Coarse NO3 formation (on sea salt) included depending on relative humidity	- Coarse nitrate not included - Part of nitrate, ammonium and sulphate in coarse mode. About 40 % of SIA is coarse.
	RCG	**MATCH**	**EUROS-LOTOS**	**EMEP**	**CHIMERE**
Dry deposition	Resistance analogy	- resistance approach depending on land-use (four different land-use) - PPM: Zhang et al., 2001	Resistance approach depending on land-use (9 land use classes)	Resistance approach depending on 16 landuse classes and varying by compound. -For ozone, stomatal flux calculations are included. -For ammonia and SO2, co deposition processes are included according to Smith et al. 2003.	Resistance approach (Wesely, 1989)
Wet Deposition	*Gases*: function of the species dependent Henry constant and precipitation rate. *Particles*: simple scavenging coefficient approach with identical coefficients for all particles.	Gases: proportional to precipitation and a species-specific scavenging coefficient Particles: In-cloud and sub-cloud scavenging are included	Below cloud scavenging is described using simple scavenging coefficients for gases (Schaap et al., 2004) and following Simpson et al. (2003) for particles. In-cloud scavenging is neglected.	Gases: proportional to precipitation and a species-specific scavenging coefficient, both in cloud and subcloud Particles: both in cloud and sub-cloud scavenging coefficients	*Gases*: function of the species dependent Henry constant and precipitation rate. *PM* In-cloud and sub-cloud scavenging are included

European Commission

EUR 24474 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: EURODELTA: Evaluation of a sectoral Approach to Integrated Assessment Modelling - Second report
Author(s): P. Thunis, C. Cuvelier, P. Roberts, L. White, Á. Nyiri, R. Stern, A. Kerschbaumer, B. Bessagnet, R. Bergström, M. Schaap
Luxembourg: Publications Office of the European Union
2010 – 55 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-16357-9
doi:10.2788/40803

Abstract

The EURODELTA project is a continuing collaboration between the European Commission Joint Research Centre (JRC) at Ispra (Italy) and five air quality modeling teams at Ineris (France), the Free University of Berlin (Germany), Met.no (Norway), TNO (Netherlands) and SMHI (Sweden). This phase of Eurodelta investigates how different air quality models would represent the effect on pollutant impacts of applying, on a European scale, emission reductions to individual emission sectors. The reason for doing this is to test whether there are important sensitivities not captured by the sound science approach to air quality policy making on a European scale which is based on an integrated assessment (IA) approach and embodied in the IIASA RAINS/GAINS model.
This study shows that there are important differences between sectors in the amount of concentration (deposition) reduction obtained by changing a pollutant emission. This difference is not accounted for in the present process used to evaluate future national emissions ceiling reductions for both beneficial effect and cost-effectiveness. This raises the possibility that, when national bodies consider how to implement an emission ceiling taking account of the information used in deriving that ceiling, choices might be made that are less effective than expected.

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LB-NA-24474-EN-C

ISBN 978-92-79-16357-9