Service Contract for Carrying out
Cost-Benefit Analysis of Air Quality Related Issues,
in particular in the
Clean Air for Europe (CAFE) Programme

Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas

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Executive Summary

This report provides the damage per tonne of pollutant ($PM_{2.5}$, SO_2, NOx, NH_3 and VOCs), accounting for variation in the site of emission by providing estimates for each country in the EU25 (excluding Cyprus) and for surrounding sea areas.

The new results include a number of refinements:

- They add NH_3 (ammonia) to the list of pollutant emissions considered (originally, just NOx, SO_2, $PM_{2.5}$ and VOCs were included).
- The countries for which results are provided have increased from the EU15 (excluding Luxembourg) to the EU25 excluding Cyprus.
- Dispersion modelling is based on the new EMEP model, with a 50 x 50 km resolution and updated chemistry and meteorology. The modelling was carried out for a series of scenarios where emissions for the baseline 2010 scenario were changed individually by country and pollutant.
- Dispersion modelling has provided data specific to the assessment of the four major sea areas around Europe (Eastern Atlantic, Baltic Sea, Mediterranean Sea and North Sea).
- Impact assessment has been carried out using the CAFE CBA methodology, published on the internet[1] in 2005. This includes refinements to the suite of health functions for which impacts have been assessed, updates to the functions and updates to the valuation. Crop damage assessment has also been performed, though at present there is no analysis of damage to materials. The omission of materials is of most significance for SO_2, though should not make a major difference to the results.

Summary results are presented in the table below as averages for the EU25 (excluding Cyprus) and the four sea areas considered, to show the order of magnitude of damages. The range takes account of variation in the method used to value mortality, reflecting the use of the median and mean estimates of the value of a life year (VOLY) from NewExt (2004) (€50,000 and €120,000 respectively), and the use of the median and mean estimates of the value of statistical life (VSL), also from NewExt (€980,000 and €2,000,000 respectively). The overall range shown also includes sensitivity to the range of effects included, and to the use of a zero cut-point for assessment of ozone impacts[2]. Detailed results with damages per tonne disaggregated to the level of country and sea area are presented in the main text.

In interpreting the data given in this and other tables presented in the report, it is essential to remember that a number of effects are excluded from quantification, including impacts on ecosystems and cultural heritage. Inclusion of these effects would further increase the results. A listing of effects included and excluded from the analysis is given in the main text.

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[1] http://europa.eu.int/comm/environment/air/cafe/index.htm

[2] The core analysis is based on use of a cut-point of 35 ppb for ozone impacts. No cut-point is used for assessment of $PM_{2.5}$ effects.

Average damages per tonne of emission of NH_3, NOx, $PM_{2.5}$, SO_2 and VOCs for the EU25 (excluding Cyprus) and surrounding sea areas under different sets of assumptions. Detailed results specific to each country and sea area are given in the main text.

PM mortality	**VOLY median**	**VSL median**	**VOLY mean**	**VSL mean**
O_3 mortality	**VOLY median**	**VOLY median**	**VOLY mean**	**VOLY mean**
Health core?	**Included**	**Included**	**Included**	**Included**
Health sensitivity?	**Not included**	**Not included**	**Included**	**Included**
Crops	**Included**	**Included**	**Included**	**Included**
O_3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
EU25 (excluding Cyprus) averages				
NH_3	€11,000	€16,000	€21,000	€31,000
NOx	€4,400	€6,600	€8,200	€12,000
$PM_{2.5}$	€26,000	€40,000	€51,000	€75,000
SO_2	€5,600	€8,700	€11,000	€16,000
VOCs	€950	€1,400	€2,100	€2,800
Seas averages				
NH_3	n/a	n/a	n/a	n/a
NOx	€ 2,500	€ 3,800	€ 4,700	€ 6,900
$PM_{2.5}$	€ 13,000	€ 19,000	€ 25,000	€ 36,000
SO_2	€ 3,700	€ 5,700	€ 7,300	€ 11,000
VOCs	€ 780	€ 1,100	€ 1,730	€ 2,300

Results are based on modelling a uniform relative reduction in emissions of each pollutant within each country. As such, they represent something of an average of damages between rural and urban emissions. Specific analysis of NH_3, SO_2 and VOCs comparing the effects of urban and rural release would make little difference to the results, given that the effects of these pollutants are mediated here through formation of secondary aerosols and ozone whose formation in the atmosphere requires time. For NOx, little difference is expected for impacts via secondary aerosol exposure, though impacts from ozone exposure would be likely to vary significantly between urban and rural sites. However, given that ozone damages are found here to be small compared to PM effects, this too should have little effect on the results. The one pollutant for which site of release is likely to be significant is (primary) $PM_{2.5}$. The results here for $PM_{2.5}$ cannot be considered to represent either the urban or the rural position, but something in-between. This issue requires further research, though the order of magnitude of the PM damages provides a useful indication that damages linked to this pollutant will be substantial.

The following improvements can be made to the data presented in this report:

1. Development of datasets for other years (2000, 2020).
2. Use of national demographic data (e.g. on birth and death rates) rather than EU25 (excluding Cyprus) averages.
3. Updating of crop damage models.
4. Updating of materials damage models.
5. Preparation of separate estimates of the impacts of rural and urban releases of fine particles.

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Introduction

Background and objectives

The objective of this analysis is to generate damage estimates per tonne emission for a range of air pollutants in different situations. The analysis recognises that the location of emission is important, and so distinguishes between countries and also between different sea areas in Europe, and between urban and rural emissions. Much interest was expressed in earlier work (Holland and Watkiss, 2002). As part of the Clean Air for Europe Programme the most recent data and methodological advances have been used to derive the new set of marginal damage of air pollution (AEAT 2005).

Updates

The results contained in this report update the earlier estimates in a number of ways:

- Impact assessment has been carried out using the CAFE CBA methodology, published on the internet in 2005. This includes refinements to the suite of health functions for which impacts have been assessed, updates to the functions and updates to the valuation. Crop damage assessment has also been performed, though at present there is no analysis of damage to materials. The omission of materials is of most significance for SO_2.[3]
- Dispersion modelling is based on the new EMEP model, with a 50 x 50 km resolution and updated chemistry and meteorology. The modelling was carried out for a series of scenarios where emissions for the baseline 2010 scenario were changed individually by country and pollutant.
- NH_3 (ammonia) has been added to the list of pollutant emissions considered (originally, just NOx, SO_2, $PM_{2.5}$ and VOCs were included).
- The countries for which results are provided have increased from the EU15 (excluding Luxembourg) to the EU25 (excluding Cyprus).
- Dispersion modelling has provided data specific to the assessment of the four major sea areas around Europe (Eastern Atlantic, Baltic Sea, Mediterranean Sea and North Sea).

Use of the methodology agreed for impact assessment and valuation in the CAFE-CBA analysis is important, as it means that the methods used to quantify impacts and perform valuation have been subject to intensive scrutiny and peer review. Three areas where methodological advances are most significant relate to:

- Change in scale used for the dispersion modelling (resolution increases by a factor of 9, going from 150 x 150 km to 50 x 50 km).
- The approach used for quantification of deaths linked to chronic exposure to fine particles. This is now carried out directly, rather than through the use of assumptions concerning the average loss of life years per death.
- The valuation of mortality effects, now based on survey work which is likely to better reflect the valuation of death in relation to air pollution.

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[3] Information on the CAFE CBA, including the methodology reports is provided at http://www.cafe-cba.org/ and http://europa.eu.int/comm/environment/air/cafe/index.htm

Overview of methods

Analysis contained in this report follows the impact pathway methodology developed in the ExternE Project funded by EC DG Research[4]. The pathway described by the analysis is as follows:

Emission of pollutants
→ Dispersion of pollutants
→ Exposure of people, ecosystems, materials, etc.
→ Quantification of impacts
→ Valuation of impacts

The dispersion modelling is carried out in a way that tracks pollutants through the atmosphere, and follows their chemical reactions, enabling quantification of effects linked to emission, not simply to atmospheric concentration of the pollutant in the chemical state in which it was released. An important consequence of this is that effects caused by *secondary* particulates are not assigned to $PM_{2.5}$, but to the primary pollutant from which they are formed (e.g. SO_2 for sulphate aerosol, NOx for nitrate aerosol and NH_3 for ammonium aerosol). It also enables account to be taken of less obvious interactions between air pollutants, for example the effects of VOC emissions on inorganic particle concentrations[1], or the effects of SO_2 and NH_3 emissions on ozone.

Further details on the methods that underpin the quantification made here are given below.

Impacts considered and omitted from the analysis

The impacts that have been quantified for this report are listed in Table 1. It is important not to forget those effects that remain unquantified as a result of limitations in the availability of data on response functions and / or valuation. These are listed in Table 2, which shows that a large number of effects have not been quantified. To interpret the information presented in the two tables it is important to be aware that:

1. The effects that have been quantified are substantial, and
2. Several of the effects that have not been quantified here are likely to be negligible (e.g. direct effects of SO_2 and NOx on crops) and would not lead to a significant increase in damages per tonne emission.

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[4] For further information on ExternE, see http://www.externe.info/

Table 1 – Impacts quantified

Burden	Effect
Human exposure to $PM_{2.5}$	Chronic effects on: Mortality Adults over 30 years Infants Morbidity Bronchitis Acute effects on: Morbidity Respiratory hospital admissions Cardiac hospital admissions Consultations with primary care physicians Restricted activity days Use of respiratory medication Symptom days
Human exposure to ozone	Acute effects on: Mortality Morbidity Respiratory hospital admissions Minor restricted activity days Use of respiratory medication Symptom days
Exposure of crops to ozone	Yield loss for: barley, cotton, fruit, grape, hops, millet, maize, oats, olive, potato, pulses, rapeseed, rice, rye, seed cotton, soybean, sugarbeet, sunflower seed, tobacco, wheat

Put together, whilst the omission of any impact leads to a bias to underestimation of damages, and that some of the omitted effects are undeniably important, the results generated here quantify a large fraction of total damages for most of the pollutants considered. The pollutant for which the most serious omissions apply is probably VOCs, because of the failure to account for organic aerosols, and, possibly, a failure to account for impacts associated with long term (chronic) exposure to ozone should they exist.

The effect of omission of impacts has to be seen in the context of the full range of uncertainties in the assessment. Whilst it does clearly bias to underestimation, the full set of uncertainties, including also model assumptions and statistical uncertainties, may push the results either way, up or down. More information on these uncertainties is provided in the third volume of the CAFE CBA methodology.

Table 2 – Effects omitted from the analysis

Effect	Comments
Health	
Ozone	
chronic – mortality	No information on possible chronic effects, suspected but not proven
chronic – morbidity	
Direct effects of SO_2 , NOx, VOCs	
Effects of VOCs through the formation of secondary organic particles	Not currently included in the EMEP model
Social impacts	Limited data availability
Altruistic effects	Reliable valuation data unavailable
Agricultural production	
Direct effects of SO_2 and NO_x	Negligible according to past work
N deposition as crop fertiliser	Negligible according to past work
Visible damage to marketed produce	Locally important for some crops
Interactions between pollutants, with pests and pathogens, climate…	Exposure-response data unavailable
Acidification/liming	Negligible according to past work
Materials	
SO_2/acid effects on utilitarian buildings	
Effects on cultural assets, steel in re-inforced concrete	Lack of stock at risk inventory and valuation data
PM and building soiling	
Effects of O_3 on paint, rubber	
Ecosystems	
Effects on biodiversity, forest production, etc. from excess O_3 exposure, acidification and nitrogen deposition	Valuation of ecological impacts is currently too uncertain
Visibility: Change in visual range	Impact of little concern in Europe.
Drinking water supply and quality	Limited data availability

Other uncertainties considered

In addition to the uncertainty arising from the omission of a number of impacts from the analysis, this report has addressed specifically some other key uncertainties and sensitivities:

- Valuation of mortality using the value of statistical life (VSL) and value of a life year (VOLY) approaches.
- Quantification of ozone effects on health with and without a ‘cut-point’ (effectively, the assumption of a threshold at 35 ppb).
- Separation of health impacts into a ‘core’ set of functions which we conclude to be most robust, and a ‘sensitivity’ set of functions that are less robust.

These uncertainties have been investigated and used to define ranges for the damages associated with each country or sea area and pollutant combination.

An important issue that has not been addressed relates to the uncertainty in apportioning impacts to each pollutant. This is most problematic for quantification of the impacts of fine particles, which are typically described by epidemiological studies in terms of PM_{10} or $PM_{2.5}$ rather than the constituent species of particles (e.g. sulphate aerosol, combustion particles, natural material). On the “Systematic Review of Health Aspects of Air Pollution in Europe” carried out by WHO differentiation between particles has not been attempted.

Methods

Development of source-receptor relationships

Data on source-receptor relationships was provided by Simpson and Wind (2005)[5]. The matrices are based on a number of model runs with the EMEP model considering a 15 percent emission reduction of SO_2, NO_X, NH_3, NMVOC, coarse or fine particulates at the emission level of current legislation in 2010. The substances for which concentration changes per grid cell caused by emission changes in a specific country were provided are listed in Table 3. The regions considered include the EU25 Member States (excluding Cyprus) and the four sea regions North Sea, Baltic Sea, Atlantic, and Mediterranean.

Table 3 – Substances considered in the calculations

Data_id	Description	Unit
D2_NOX	NOX	micro gN/m^3
aNO3	fine NO_3	micro gN/m^3
pNO3	coarse NO_3	micro gN/m^3
WDEP_OXN	Wet deposited HNO_3+PAN+NO_2+aNO_3+pNO_3	mgN/m^2
DDEP_OXN	Dry deposited HNO_3+PAN+NO_2+aNO_3+pNO_3	mgN/m^2
D2_SO2	SO_2	micro gS/m^3
SO4	SO_4	micro gS/m^3
WDEP_SOX	Wet deposited SO_2+SO_4	mgS/m^2
DDEP_SOX	Dry deposited SO_2+SO_4	mgS/m^2
D2_NH3	NH_3	micro gN/m^3
NH4	NH_4	micro gN/m^3
WDEP_RDN	Wet deposited NH_3+aNH_4	micro gN/m^3
DDEP_RDN	Dry deposited NH_3+aNH_4	mgN/m^2
O3	annual mean surface O_3	Ppb
SOMO0	Sum of Means Over 0 ppbV	ppb.days
SOMO35	Sum of Means Over 35 ppbV	ppb.days
PPM25	Primary $PM_{2.5}$	micro g/m^3
PPMco	Primary coarse	micro g/m^3
AOT30f	AOT30 for April-September, grid-average ozone from a height of 3m	ppb.h
AOT40c	AOT40 for May-July, grid-average ozone from a height of 3m	ppb.h
AOT40f	AOT40 for April-September, grid-average ozone from a height of 3m	ppb.h
AOT60	AOT60 for April-September, grid-average ozone from a height of 3m	ppb.h

In order to use the data which was originally given as concentration increase caused by the last 15 percent of emissions for impact assessment, a recalculation on a per

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[5] Simpson, D. and P. Wind (2005): Source-receptor matrices derived from EMEP model runs carried out for the CAFE process. Meteorologisk institutt (met.no), Oslo

kilo-tonne basis was necessary. Additionally, the concentration at the emission level of current legislation in 2010 was provided. Results are shown in Appendix 1.

Implementation of CAFE-CBA methodology for quantifying benefits per unit of pollutant release

The methodology used here has been developed through extensive discussion and consultation with stakeholders from the EU Member States, various European Agencies, WHO, industry and NGOs from October 2003 to January 2005. Documentation, including comments made by the peer reviewers, is available at http://cafe-cba.org/ and http://europa.eu.int/comm/environment/air/cafe/activities/cba.htm.

The analysis presented here is limited to assessment of exposure of people and crops to $PM_{2.5}$ and ozone. This limitation to the analysis should not be interpreted to imply that non-quantified effects are unimportant: it is simply that there is not currently an adequate basis to permit their quantification with an acceptable level of reliability. The one exception concerns damages to materials in 'utilitarian' applications, which will be brought into the analysis when the necessary pollution data become available.

Quantification of health damages

The data used for quantification of health damages, based on information from UN health statistics and data, functions and valuations presented in Volume 2 of the CAFE-CBA methodology report, are given in Table 4 for effects of exposure to $PM_{2.5}$ and Table 5 for effects of exposure to ozone. It should be noted that:

- Chronic mortality estimates for $PM_{2.5}$ based on VSL/VOLY or median/mean estimates are not additive, but are used as alternatives in sensitivity analysis.
- Similarly, for the VOLY mean and median valuations listed for ozone.
- Several effects listed in CAFE-CBA Methodology volume 2 have not been included in the quantification as further validation of incidence data is required:
    - Upper bound estimate for chronic bronchitis, recommended for inclusion in the sensitivity functions for $PM_{2.5}$.
    - Respiratory medication use and lower respiratory symptoms among children, recommended for inclusion in the core functions for ozone.
    - Consultations for allergic rhinitis in adults and children, recommended for inclusion in the sensitivity functions for ozone.
- Valuation of ozone mortality impacts using the VOLY approach assumes an average loss of life expectancy amongst those affected of 1 year.
- The 'pollution factors' and 'population factors' convert from units (etc.) defined in the CAFE-CBA Methodology report volume 2 to units that match the population weighted pollution metrics that form the basis of the quantification.
- Population factors are specific to 2010.
- Valuation data refer to the year 2000.

Sufficient data is given in Table 4 and Table 5 to reconstruct the final result tables presented in this report (below, in Table 8 to Table 12), when combined with the population exposure data given in Appendix 1 and the crop damage results in Table 7.

Some explanation of the parameters in Table 4 and Table 5 is likely to be useful. Note that in any column a figure of 1 is the default, given that quantification simply multiplies all of the variables shown together:

Pollutant factor 1 for $PM_{2.5}$: Uses a figure of 1 or 1.54 where the original function is expressed in terms of $PM_{2.5}$ or PM_{10} respectively. For ozone, a factor of 0.0055 (calculated as 2/365) is used to convert from the metric produced by the EMEP model (SOMO 0 or 35 as ppb.hours) to change in annual 8 hr mean (with and without the cut point) in $\mu g.m^{-3}$.

Pollutant factor 2: Where the original function is expressed per $\mu g.m^{-3}$ the factor = 1, where it is expressed per 10 $\mu g.m^{-3}$ a factor of 0.1 is used.

Population factor 1: This factor accounts for most functions applying to only part of the population. For example, the chronic mortality function (deaths) is applicable only to those aged over 30, who account for 62.8% of the population in the modelled domain.

Population factor 2: This factor accounts for some functions being expressed per thousand or per hundred thousand of population.

Incidence rate, response functions, valuation data: These are all given in Volume 2 of the CAFE CBA methodology report.

Table 4 – Incidence data, response functions and valuation data for quantification of health damages linked to PM exposure for 2010

Effect	Pollutant factor 1	Pollutant factor 2	Population factor 1	Population factor 2	Incidence rate	Response functions	Valuation
CORE FUNCTIONS							
Chronic mortality (deaths, VSL valuation)	1	0.1	0.628	1	1.61%	6.00%	€ 2,000,000
Chronic mortality (life years lost, VOLY valuation)	1	1	1	1.00E-05	1	65.1	€ 52,000
Infant mortality (1 – 11 months)	1.54	0.1	0.009	1	0.19%	4.00%	€ 1,500,000
Chronic bronchitis, population aged over 27 years	1.54	0.1	0.7	1	0.378%	7.00%	€ 190,000
Respiratory hospital admissions, all ages	1.54	0.1	1	1.00E-05	617	1.14%	€ 2,000
Cardiac hospital admissions, all ages	1.54	0.1	1	1.00E-05	723	0.60%	€ 2,000
Restricted activity days (RADs) working age population	1	1	0.672	1	19	0.475%	€ 82
Respiratory medication use by adults	1.54	0.1	0.817	0.001	4.50%	908	€ 1
Respiratory medication use by children	1.54	0.1	0.112	0.001	20%	180	€ 1
Lower respiratory syndromes (LRS), including cough, among adults with chronic symptoms	1.54	0.1	0.817	1	0.3	1.30	€ 38
LRS (including cough) among children	1.54	0.1	0.112	1	1	1.85	€ 38
SENSITIVITY FUNCTIONS							
Consultations for asthma, ages 0-14	1.54	0.1	0.170	0.001	47.1	2.50%	€ 53
Consultations for asthma, ages 15-64	1.54	0.1	0.672	0.001	16.5	3.10%	€ 53
Consultations for asthma, ages over 65	1.54	0.1	0.158	0.001	15.1	6.30%	€ 53
Consultations for upper respiratory symptoms (excluding allergic rhinitis) ages 0-14	1.54	0.1	0.170	0.001	574	0.70%	€ 53
Consultations for upper respiratory symptoms (excluding allergic rhinitis) ages 15-64	1.54	0.1	0.672	0.001	180	1.80%	€ 53
Consultations for upper respiratory symptoms (excluding allergic rhinitis) ages over 65	1.54	0.1	0.158	0.001	141	3.30%	€ 53
Extra for RADs, total population	1	1	0.328	1	19	0.475%	€ 69

Table 5 – Incidence data, response functions and valuation data for quantification of health damages linked to ozone exposure for 2010

Effect	**Pollutant factor 1**	**Pollutant factor 2**	**Population factor 1**	**Population factor 2**	**Incidence rate**	**ERF**	**Valuation**
CORE FUNCTIONS							
Acute mortality (life years lost, VOLY median valuation)	0.0055	0.1	1	1	1.09%	0.30%	€ 52,000
Acute mortality (life years lost, VOLY mean valuation)	0.0055	0.1	1	1	1.09%	0.30%	€120,000
Respiratory hospital admissions, ages over 65	0.0055	0.1	1	1.00E-05	617	0.30%	€ 2,000
Minor restricted activity days, ages 18-64	0.0055	0.1	0.64	1	7.8	1.48%	€ 38
Respiratory medication use by adults	0.0055	0.1	0.817	0.001	4.50%	730	€ 1
SENSITIVITY FUNCTIONS							
Minor restricted activity days, ages over 65	0.0055	0.1	0.158	1	7.8	1.48%	€ 38
Respiratory symptoms among adults	0.0055	0.1	1	0.001	1	343	€ 38

Quantification of ozone-crop damages

The analysis of crop damages included here is based on the use of AOT40 relationships, combined with EMEP estimates of change in AOT40 on a 50 x 50 km grid. The functions and pollution data have been adjusted as follows:

- The AOT40 outputs from EMEP are for the period May to July. These have been adjusted by country-specific factors derived from earlier EMEP model runs to better represent the growing season for each country.
- The EMEP data is generated for a height of 3m. This has been adjusted to canopy height for each crop based on default relationships in the ICP Mapping and Modelling Manual[6].

Functions and other data are shown in Table 6. Valuation data are based on world market prices as reported by FAO.

Table 6 – Functions and associated factors for quantification of ozone damage to crop production. The height factor accounts for variation in ozone concentration with height and is based on default estimates in the ICP Mapping and Modelling (2004) Manual. The function shows proportional change in yield per ppm.hour.

Crop	Value (€)	Function	Height (m)	Height factor
Barley	120	0	1	0.88
Fruit	680	0.001	2	0.93
Grapes	360	0.003	1	0.88
Hops	4100	0.009	4	0.96
Maize	100	0.004	2	0.93
Millet	90	0.004	1	0.88
Oats	110	0	1	0.88
Olives	530	0	2	0.93
Potatoes	250	0.006	1	0.88
Pulses	320	0.017	1	0.88
Rapeseed	240	0.006	1	0.88
Rice	280	0.004	1	0.88
Rye	80	0	1	0.88
Seed cotton	1350	0.016	1	0.88
Soybeans	230	0.012	1	0.88
Sugar beets	60	0.006	0.5	0.81
Sunflower seed	240	0.012	2	0.93
Tobacco leaves	4000	0.005	0.5	0.81
Wheat	120	0.017	1	0.88

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[6] http://www.oekodata.com/pub/mapping/manual/mapman_2004.pdf

Results

Crop damage

Damages for health impacts have been reported in detail in other reports produced from the benefits analysis for CAFE. However, this is the first occasion on which impacts to crops have been quantified. In order to provide some sense of their importance with the overall figures given below, the crop damages are presented separately in Table 7.

Table 7 – Marginal damages in 2010 from ozone effects on crops arising per tonne emission for NH_3, NOx, SO_2 and VOCs. Negative figures denote a reduction in damage.

	NH_3	NOx	SO_2	VOC
Austria	-€ 3	€ 340	-€ 39	€ 72
Belgium	-€ 12	-€ 13	-€ 32	€ 290
Cyprus	-	-	-	-
Czech Republic	-€ 3	€ 290	-€ 27	€ 94
Denmark	-€ 7	€ 150	-€ 39	€ 160
Estonia	-€ 2	€ 130	-€ 16	€ 33
Finland	-€ 2	€ 100	-€ 22	€ 33
France	-€ 4	€ 500	-€ 35	€ 140
Germany	-€ 7	€ 330	-€ 49	€ 180
Greece	-€ 5	€ 310	-€ 2	€ 27
Hungary	-€ 2	€ 360	-€ 7	€ 44
Ireland	-€ 2	€ 210	-€ 42	€ 99
Italy	-€ 6	€ 270	-€ 29	€ 100
Latvia	-€ 1	€ 200	-€ 15	€ 47
Lithuania	-€ 1	€ 210	-€ 14	€ 34
Luxembourg	-€ 9	€ 320	-€ 59	€ 260
Malta	-€ 17	€ 150	-€ 7	€ 84
Netherlands	-€ 12	-€ 95	-€ 31	€ 280
Poland	-€ 3	€ 230	-€ 8	€ 70
Portugal	-€ 1	€ 160	-€ 28	€ 50
Slovakia	-€ 2	€ 350	-€ 9	€ 54
Slovenia	-€ 2	€ 340	-€ 37	€ 84
Spain	-€ 3	€ 310	-€ 35	€ 67
Sweden	-€ 4	€ 180	-€ 32	€ 61
United Kingdom	-€ 7	€ 49	-€ 32	€ 180
Atlantic		€ 150	-€ 18	€ 50
Baltic Sea		€ 110	-€ 32	€ 130
Mediterranean		€ 70	-€ 12	€ 59
North Sea		€ 26	-€ 30	€ 240

Total damages, by pollutant

Total damages from each of the 5 pollutants considered in this analysis are given in the tables for 4 combinations of sensitivity: The low end is calculated on the following basis:

- Inclusion of core health functions and crop functions
- Use of the *median* estimate of *VOLY* from the NewExt study for mortality impacts of $PM_{2.5}$ and ozone
- Use of the 35 ppb cut-point for quantification of ozone health impacts

The change in magnitude of damages for the central scenarios is largely a reflection of the unit values used for mortality valuation, rather than a response to the other sensitivities explored. It is notable that there is not clear separation of the results based on the VSL and VOLY approaches – although VOLY gives generally lower results than VSL, the result based on mean VOLY is greater than the one based on median VSL.

The upper end is calculated on the following basis:

- Inclusion of core and sensitivity health functions and crop functions
- Use of the *mean* estimate of *VSL* from the NewExt study for mortality impacts of $PM_{2.5}$ and the *mean* estimate of *VOLY* for mortality impacts of ozone
- Use of no cut-point for quantification of ozone health impacts

Assumptions specific to each set of results are shown at the top of each table.

The results show very large variations in damage per tonne emission between countries. Generally, the highest damages are found from emissions in central Europe and the lowest from countries around the edges of Europe. This simply reflects variation in exposure of people and crops to the pollutants of interest – emissions at the edges of Europe will affect fewer people than emissions at the centre of Europe. The results for Cyprus looked to be artificially low most likely due to modelling uncertainties and have been omitted from the tables.

NH_3

Table 8 – Marginal NH_3 damage (€) per tonne emission for 2010, with three sets of sensitivity analysis.

PM mortality	**VOLY - median**	**VSL - median**	**VOLY - mean**	**VSL - mean**
O_3 mortality	**VOLY - median**	**VOLY - median**	**VOLY - mean**	**VOLY - mean**
Health core?	**Yes**	**Yes**	**Yes**	**Yes**
Health sensitivity?	**No**	**No**	**Yes**	**Yes**
Crops	**Yes**	**Yes**	**Yes**	**Yes**
O_3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
Austria	€ 12,000	€ 19,000	€ 24,000	€ 35,000
Belgium	€ 30,000	€ 47,000	€ 60,000	€ 87,000
Cyprus	-	-	-	-
Czech Republic	€ 20,000	€ 31,000	€ 39,000	€ 57,000
Denmark	€ 7,900	€ 12,000	€ 16,000	€ 23,000
Estonia	€ 2,800	€ 4,300	€ 5,600	€ 8,100
Finland	€ 2,200	€ 3,400	€ 4,300	€ 6,300
France	€ 12,000	€ 18,000	€ 23,000	€ 34,000
Germany	€ 18,000	€ 27,000	€ 35,000	€ 51,000
Greece	€ 3,200	€ 4,900	€ 6,300	€ 9,100
Hungary	€ 11,000	€ 17,000	€ 22,000	€ 32,000
Ireland	€ 2,600	€ 4,000	€ 5,100	€ 7,400
Italy	€ 11,000	€ 17,000	€ 22,000	€ 32,000
Latvia	€ 3,100	€ 4,700	€ 6,000	€ 8,800
Lithuania	€ 1,700	€ 2,700	€ 3,400	€ 5,000
Luxembourg	€ 25,000	€ 39,000	€ 50,000	€ 72,000
Malta	€ 8,200	€ 13,000	€ 16,000	€ 24,000
Netherlands	€ 22,000	€ 34,000	€ 44,000	€ 64,000
Poland	€ 10,000	€ 15,000	€ 20,000	€ 29,000
Portugal	€ 3,700	€ 5,800	€ 7,400	€ 11,000
Slovakia	€ 14,000	€ 22,000	€ 28,000	€ 41,000
Slovenia	€ 13,000	€ 20,000	€ 25,000	€ 37,000
Spain	€ 4,300	€ 6,700	€ 8,600	€ 13,000
Sweden	€ 5,900	€ 9,000	€ 12,000	€ 17,000
United Kingdom	€ 17,000	€ 27,000	€ 34,000	€ 50,000
Baltic Sea	n/a	n/a	n/a	n/a
Mediterranean Sea	n/a	n/a	n/a	n/a
North East Atlantic	n/a	n/a	n/a	n/a
North Sea	n/a	n/a	n/a	n/a

NOx

Table 9 – Marginal NOx, damage (€) per tonne emission for 2010, with three sets of sensitivity analysis.

PM mortality	**VOLY - median**	**VSL - median**	**VOLY - mean**	**VSL – mean**
O3 mortality	**VOLY - median**	**VOLY - median**	**VOLY - mean**	**VOLY – mean**
Health core?	**Yes**	**Yes**	**Yes**	**Yes**
Health sensitivity?	**No**	**No**	**Yes**	**Yes**
Crops	**Yes**	**Yes**	**Yes**	**Yes**
O3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
Austria	€ 8,700	€ 13,100	€ 16,000	€ 24,000
Belgium	€ 5,200	€ 8,200	€ 9,100	€ 14,000
Cyprus	-	-	-	-
Czech Republic	€ 7,300	€ 11,000	€ 13,700	€ 20,000
Denmark	€ 4,400	€ 6,700	€ 8,300	€ 12,100
Estonia	€ 810	€ 1,100	€ 1,600	€ 2,200
Finland	€ 750	€ 1,100	€ 1,500	€ 2,000
France	€ 7,700	€ 12,000	€ 14,000	€ 21,000
Germany	€ 9,600	€ 15,000	€ 18,000	€ 26,000
Greece	€ 840	€ 1,100	€ 1,400	€ 1,900
Hungary	€ 5,400	€ 8,100	€ 10,000	€ 15,000
Ireland	€ 3,800	€ 5,600	€ 7,500	€ 11,000
Italy	€ 5,700	€ 8,600	€ 11,000	€ 16,000
Latvia	€ 1,400	€ 1,900	€ 2,700	€ 3,700
Lithuania	€ 1,800	€ 2,700	€ 3,700	€ 5,000
Luxembourg	€ 8,700	€ 13,000	€ 16,000	€ 24,000
Malta	€ 670	€ 930	€ 1,300	€ 1,700
Netherlands	€ 6,600	€ 10,000	€ 12,000	€ 18,000
Poland	€ 3,900	€ 5,800	€ 7,100	€ 10,000
Portugal	€ 1,300	€ 1,900	€ 2,200	€ 3,200
Slovakia	€ 5,200	€ 7,800	€ 9,700	€ 14,000
Slovenia	€ 6,700	€ 10,000	€ 13,000	€ 18,000
Spain	€ 2,600	€ 3,800	€ 5,200	€ 7,200
Sweden	€ 2,200	€ 3,200	€ 4,100	€ 5,900
United Kingdom	€ 3,900	€ 6,000	€ 6,700	€ 10,000
Baltic Sea	€ 2,600	€ 4,000	€ 4,900	€ 7,200
Mediterranean Sea	€ 530	€ 760	€ 990	€ 1,400
North East Atlantic	€ 1,600	€ 2,400	€ 3,500	€ 4,800
North Sea	€ 5,100	€ 7,900	€ 9,500	€ 14,000

PM$_{2.5}$

Table 10 –Marginal PM$_{2.5}$ damage (€) per tonne emission for 2010, with three sets of sensitivity analysis.

PM mortality	**VOLY - median**	**VSL - median**	**VOLY - mean**	**VSL - mean**
O3 mortality	**VOLY - median**	**VOLY - median**	**VOLY - mean**	**VOLY - mean**
Health core?	**Yes**	**Yes**	**Yes**	**Yes**
Health sensitivity?	**No**	**No**	**Yes**	**Yes**
Crops	**Yes**	**Yes**	**Yes**	**Yes**
O3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
Austria	€ 37,000	€ 56,000	€ 72,000	€ 110,000
Belgium	€ 61,000	€ 94,000	€ 120,000	€ 180,000
Cyprus	-	-	-	-
Czech Republic	€ 32,000	€ 49,000	€ 62,000	€ 91,000
Denmark	€ 16,000	€ 25,000	€ 33,000	€ 48,000
Estonia	€ 4,200	€ 6,500	€ 8,300	€ 12,000
Finland	€ 5,400	€ 8,300	€ 11,000	€ 16,000
France	€ 44,000	€ 68,000	€ 87,000	€ 130,000
Germany	€ 48,000	€ 74,000	€ 95,000	€ 140,000
Greece	€ 8,600	€ 13,000	€ 17,000	€ 25,000
Hungary	€ 25,000	€ 39,000	€ 50,000	€ 72,000
Ireland	€ 15,000	€ 22,000	€ 29,000	€ 42,000
Italy	€ 34,000	€ 52,000	€ 66,000	€ 97,000
Latvia	€ 8,800	€ 14,000	€ 17,000	€ 25,000
Lithuania	€ 8,400	€ 13,000	€ 17,000	€ 24,000
Luxembourg	€ 41,000	€ 63,000	€ 81,000	€ 120,000
Malta	€ 9,300	€ 14,000	€ 18,000	€ 27,000
Netherlands	€ 63,000	€ 96,000	€ 120,000	€ 180,000
Poland	€ 29,000	€ 44,000	€ 57,000	€ 83,000
Portugal	€ 22,000	€ 34,000	€ 44,000	€ 64,000
Slovakia	€ 20,000	€ 31,000	€ 40,000	€ 58,000
Slovenia	€ 22,000	€ 34,000	€ 44,000	€ 64,000
Spain	€ 19,000	€ 29,000	€ 37,000	€ 54,000
Sweden	€ 12,000	€ 18,000	€ 23,000	€ 34,000
United Kingdom	€ 37,000	€ 57,000	€ 73,000	€ 110,000
Baltic Sea	€ 12,000	€ 19,000	€ 24,000	€ 35,000
Mediterranean Sea	€ 5,600	€ 8,700	€ 11,000	€ 16,000
North East Atlantic	€ 4,800	€ 7,400	€ 9,400	€ 14,000
North Sea	€ 28,000	€ 42,000	€ 54,000	€ 80,000

SO$_2$

Table 11 – Marginal SO$_2$ damage (€) per tonne emission for 2010, with three sets of sensitivity analysis.

PM mortality	**VOLY - median**	**VSL - median**	**VOLY - mean**	**VSL - mean**
O3 mortality	**VOLY - median**	**VOLY - median**	**VOLY - mean**	**VOLY - mean**
Health core?	**Yes**	**Yes**	**Yes**	**Yes**
Health sensitivity?	**No**	**No**	**Yes**	**Yes**
Crops	**Yes**	**Yes**	**Yes**	**Yes**
O3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
Austria	€ 8,300	€ 13,000	€ 16,000	€ 24,000
Belgium	€ 11,000	€ 16,000	€ 21,000	€ 31,000
Cyprus	-	-	-	-
Czech Republic	€ 8,000	€ 12,000	€ 16,000	€ 23,000
Denmark	€ 5,200	€ 8,100	€ 10,000	€ 15,000
Estonia	€ 1,800	€ 2,800	€ 3,600	€ 5,200
Finland	€ 1,800	€ 2,700	€ 3,500	€ 5,100
France	€ 8,000	€ 12,000	€ 16,000	€ 23,000
Germany	€ 11,000	€ 17,000	€ 22,000	€ 32,000
Greece	€ 1,400	€ 2,100	€ 2,700	€ 4,000
Hungary	€ 4,800	€ 7,300	€ 9,400	€ 14,000
Ireland	€ 4,800	€ 7,500	€ 9,500	€ 14,000
Italy	€ 6,100	€ 9,300	€ 12,000	€ 18,000
Latvia	€ 2,000	€ 3,100	€ 3,900	€ 5,700
Lithuania	€ 2,400	€ 3,600	€ 4,700	€ 6,800
Luxembourg	€ 9,800	€ 15,000	€ 19,000	€ 28,000
Malta	€ 2,200	€ 3,300	€ 4,300	€ 6,200
Netherlands	€ 13,000	€ 21,000	€ 26,000	€ 39,000
Poland	€ 5,600	€ 8,600	€ 11,000	€ 16,000
Portugal	€ 3,500	€ 5,400	€ 6,900	€ 10,000
Slovakia	€ 4,900	€ 7,500	€ 9,600	€ 14,000
Slovenia	€ 6,200	€ 9,500	€ 12,000	€ 18,000
Spain	€ 4,300	€ 6,600	€ 8,400	€ 12,000
Sweden	€ 2,800	€ 4,300	€ 5,500	€ 8,100
United Kingdom	€ 6,600	€ 10,000	€ 13,000	€ 19,000
Baltic Sea	€ 3,700	€ 5,800	€ 7,400	€ 11,000
Mediterranean Sea	€ 2,000	€ 3,200	€ 4,000	€ 5,900
North East Atlantic	€ 2,200	€ 3,400	€ 4,300	€ 6,300
North Sea	€ 6,900	€ 11,000	€ 14,000	€ 20,000

VOCs

Table 12 – Marginal VOC damage (€) per tonne emission for 2010, with three sets of sensitivity analysis.

PM mortality	**VOLY - median**	**VSL - median**	**VOLY - mean**	**VSL - mean**
O3 mortality	**VOLY - median**	**VOLY - median**	**VOLY - mean**	**VOLY - mean**
Health core?	**Yes**	**Yes**	**Yes**	**Yes**
Health sensitivity?	**No**	**No**	**Yes**	**Yes**
Crops	**Yes**	**Yes**	**Yes**	**Yes**
O3/health metric	**SOMO 35**	**SOMO 35**	**SOMO 0**	**SOMO 0**
Austria	€ 1,700	€ 2,600	€ 3,800	€ 5,200
Belgium	€ 2,500	€ 3,500	€ 5,300	€ 7,100
Cyprus	-	-	-	-
Czech Republic	€ 1,000	€ 1,400	€ 2,300	€ 3,000
Denmark	€ 720	€ 970	€ 1,600	€ 2,000
Estonia	€ 140	€ 190	€ 340	€ 420
Finland	€ 160	€ 220	€ 390	€ 490
France	€ 1,400	€ 2,000	€ 3,100	€ 4,200
Germany	€ 1,700	€ 2,500	€ 3,900	€ 5,100
Greece	€ 280	€ 400	€ 670	€ 880
Hungary	€ 860	€ 1,300	€ 2,000	€ 2,700
Ireland	€ 680	€ 950	€ 1,600	€ 2,000
Italy	€ 1,100	€ 1,600	€ 2,600	€ 3,500
Latvia	€ 220	€ 300	€ 520	€ 650
Lithuania	€ 230	€ 330	€ 550	€ 710
Luxembourg	€ 2,700	€ 4,000	€ 5,900	€ 8,000
Malta	€ 430	€ 580	€ 1,000	€ 1,300
Netherlands	€ 1,900	€ 2,700	€ 4,100	€ 5,400
Poland	€ 630	€ 900	€ 1,400	€ 1,900
Portugal	€ 500	€ 700	€ 1,200	€ 1,600
Slovakia	€ 660	€ 960	€ 1,500	€ 2,000
Slovenia	€ 1,400	€ 2,000	€ 3,200	€ 4,400
Spain	€ 380	€ 510	€ 920	€ 1,100
Sweden	€ 330	€ 440	€ 780	€ 980
United Kingdom	€ 1,100	€ 1,600	€ 2,500	€ 3,200
Baltic Sea	€ 530	€ 700	€ 1,200	€ 1,500
Mediterranean Sea	€ 340	€ 470	€ 790	€ 1,000
North East Atlantic	€ 390	€ 540	€ 900	€ 1,200
North Sea	€ 1,900	€ 2,600	€ 4,000	€ 5,400

Discussion

Comparison with the 2002 estimates for emissions from rural locations has been made by taking a crude average (unweighted by emission) across the EU15 less Luxembourg in accordance with earlier estimates that did not include Luxembourg or the new Member States. Results are shown in Table 13 for a sensitivity case that has been constructed to reflect as closely as possible the assumptions made in the 2002 estimates. Results for this scenario are roughly central to the new ranges, for the most part lying between the two central scenarios. The comparison shows that results for NOx and VOCs are comparable with the earlier estimates, results for SO_2 are significantly higher, and results for $PM_{2.5}$ are very significantly higher.

Table 13 – Comparison of BeTa (2002) and CAFE CBA results.

Pollutant	**BeTa (2002)**	**CAFE CBA results (comparison case)**	**Ratio**
NH_3	No result	17,000	-
NOx	4,500	6,300	1.4
$PM_{2.5}$	10,000	48,000	4.8
SO_2	4,600	9,800	2.13
VOCs	2,100	2,800	1.33

Table 14 repeats this exercise, but for the two ends of the ranges identified here.

Table 14 – Comparison of BeTa (2002) and CAFE CBA results from the lower (top table) and upper end (lower table) of the ranges shown in Table 8 to 12

Median VOLY based mortality valuation, health core + crop functions only, 35 ppb cut-point used for ozone damages.

Pollutant	**BeTa (2002)**	**CAFE CBA results (lower bound)**	**Ratio**
NH_3	No result	10,900	-
NOx	4,500	4,500	1
$PM_{2.5}$	10,000	30,000	3
SO_2	4,600	6,300	1.37
VOCs	2,100	1,000	0.48

Mean VSL based mortality valuation for $PM_{2.5}$ exposure, mean VOLY based mortality valuation for ozone, health core + health sensitivity + crop functions, 0 ppb cut-point used for ozone damages.

Pollutant	**BeTa (2002)**	**CAFE CBA results (upper bound)**	**Ratio**
NH_3	No result	31,000	-
NOx	4,500	12,000	2.67
$PM_{2.5}$	10,000	87,000	8.7
SO_2	4,600	18,000	3.91
VOCs	2,100	3,000	1.43

The most striking increase in estimated damages concerns $PM_{2.5}$. It is possible that the increase arises in part because of the increased resolution of the EMEP model, with the effect of emissions in densely populated areas being more sharply focused on the population around the emission source. Consideration of a uniform abatement across all sources may also go to explain the higher damage primary $PM_{2.5}$, given that the earlier estimates were specifically for high level sources in rural areas. Further work is needed to improve the understanding of damage caused by $PM_{2.5}$.

Results for VOCs are particularly interesting, as they can be attributed in large measure to the effect of VOCs on *inorganic* particle concentrations, through formation of ozone and subsequent oxidation of NOx and SO_2 closer to the site of emission. As noted elsewhere, no account is taken of effects of VOC emissions on exposure to *organic* aerosols as these are not yet included in the EMEP model. This is a clear bias to underestimation in the VOC estimates.

When considering the results presented in this report it is important not to forget the impacts that have not been quantified. These were listed in Table 2.

Further results will be provided for the years 2000 and 2020 as soon as pollution data are available.

A series of other useful results can also be generated, for example:

- Analysis showing how much of the benefit accruing to each country under any scenario is a result of its own emission control and action taken in other countries.
- Analysis showing the benefits arising from emission control by each country, in contrast to the existing scenario results from CAFE which instead show the benefit accruing to each country from pan-European action on air quality improvement. This will enable an alternative way of comparing costs and benefits for each country.

The following improvements can be made to the data presented in this report:

1. Development of datasets for other years.
2. Use of national demographic data rather than EU25 averages.
3. Updating of crop damage models.
4. Updating of materials damage models.

References

AEAT (2005) Methodology for the Cost-Benefit Analysis for CAFE. Reports prepared for the Clean Air for Europe Programme. Volumes 1, 2 and 3. http://europa.eu.int/comm/environment/air/cafe/activities/cba.htm

Holland, M.R. and Watkiss, P. (2002) Benefits Table database: Estimates of the marginal external costs of air pollution in Europe BeTa Version E1.02a. http://europa.eu.int/comm/environment/enveco/air/betaec02aforprinting.pdf

ICP Mapping and Modelling (2004) Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends. http://europa.eu.int/comm/environment/air/cafe/activities/cba.htm

Krupnick A. et al (2004) Peer Review of the Methodology of Cost-Benefit Analysis of the Clean Air For Europe Programme. Paper prepared for European Commission, Environment Directorate General. October 12, 2004. http://europa.eu.int/comm/environment/air/cafe/activities/krupnick.pdf

NewExt (2004) New Elements for the Assessment of External Costs from Energy Technologies". Funded under the EC 5th Framework Programme (1998 – 2002), Thematic programme: Energy, Environment and Sustainable Development, Part B: Energy; Generic Activities: 8.1.3. Externalities ENG1-CT2000-00129.

Simpson, D. and P. Wind (2005): Source-receptor matrices derived from EMEP model runs carried out for the CAFE process. Meteorologisk institutt, Oslo

WHO (2004) Systematic Review of Health Aspects of Air Pollution in Europe. http://www.euro.who.int/eprise/main/WHO/Progs/AIQ/Activities/20020530_1

Appendix 1: Relationships between emissions of each pollutant and exposure to particles and ozone in 2010

The following tables describe the processed outputs from the EMEP pollution chemistry and dispersion modelling, showing the change in population-weighted concentration across Europe for $PM_{2.5.}$ (Table 15), SOMO 35 (Table 17) and SOMO 0 (Table 19) associated with a 1000t increase or decrease in emission of ammonia, $PM_{2.5}$, NOx, SO_2 or VOCs for the year 2010. A brief commentary is given below these tables reviewing the overall direction of effect linked to each emitted pollutant and the mechanisms involved.

These data can be combined with the information presented in Table 4, Table 5 and Table 7 to recreate the results given in this report should readers so wish.

Subsequent reports will provide similar data for the years 2000 and 2020.

Effects on European $PM_{2.5}$ exposure

Table 15 – Effect of emission of 1,000 t (1 kt) of each pollutant from each country on population weighted concentration of $PM_{2.5}$ across Europe.

Country	Ammonia	$PM_{2.5}$	NOx	SO_2	VOC
Austria	254,177	770,572	173,443	176,971	32,867
North East Atlantic	-	100,619	29,329	46,327	6,203
Baltic Sea	-	254,822	52,153	79,522	6,808
Belgium	637,946	1,287,475	114,055	223,612	41,636
Cyprus	282	701	1,110	395	948
Czech Republic	417,851	663,953	145,615	169,999	17,078
Germany	372,661	1,014,694	194,817	230,948	29,555
Denmark	166,988	346,672	89,124	111,616	9,637
Estonia	59,539	88,862	12,756	38,616	1,829
Spain	91,477	393,695	46,330	90,917	5,246
Finland	46,275	113,133	12,483	37,950	2,208
France	248,964	927,733	148,769	169,665	24,065
United Kingdom	365,995	782,425	82,645	138,841	17,100
Greece	66,795	180,409	10,003	29,158	4,794
Hungary	232,842	527,502	104,576	100,240	16,156
Ireland	54,392	307,605	72,621	103,276	10,606
Italy	233,809	706,453	113,157	128,422	19,600
Lithuania	36,659	176,250	31,684	50,227	3,714
Luxembourg	528,831	865,502	175,092	207,475	48,202
Latvia	64,397	185,667	22,157	42,314	3,067
Mediterranean Sea	-	118,356	9,037	43,327	5,074
Malta	173,866	194,770	10,255	45,712	5,933
Netherlands	468,764	1,317,518	144,839	282,954	30,595
North Sea	-	580,310	108,737	146,729	30,694
Poland	210,001	603,355	75,402	118,192	10,539
Portugal	78,688	464,112	23,189	74,204	7,975
Sweden	123,977	248,347	39,973	60,115	4,605
Slovenia	268,688	470,088	130,420	131,395	26,250
Slovakia	295,757	424,163	99,947	102,704	11,707

Note: the very low results for Cyprus need validation before they can be used for further quantification.

Table 16 – Overall effects and mechanisms behind the results shown in Table 15.

Emitted pollutant	**Overall effect**	**Mechanism**
Ammonia	Increases concentrations	Forms ammonium aerosols
NOx	Increases concentrations	Oxidises to nitrate aerosols
$PM_{2.5}$	Increased concentrations	Simple dispersion of non-reactive pollutants
SO_2	Increases concentrations	Oxidises to sulphate aerosol
VOCs	Increases concentrations	Drives ozone formation, leading to enhanced oxidation of NOx and SO_2 and hence enhanced formation of sulphate and nitrate aerosols

For some country to country combinations there is a small negative effect on exposure to total particle concentrations from emission of ammonia, NOx and/or VOCs. This is explained by emission in one location reacting in the atmosphere and changing the availability of other pollutants in other parts of Europe. The overall effect, however, is for a significant increase in concentrations for all pollutant and country to country combinations. In the few cases where negative effects to exposure to particles do arise, they are generally less than 1% of the total change in exposure estimated for each country.

Effects on European SOMO 35 exposure

Table 17 – Effect of emission of 1,000 t (1 kt) of each pollutant from each country on population weighted concentration of SOMO 35 across Europe.

Country	Ammonia	$PM_{2.5}$	NOx	SO_2	VOC
Austria	-1,208,128	0	49,174,904	-8,662,432	33,247,973
North East Atlantic		0	44,248,094	-4,860,781	16,402,530
Baltic Sea		0	10,312,613	-6,020,619	30,597,184
Belgium	-2,214,603	0	-63,166,016	-4,220,272	83,085,281
Cyprus	-111,379	0	1,126,342	-120,674	544,231
Czech Republic	-969,584	0	40,747,424	-5,556,581	36,765,028
Germany	-1,470,312	0	21,765,828	-8,278,706	60,875,738
Denmark	-1,024,982	0	4,391,316	-6,855,733	41,336,660
Estonia	-1,056,526	0	31,624,491	-3,201,456	8,071,285
Spain	-1,046,691	0	54,833,545	-8,480,217	23,515,265
Finland	-1,012,734	0	21,532,925	-4,771,601	8,735,702
France	-1,247,383	0	59,281,117	-8,201,556	47,164,930
United Kingdom	-1,179,738	0	-41,901,537	-5,559,799	50,617,396
Greece	-801,218	0	20,544,850	-413,878	9,325,537
Hungary	-620,938	0	47,534,166	-1,481,912	17,810,459
Ireland	-545,630	0	40,805,494	-9,850,846	30,381,217
Italy	-1,966,120	0	28,877,434	-5,533,346	40,829,467
Lithuania	-255,148	0	51,707,178	-3,866,188	9,276,700
Luxembourg	-2,136,035	0	20,520,315	-9,793,168	75,279,232
Latvia	-503,811	0	47,806,839	-3,386,477	11,037,252
Mediterranean Sea		0	10,765,214	-2,408,272	15,269,240
Malta	-3,405,005	0	15,021,122	-1,404,485	25,705,889
Netherlands	-1,639,576	0	-78,356,692	-3,353,709	69,977,272
North Sea		0	-25,031,358	-4,901,117	65,595,974
Poland	-535,965	0	27,721,219	-1,814,708	22,206,054
Portugal	-728,661	0	6,099,042	-5,952,379	27,494,078
Sweden	-1,205,670	0	31,313,175	-7,110,371	18,153,001
Slovenia	-1,365,518	0	59,217,680	-8,650,791	34,430,267
Slovakia	-690,224	0	57,245,256	-1,935,990	17,920,365

Note: the very low results for Cyprus need validation before they can be used for further quantification.

Table 18 – Overall effects and mechanisms behind the results shown in Error! Reference source not found.**.**

Emitted pollutant	**Effect**	**Mechanism**
Ammonia	Reduces concentrations	Formation of ammonium nitrate aerosol, reducing availability of NO_2 for ozone formation
NOx	Increases concentrations in some place, reduces them in others	NOx emissions can increase ozone levels through reaction with VOCs and sunlight, or reduce concentrations through reaction of NO_2 with O_3. Effect dependent on balance of O_3, VOCs, NO and NO_2 in the atmosphere.
$PM_{2.5}$	No effect	
SO_2	Reduces concentrations	Reacts with ozone, but unlike NOx has no role in ozone formation
VOCs	Increases concentrations	Drives ozone formation in reaction with NOx, sunlight

Effects on European SOMO 0 exposure

Table 19 – Effect of emission of 1,000 t (1 kt) of each pollutant from each country on population weighted concentration of SOMO 0 across Europe.

Country	Ammonia	$PM_{2.5}$	NOx	SO_2	VOC
Austria	-1,375,304	0	-20,740,172	-8,001,746	58,128,230
North East Atlantic		0	57,317,165	-6,449,219	23,830,251
Baltic Sea		0	-7,978,043	-6,328,817	38,599,921
Belgium	-2,540,424	0	-142,877,578	-4,525,235	100,659,935
Cyprus	-270,482	0	2,829,430	-359,374	1,942,446
Czech Republic	-1,278,610	0	-22,960,454	-5,324,003	51,975,036
Germany	-1,686,692	0	-55,035,220	-8,278,492	80,096,149
Denmark	-1,128,410	0	-19,975,632	-7,343,767	50,327,049
Estonia	-1,349,738	0	28,498,417	-3,612,709	12,004,963
Spain	-1,350,932	0	44,850,244	-9,938,082	31,868,831
Finland	-1,398,147	0	18,695,908	-5,916,807	13,330,389
France	-1,565,985	0	-844,885	-8,876,595	67,109,242
United Kingdom	-1,507,317	0	-97,856,201	-6,958,504	62,787,702
Greece	-1,213,613	0	16,113,228	-872,224	17,513,762
Hungary	-1,052,892	0	-16,811,725	-969,700	37,724,539
Ireland	-694,968	0	38,113,374	-12,370,546	41,943,250
Italy	-2,287,057	0	-13,537,052	-5,731,556	59,551,583
Lithuania	-346,804	0	43,428,201	-4,072,719	15,010,734
Luxembourg	-2,512,004	0	-49,133,594	-10,059,565	98,960,044
Latvia	-750,789	0	40,702,975	-3,643,971	16,303,496
Mediterranean Sea		0	6,326,872	-2,813,760	22,253,219
Malta	-4,582,743	0	16,503,350	-1,962,704	35,342,043
Netherlands	-1,839,207	0	-160,234,454	-3,932,583	83,720,717
North Sea		0	-62,893,459	-5,804,228	81,529,100
Poland	-708,687	0	-16,952,114	-1,766,426	33,216,115
Portugal	-942,636	0	-8,728,053	-7,118,130	36,601,103
Sweden	-1,540,454	0	18,449,923	-8,443,381	25,183,406
Slovenia	-1,792,182	0	2,656,885	-8,206,940	61,989,401
Slovakia	-980,983	0	-824,510	-1,532,620	31,320,797

Note: the very low results for Cyprus need validation before they can be used for further quantification.

The effects observed and mechanisms for these effects are the same as described in Table 18. It is, however, notable that the effect of NOx is more negative for SOMO0 than for SOMO 35.