BeTa Version E1.02a

Benefits Table database:

Estimates of the marginal external costs of air pollution in Europe

Created for European Commission DG Environment by netcen

Authors: Mike Holland hollont@aol.com

Paul Watkiss paul.watkiss@aeat.co.uk

netcen

About BeTa

BeTa (the Benefits Table database) has been developed by netcen, part of AEA Technology, to provide a simple ready reckoner for estimation of the external costs of air pollution. This version is a pdf extract providing the main details of the database and default estimates of externalities, but lacking the facility for manipulation of functions, etc. that is present in the full version of the database. The main contacts for this work are:

Paul Watkiss: paul.watkiss@aeat.co.uk
Mike Holland: hollont@aol.com

This version of BeTa has been developed specifically for the European Commission. Contact:
matti.vainio@cec.eu.int

Contents

Pollutants addressed in BeTa

BeTa includes assessment of the externalities of emissions in 1998 of:

SO2 (sulphur dioxide): through effects of SO2 and sulphate aerosols on health, and SO2 and acidity on materials

NOx (oxides of nitrogen): through effects of nitrate aerosols on health and ozone on health and crop production

VOCs (volatile organic compounds): through effects of ozone on health and crop production

PM (particulate matter, focussed on PM2.5, particles with an aerodynamic diamter less than 2.5 micrometre): through effects on health

Glossary

This brief glossary provides information on some of the terms used in BeTa. It is not intended to provide a full explanation of all terms, merely those that are most likely to lead to questions of interpretation.

Health effects are divided into two types of category. The first deals with the duration of exposure leading to an effect. Effects caused by short-term exposure (in the order of days or hours) are described as 'acute effects'. Those caused by long-term exposure (in the order of months or years) are identified as 'chronic effects'. The second category deals with the general type of effect, described as 'mortality' or 'morbidity'. Impacts on mortality relate to people dying earlier than they would in the absence of air pollution. Morbidity relates instead to illness, ranging from minor effects such as coughing to life threatening conditions that require hospitalisation.

The words 'costs', 'damages', 'externalities' and 'external costs' may be used interchangeably in this document, reflecting common usage. In all cases externalities are calculated to give marginal figures, or figures cose to being marginal. The dominance of health impacts, combined with the straight line, no threshold functions that are considered to be appropriate for them, mean that to a large extent marginal externalities are equivalent to average externalities. The area currently quantified for which this is least likely to be true concerns the effects of ozone. It would also not be true for effects of ecological acidification and eutrophication, as both effects are subject to exceedence of thresholds.

Pollutants are described as being 'primary' or 'secondary'. Primary pollutants are pollutants present in the state that they were emitted, whilst secondary pollutants are not emitted as such, but formed in the atmosphere through chemical reactions between one or more pollutants. SO_2 is a primary pollutant because it is emitted as SO_2 from various combustion processes. Ozone is not a primary pollutant, because it is not emitted as such, but forms through the reaction of precursor species, NO_x and VOCs.

The tables of results contain a row for 'EU average'. This is not a straight average across the results of all of the countries listed. It is calculated from the above results, but weighted by emissions in each country.

Situations addressed in BeTa

Three 'situations' are addressed here and described below, with respect to external costs. All of these situations are concerned with an emission scenario of 1998. The effect of using alternative years for the underlying emission scenario would have little effect on the results for SO_2 and PM. However, it would have a significant effect on the VOC results, because of the non-linearities of ozone chemistry in the atmosphere. Effects on NO_x would be intermediate, as it has two components, one from ozone that would be affected by the emission scenario, and one from nitrate aerosol that would be less influenced.

Emission from all sources in rural locations in each country of the EU15 except Luxembourg. Results reflect the impacts of emissions up to a range of, typically, 1000 km from the site of emission. Modelling work undertaken in the ExternE Project has suggested that this is sufficient to capture 95% of the damages associated with emissions. The precise distance over which impacts are calculated is a function of the position of the modelled sources within each country, within the modelling domain. Here, and elsewhere, effects in eastern Europe are included although analysis has not been undertaken to quantify the damages linked to emissions from non-EU states. The main reasons for variation in figures between countries are differences in national population density, differences in distance from each country to the major population centres in Europe, and prevailing wind direction.

Emission at ground level (e.g. from traffic) in cities of different sizes. A base case of a city with a population of 100,000 is selected. Factors are then provided for multiplying the results up to account for larger cities. Results for rural areas should be added to the urban results to reflect impacts outside the city boundaries. Impacts of VOC and NOx emissions are estimated solely from the rural data because of the time taken after emission for formation of ozone and nitrate aerosols.

Emissions from shipping. These are based on data for urban areas of various sizes, as above, in the case of ports; on data for rural areas, as above, for coastal regions of each country; and on the weighted average of rural data from countries surrounding the following sea areas - Eastern Atlantic, Baltic Sea, Northern Mediterranean, English Channel and North Sea. Weightings were calculated from straight-line measurement of the length of each country's coastline bordering the sea area in question. The weighted average was then calculated as the sum of:
{[externality of country_a] * [length of coast for country_a bordering the sea area in question] / [total length of coast bordering the sea area]}
for all countries bordering the sea area.

General methods for external costs analysis using the impact pathway approach

The original methods for calculating the estimates that have been adapted for this study were calculated using the ExternE methodology (European Commission, 1998). This follows the 'impact pathway approach' tracing emissions through dispersion and environmental chemistry, to exposure of sensitive receptors, impacts (calculated using exposure-response functions) and finally economic valuation using the willingness to pay approach.

The results for the core analysis presented in this database have been updated to follow some changes to functions, etc. since 1998, and EC DG Environment's preferred approach to economic valuation of mortality, based on a starting point estimate of the value of statistical life of €1 million. The database has been constructed so as to be flexible enough to permit alternative values to be applied in the future.

External costs of air pollution vary according to a variety of environmental factors, including overall levels of pollution, geographic location of emission sources, height of emission source, local and regional population density, meteorology and so on. This database takes these issues into account to a certain degree only. It is envisaged that this will provide an acceptable quality of data for a variety of purposes, though not all. Exceptions would include very detailed local assessments, for example, investigation of the costs and benefits of meeting air quality standards in a particular city, or, at the other extreme, analysis of options for reducing exposure to ozone, for which relationship between emission of precursors (NOx and VOC) and concentration is complex.

Most of the effects considered are referred to as 'acute' effects, those linked to short term exposure to air pollution. Analysis to support these functions is typically based around estimation of annual mean concentrations. The effect of release of a tonne of pollutant from any facility can simply be assessed by dividing the concentration field arising from total emissions from the plant in a year, by the annual emission in tonnes. Linearity of exposure-response functions is assumed across the full range of concentrations likely to be encountered in Europe. Following the trends in emissions of the last 10 years this is not an unreasonable assumption.

A few effects arise from chronic, long-term exposure to air pollution. Given that chronic conditions typically take some time to develop, and then persist for a number of years, it is appropriate to apply a dicount rate in describing the externalities. This has been done in this work using a discount rate of 4%.

Coverage of the database and limitations

The main limitations of the database reflect the availability of modelling work, particularly for ozone and for shipping, and the availability of data on exposure-response and valuation.

The starting point for the BeTa database is a set of data on pollutant chemistry and dispersion generated for the EC DG Research ExternE Project. It should be recognised that the **original purpose of these calculations was not to develop a database of externalities figures for different parts of the EU for wider policy use like BeTa.** For this reason users should consider the results in the context in which they will be used - are the figures given here appropriate, or should they be adjusted in some way?

The main difficulties relate to **ozone modelling**. Results are based on a single scenario of emissions in the late 1990s. Assuming that countries will meet their obligations under the National Emission Ceilings Directive and the Gothenburg Protocol, emissions of the anthropogenic precursors of ozone, NOx and VOCs will fall significantly by 2010. Problems in extrapolation of the results generated here for the late 1990s arise because of the non-linear nature of the atmospheric chemistry of ozone. Indeed, this is so non-linear that at high NOx concentrations, NOx emissions will reduce, rather than increase ozone concentrations. In discussion with the Commission, it was decided that it would provide a misleading signal if negative externalities (i.e. benefits) were given to those countries where increasing NOx emissions led to reduced ozone according to the model results used here. As a result, ozone damages are set to zero for those countries for which marginal reductions in NOx would lead to increased damages.

Specific analysis of pollutant dispersion has not been undertaken for **shipping** emissions. However, given that their contribution to trans-boundary air pollution impacts is increasingly recognised, it is useful to provide some estimates. These are based on results for cities when ships are in port, and on rural damages when they are at sea. Until such time as modelling exercises have taken shipping emissions into account this is considered appropriate for gaining an insight on the order of magnitude of associated externalities.

A number of types of damage, including effects on ecosystems and cultural heritage have been omitted. The reason for this is that information for some stage in the impact pathway from emission to impact to monetary damage is lacking in the analysis, for example, dose response or valuation estimates. The following list shows what has been included and what has been excluded:

Effects included:

- **Acute (short-term) effects of PM10, SO2, ozone on mortality and morbidity** to the extent that these have been reported
- **Chronic (long-term) effects of PM10 on mortality and morbidity** to the extent that these have been reported
- **Effects of SO2 and acidity on materials used in buildings and other structures (houses, offices, bridges, pylons, etc.) of no significant cultural value** (i.e. excluding damage to statues, cathedrals and churches with fine carvings, etc.)
- **Effects of ozone on arable crop yield**

Effects excluded:

- **Non-ozone effects on agriculture** (e.g. through acid deposition, nutrient deposition, etc.). Previous analysis has shown these effects to be small in comparison to those that are quantified.
- **Change in visibility (visual range)** as a function of particle and NO2 concentration. Research in the USA suggests that this results in a serious loss of amenity. However, following analysis carried out for EC DG Environment and the UNECE, and resulting debate, it was concluded that the issue is not regarded as being so serious in Europe (possibly because reduced visibility through poor air quality is now less of a problem than it was a few years ago). It was also concluded that the US results were not generalisable to Europe.
- **Impacts on ecosystems through exceedence of critical loads and critical levels (including forests, freshwaters, etc.).** This would seem to be the most serious of the known omitted impacts, with potentially significant consequences for ecological sustainability. With respect to acidification, which is linked to emissions of SO2, NH3 and NOx, the problem is worst in areas of northern Europe where the bed rock is hard and weathers too slowly to counteract deposited acidity (e.g. Scandinavia) and much less severe in southern Europe (e.g. Spain, Greece). The most evident impact of acidification is the loss of fish, particularly salmon and trout, though terrestrial ecosystems are also affected. Problems of eutrophication, caused by emissions of nitrogen-containing pollutants (NOx, NH3) are widespread in Europe, with particular hot-spots in a few countries, such as the Netherlands. The most visible effect is one of reducing the viability of rarer species of plant, allowing other species, particularly grasses, to invade land that was previously too nutrient deficient for them.
- **Damage to cultural heritage, such as cathedrals and other fine buildings, statues, etc.** Whilst this provided the earliest and clearest demonstration of air pollution effects to many people, its importance has decreased substaintially over time, as urban SO2 levels have reduced substantially. However, it is unknown whether this reduced rate of deterioration is still important or not. Analysis is not possible because of a lack of data on stock at risk (e.g. number of culturally important buildings, their surface areas, number and size of statues, repair and maintenance costs).
- **Effects of ozone on materials, particularly rubber.**
- **Macroeconomic effects of reduced crop yield and damage to building materials.**
- **Altruistic effects of health impacts.**
- **Unknown effects.** Additional effects are suspected in a number of areas, for example, on morbidity and mortality from chronic (long-term) exposure to ozone.

Overall, however, it is considered that the externalities taken into account in the database are likely to dominate the full external costs. Many of those not quantified are likely to be small, as shown through past analyses. The authors of this database believe that the most important exceptions in the above list relate to ecosystems and unknown effects on health.

Key assumptions

Given that health impacts dominate the damage figures in this analysis, **the key assumption underpinning this work is that reported relationships between air pollutants and health are causal**, rather than simple associations whose true cause is unrelated to air pollution. This assumption has been independently and widely reviewed by various groups of health experts around the world and is now considered to be robust.

Further to this, it is here **assumed that the effects quantified for SO2, PM10 and ozone are additive**. Again, this assumption has been widely reviewed. Direct effects of NO2 (as opposed to indirect effects through the formation of nitrate aerosols) are not quantified here, as available evidence suggests that reported associations are not independent of those for particles, and hence to include them could lead to double-counting.

It is also **assumed that primary particles (i.e. those emitted directly from an emitting source) and secondary particles of different types (particularly sulphate and nitrate aerosols, formed through atmospheric chemical processes following release of SO2 and NOx) are all damaging to health.** Once again, this assumption has been widely reviewed, and health experts see no evidence on which to exclude any particular chemical fraction of particulate matter from the analysis. The same does not apply to different size fractions of particles, however, with only those of aeodynamic diameter of 10 micrometres (referred to as PM10) or less being considered relevant.

It is considered that **the relevant metric of exposure to airborne particles is the annual mean mass of PM10 or PM2.5**. Some experts believe that it may be more appropriate to consider the number of particles rather than the mass. However, at the present time this is not possible because of a lack of exposure-response functions based on particle number.

There are also important assumptions regarding the **use of these data**. The first is that accepting the values given implicitly assumes that they are correct. They are of course subject to uncertainties as noted above. Users are advised to consider to what extent potential uncertainties might affect their judgement in using the data for particular cases. Further guidance on the way that uncertainty assessment can be carried out is available through the list of references given below.

Another related issue concerns those **impacts that are not quantified**. Users should consider whether they should be considered in addition to those impacts that have been quantified. Consideration may take different forms, ranging from a formalised multi-criteria analysis to a less formal discussion of the potential scale of impacts.

In assessments carried out to inform development of the National Emission Ceilings Directive and the Gothenburg Protocol it was assumed that the number of life years lost to the chronic effects of particles on mortality was 10. This figure is an absolute upper limit based on life years lost on average to smoking. Here a probably more realistic figure of 5 years has been used. This calculation is used to convert life years lost (as estimated by the chronic response function) to deaths linked to chronic exposure, to permit valuation using the VOSL approach.

Worked examples

Worked example 1: Quantifying rural health impacts and their monetary values

Users of the system may enter their own exposure-response functions and valuation data to derive estimates of external costs that are alternative to those presented in the 'default estimates'. This example demonstrates how the system applies those data to provide new estimates.

The full analysis requires knowledge of the following:

- Pollutant concentration across Europe associated with emission of one tonne of the primary pollutant
- Number of people exposed across the same domain
- Exposure-response function
- Value

Earlier analysis undertaken in the ExternE Project provides information for each EU country on the average concentration and exposure arising from emission of one tonne of pollutant, based on emissions in 1998. For the reactive pollutants like SO2 or NOx, it provides estimates of exposure to the original pollutant, and, separately, to the products of reaction such as sulphate aerosols, or ozone.

These calculations were undertaken with models that contain data on background pollutant levels and meteorological conditions across Europe. Results from the models are overlaid onto a map of population distribution to estimate exposure (people x the concentration of a pollutant to which they are exposed). BeTa takes these outputs as the starting point for analysis of impacts and externalities.

So, to the example.

* The dispersion models, combined with GIS data on population distribution, provide an estimate of exposure for rural France of:
* 336 person.ug per m3 per tonne of PM2.5 (see 'Further data', below).
* The exposure response function for PM2.5 acute effects on respiratory hospital admissions shows that there are:
* 3.46x10-6 (0.00000346) respiratory hospital admissions for every person.ug per m3.
* Multiplying these figures together provides an estimate of:
* 0.00116 respiratory hospital admissions for each tonne of PM2.5 released.
* Each hospital admission is valued at €4,320.
* Multiplying this by the number of cases per tonne emission (0.0016) gives an estimated externalityof:
* €5.01 for effects on respiratory hospital admissions per tonne release of PM2.5 in rural France.

Respiratory hospital admissions are not the only effects of fine particles. Separate calculations are made for the others, for example, effects on mortality, bronchitis, exacerbation of asthma symptoms and so on. Once these calculations are made, the total externality per tonne emission can be calculated.

Taking the same example, this time for the EU weighted average. The 'Further data' given below provide information on the number of cases associated with emission of 1000 tonnes of the primary pollutants (NOx, SO2, PM2.5 and VOCs). A figure of 100 tonnes has been selected simply to lose decimal places in the outputs, to make them easier to read. In this case the dispersion models, combined with GIS data on population distribution, provide an estimate of exposure of: 312 person.ug per m3 per tonne of PM2.5.

Multiplying this by the function just given for respiratory hospital admissions provides an estimate of 0.00108 respiratory hospital admissions for each tonne of PM2.5 released, or 1.08 per thousand tonnes released as shown in the section 'Further data'. The sheet also gives incidence of other health effects for the same region for the same change in emissions.

A breakdown is not given for the two non-health effects quantified, acid damage to building materials and ozone damage to crops, in terms of exposure-response functions and valuations specific to different crops and materials. Ozone damage to crops is estimated here to account for a little over 20% of total ozone damages, whilst materials damage accounts for around 10% of SO2 externalities. Both figures are under review in other studies that are currently underway. Initial results suggest these may be upper bound estimates for both the crops and the materials for which effects are calculated, but are reasonable as 'ball park' figures.

Worked example 2: Quantifying effects from emissions in urban areas

The quantification of effects of emissions in urban areas need only be carried out for effects of SO2 and particles. For NOx and VOCs emissions need to be transported some distance before chemical processes in the atmosphere are able to generate signficant levels of the secondary pollutants associated with them, nitrate aerosols and ozone, for an appreciable risk to exist, according to the assumptions that underpin this work. For NOx and VOCs, therefore, there is no specific urban quantification necessary (at least as a first approximation), and the figures derived for rural areas may be used.

SO2 and particles, however, are able to cause damage in the form in which they are originally released. Additional calculations are therefore needed to capture the greater level of harm that they may cause in a densely populated urban area compared to a more sparsely populated rural area. The analysis is undertaken in two parts. First, the short-range (urban) externality is calculated, and then the longer-range (rural) externality is added to it, to capture both types of effect.

This example relates to SO2 emissions in the city of Stuttgart, which has a population of about half a million people. The default results tell us that the external cost of 1 tonne of SO2 released in a city of 100,000 people is €6,000.

The default results then provide a set of factors for cities of different sizes. To scale up to a city of 500,000 people, the initial number is multiplied by 5, to give an urban externality of €30,000 (5 * €6,000).

To this must be added the long-range effects, given by the rural figures. For Germany this is €6,100. Hence the total external cost of releasing 1 tonne of SO2 in Stuttgart is here estimated to be €36,100.

It may be noted that external costs scale linearly with population between a city of 100,000 and 500,000 people, but not thereafter. Doubling the size of the city from 500,000 to 1,000,000 increases external costs (according to the data provided here) by only 50%, not the 100% that may have been expected. There are two main reasons for this. First, in a large city there will be an appreciable loss of pollution from the layer of the atmosphere close to ground level through deposition to the ground, through material moving to higher altitudes, and through the onset of chemical processes. Small cities are not large enough for concentrations to fall markedly through these processes.

Secondly, large cities, like London, are not compact, and may contain large areas of woodland and parkland, major industrial and shopping zones, large rivers, etc., where the resident population is effectively zero. If the zone considered is drawn widely enough (as here), this effect can become significant.

Another factor is that the results given here are taken from a subset of European cities. These may, or may not, be representative of other cities across the continent.

References and other examples of the use of externalities data in Europe

Methodological development

European Commission (1999) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 7, Methodology: Update 1998. Holland, M.R. and Forster, D. (eds.). Report available from European Commission DG Research, contact: domenico.rossetti-di-valdalbero@cec.eu.int

European Commission (1998) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 10, National Implementation. Edited by CIEMAT. Report available from European Commission DG Research, contact: domenico.rossetti-di-valdalbero@cec.eu.int

Bickel, P., Schmid, S., Krewitt, W. Friedrich, R., Watkiss, P, Collings, S., Holland, M.R., Pilkington, A., Hurley, F., Donnan, P., Landrieu, G., Eyre, N., Navrud, S., Rabl, A., Spadaro, J., Assimacopoulos, D., Vossiniotis, G., Fontana, M. Frigerio, M. and Dorland, K. (1998) External Costs of Transport. R. Friedrich, P. Bickel and W. Krewitt (eds.) Published by IER, Universitat Stuttgart, Band 46. Not available on the internet.

European Commission DG Environment (2000) Paper on the valuation of mortality in the context of cost-benefit analysis of air quality options. http://europa.eu.int/comm/environment/enveco/others/value_of_life.htm

Application of external costs data

ETSU and others: (1997) Cost-benefit analysis of the draft directive on the incineration of non-hazardous waste. Contract report for DGXI of the European Commission. Not available on the internet.

Holland, M.R. and King, K. (1998) Economic evaluation of air quality targets for tropospheric ozone. Part C: Economic benefit assessment. Contract report for European Commission DG XI.
http://europa.eu.int/comm/environment/enveco/air/tropozone-c.pdf

Holland, M. R., Forster, D., King, K., Haworth, A. and Watkiss, P. (1999) Economic Evaluation of Proposals for Emission Ceilings for Atmospheric Pollutants. Contract Report for European Commission DGXI.
http://europa.eu.int/comm/environment/enveco/air/benefits.pdf

Holland, M.R. (1999) Economic evaluation of air quality limits for CO and benzene. Contract report for European Commission DG XI.
http://europa.eu.int/comm/environment/enveco/air/benzene.pdf

Faircloth, P., Barnes, C., Williams, A., Holland, M.R. and Andrews, K. (1999) Approximation of Environmental Legislation: A study of the benefits of compliance with the EU Environmental Acquis. A report prepared under subcontract to Environment Policy Europe (Brussels) and Environmental Development Consultants (Dublin) for European Commission DGXI. Not available on the internet.

Holland, M.R., Forster, D. and King, K. (1999) Cost-Benefit Analysis for the Protocol to Abate Acidification, Eutrophication and Ground Level Ozone in Europe. Report Number: Air and Energy 133, Ministry of Housing, Spatial Planning and Environment (MVROM), Directorate Air and Energy, ipc 640, P.O. Box 30945, 2500 GX The Hague, The Netherlands.
http://www.unece.org/env/tfeaas/aea2exsummary.pdf

Brown, K.A., Jones, H. and Holland, M.R. (2000) Economic Evaluation of PVC Waste Management. Contract report for European Commission DG Environment, Brussels, Belgium.
http://europa.eu.int/comm/environment/waste/pvc.pdf

Holland, M.R., Jones, H., Visschedijk, A. and Berdowski, J. (2001) Economic Evaluation of Air Quality Targets for PAHs. Report for European Commission DG Environment.
http://europa.eu.int/comm/environment/enveco/air/pah_report.pdf

Default estimates: 1998 emission scenario

RURAL

Marginal external costs of emissions in rural areas, year 2000 prices

	SO2	NOx	PM2.5	VOCs
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	7,200
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	3,000	4,100	5,800	1,500
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
UK	4,500	2,600	9,700	1,900
EU-15 average	5,200	4,200	14,000	2,100

Units:
€/tonne SO2
€/tonne NO2
€/tonne PM2.5
€/tonne VOC

URBAN

Marginal external costs of emissions in cities, year 2000 prices

Urban results for NOx and VOCs are taken to be the same as the rural effects, given that quantified impacts are linked to formation of secondary pollutants in the atmosphere (ozone, nitrate aerosols). Given that these take time to be generated in the atmosphere, local variation in population density has little effect on the results.

Urban externalities for PM2.5 and SO2 for cities of different sizes are calculated by multiplying results for a city of 100,000 people by the factors shown below. Results scale linearly to 500,000 people but not beyond. These results are independent of the country in which the city is located. Once results for the cities are calculated, nationally specific rural externalities should be added to account for impacts of long range transport of pollutants.

	PM2.5	SO2
City of 100,000 people	33,000	6,000

Population	Factors PM2.5	SO2
500,000 people	5	5
1,000,000 people	7.5	7.5
Several million people	15	15

Units:
€/tonne SO2
€/tonne PM2.5

SHIPPING

Marginal external costs from emissions at sea, year 2000 prices

Emissions in port: Use urban results for city of the same size as the port city, and add rural externality figure for the country in question.

Emissions close to shore: Use national rural results.

Offshore emissions: Based on rural results for countries surrounding sea areas, weighted by straight-line length of coast for bordering countries.

	SO2	NOx	PM2.5	VOCs
Eastern Atlantic	4,500	4,800	9,100	1,500
Baltic Sea	1,600	2,100	2,500	1,000
English Channel	5,900	5,400	12,000	1,900
Northern Mediterranean	4,700	6,200	10,000	1,700
North Sea	4,300	3,100	9,600	2,600

Units:
€/tonne SO2
€/tonne NO2
€/tonne PM2.5
€/tonne VOC

Exposure-response functions

Contents

Information

The analysis presented here is based on EC DG Environment's preferred valuation approach for mortality effects, using a value of €1,000,000 for each death linked to air pollution. To use this approach, it is necessary to estimate the number of life years lost per death linked to long-term exposure to particles (including nitrate and sulphate aerosol), as the available exposure-response function provides data only in terms of life years lost. A figure of 5 years has been adopted here, reflecting discussions with experts over the past few years. If a smaller number of life years lost per death were assumed the number of deaths linked to these effects of long-term exposure, and hence the estimates of externalities, would increase.

Only functions for health are given in the following list of functions, as these dominate the results. Application of functions for impacts on building materials and on crops requires full-scale modelling due to non-linearities, though representative values are included in the analysis to permit calculation of revised externalities data.

PM2.5	Original function	Units for original function	Factor to scale for % population affected	Factor to scale for % of affected population that is asthmatic	Assumed average loss of years per mortality case	Consolidated functions	Units for consolidated function
Congestive heart failure	3.09E-05	episodes/[elder-pers.year.ug.m-3]	0.14	1	not applicable	4.33E-06	episodes/[person.year.ug.m-3]
Restricted activity days	4.20E-02	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	3.36E-02	episodes/[person.year.ug.m-3]
Bronchodilator usage - adults	2.72E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	7.62E-03	episodes/[person.year.ug.m-3]
Cough - adults	2.80E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	7.84E-03	episodes/[person.year.ug.m-3]
Lower resp symptoms - adults	1.01E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	2.83E-03	episodes/[person.year.ug.m-3]
Bronchodilator usage - children	1.29E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	9.03E-04	episodes/[person.year.ug.m-3]
Cough - children	2.23E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	1.56E-03	episodes/[person.year.ug.m-3]
Lower resp symptoms - children	1.72E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	1.20E-03	episodes/[person.year.ug.m-3]
Respiratory hospital admission (RHA)	3.46E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	3.46E-06	episodes/[person.year.ug.m-3]
Cerebrovascular hospital admission	8.42E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	8.42E-06	episodes/[person.year.ug.m-3]
Chronic mortality - deaths	Comment:	*based on chronic mortality YOLL function*	not applicable	not applicable	5	6.85E-05	deaths/[person.year.ug.m-3]
Chronic mortality - years of life lost (YC	3.42E-04	YOLL/[person.ug.m-3.year]	1	1	not applicable	3.42E-04	YOLL/[person.ug.m-3.year]
Chronic bronchitis - adults	3.90E-05	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	3.12E-05	episodes/[person.year.ug.m-3]
Chronic cough - children	3.46E-03	episodes/[child.year.ug.m-3]	0.2	1	not applicable	6.92E-04	episodes/[person.year.ug.m-3]

Sulphate aerosol	Original function	Units for original function	Factor to scale for % population affected	Factor to scale for % of affected population that is asthmatic	Assumed average loss of years per mortality case	Consolidated functions	Units for consolidated function
Congestive heart failure	3.09E-05	episodes/[elder-pers.year.ug.m-3]	0.14	1	not applicable	4.33E-06	episodes/[person.year.ug.m-3]
Restricted activity days	4.20E-02	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	3.36E-02	episodes/[person.year.ug.m-3]
Bronchodilator usage - adults	2.72E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	7.62E-03	episodes/[person.year.ug.m-3]
Cough - adults	2.80E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	7.84E-03	episodes/[person.year.ug.m-3]
Lower resp symptoms - adults	1.01E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	2.83E-03	episodes/[person.year.ug.m-3]
Bronchodilator usage - children	1.29E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	9.03E-04	episodes/[person.year.ug.m-3]
Cough - children	2.23E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	1.56E-03	episodes/[person.year.ug.m-3]
Lower resp symptoms - children	1.72E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	1.20E-03	episodes/[person.year.ug.m-3]
Respiratory hospital admission (RHA)	3.46E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	3.46E-06	episodes/[person.year.ug.m-3]
Cerebrovascular hospital admission	8.42E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	8.42E-06	episodes/[person.year.ug.m-3]
Chronic mortality - deaths	Comment:	*based on chronic mortality YOLL function*	not applicable	not applicable	5	6.85E-05	deaths/[person.year.ug.m-3]
Chronic mortality - years of life lost (YC	3.42E-04	YOLL/[person.ug.m-3.year]	1	1	not applicable	3.42E-04	YOLL/[person.ug.m-3.year]
Chronic bronchitis - adults	3.90E-05	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	3.12E-05	episodes/[person.year.ug.m-3]
Chronic cough - children	3.46E-03	episodes/[child.year.ug.m-3]	0.2	1	not applicable	6.92E-04	episodes/[person.year.ug.m-3]

Nitrate aerosols	Original function	Units for original function	Factor to scale for % population affected	Factor to scale for % of affected population that is asthmatic		Consolidated functions	Units for consolidated function
Congestive heart failure	1.85E-05	episodes/[elder-pers.year.ug.m-3]	0.14	1	not applicable	2.59E-06	episodes/[person.year.ug.m-3]
Restricted activity days	2.50E-02	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	2.00E-02	episodes/[person.year.ug.m-3]
Bronchodilator usage - adults	1.63E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	4.56E-03	episodes/[person.year.ug.m-3]
Cough - adults	1.68E-01	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	4.70E-03	episodes/[person.year.ug.m-3]
Lower resp symptoms - adults	6.10E-02	episodes/[asth-adult.year.ug.m-3]	0.8	0.035	not applicable	1.71E-03	episodes/[person.year.ug.m-3]
Bronchodilator usage - children	7.80E-02	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	5.46E-04	episodes/[person.year.ug.m-3]
Cough - children	1.33E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	9.31E-04	episodes/[person.year.ug.m-3]
Lower resp symptoms - children	1.03E-01	episodes/[asth-child.year.ug.m-3]	0.2	0.035	not applicable	7.21E-04	episodes/[person.year.ug.m-3]
Respiratory hospital admission (RHA)	2.07E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	2.07E-06	episodes/[person.year.ug.m-3]
Cerebrovascular hospital admission	5.04E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	5.04E-06	episodes/[person.year.ug.m-3]
Chronic mortality - deaths	Comment:	*based on chronic mortality YOLL function*	not applicable	not applicable	5	4.11E-05	deaths/[person.year.ug.m-3]
Chronic mortality - years of life lost (YC	2.05E-04	YOLL/[person.ug.m-3.year]	1	1	not applicable	2.05E-04	YOLL/[person.ug.m-3.year]
Chronic bronchitis - adults	2.50E-05	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	2.00E-05	episodes/[person.year.ug.m-3]
Chronic cough - children	2.07E-03	episodes/[child.year.ug.m-3]	0.2	1	not applicable	4.14E-04	episodes/[person.year.ug.m-3]

SO2	Original function	Units for original function	Factor to scale for % population affected	Factor to scale for % of affected population that is asthmatic		Consolidated functions	Units for consolidated function
Respiratory hospital admission (RHA)	2.04E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	2.04E-06	episodes/[person.year.ug.m-3]
Acute mortality - deaths	0.072%	% change death rate/ug.m-3 (cases)	0.0099	1	not applicable	7.13E-06	deaths/[person.year.ug.m-3]

Ozone	Original function	Units for original function	Factor to scale for % population affected	Factor to scale for % of affected population that is asthmatic		Consolidated functions	Units for consolidated function
Acute mortality - deaths	0.059%	% change death rate/ug.m-3 (cases)	0.0099	1	not applicable	5.84E-06	deaths/[person.year.ug.m-3]
Respiratory hospital admission (RHA)	3.54E-06	episodes/[person.year.ug.m-3]	1	1	not applicable	3.54E-06	episodes/[person.year.ug.m-3]
Asthma attacks	4.29E-03	episodes/[asthmaticperson.year.ug.m-3]	1	0.035	not applicable	1.50E-04	episodes/[person.year.ug.m-3]
Minor restricted activity day (MRAD)	9.76E-03	episodes/[adult.year.ug.m-3]	0.8	1	not applicable	7.81E-03	episodes/[person.year.ug.m-3]

APPLICATION OF FUNCTIONS

IMPACTS = EXPOSURE[PEOPLE * UG.M-3] * FUNCTION * FRACTION OF POPULATION * FRACTION ASTHMATIC (WHERE APPROPRIATE)

(note: YEARS LOST PER CASE) is already factored into the relevant mortality functions)

MONETARY DAMAGE = IMPACTS * VALUES EURO2000 = CONSOLIDATED FUNCTIONS * VALUES EURO2000

Valuation data

The valuation of effects of long-term (chronic) exposure on mortality are based on the same figure of €1 million used to value short term (acute) effects of exposure on mortality. Recognising that the effect of an emission now will be spread over a number of years (as this is a long-term effect), the figure has been discounted at a rate of 4%, giving a value of €490,000 per death.

Valuation data	Value €, year 2000 price level	Source
Congestive heart failure	3,260	ExternE
Restricted activity days	110	ExternE
Bronchodilator usage - adults	40	ExternE
Cough - adults	45	ExternE
Lower resp symptoms - adults	8	ExternE
Bronchodilator usage - children	40	ExternE
Cough - children	45	ExternE
Lower resp symptoms - children	8	ExternE
Respiratory hospital admission (RHA)	4,320	ExternE
Cerebrovascular hospital admission	16,730	ExternE
Chronic mortality - deaths	490,000	European Commission
Chronic bronchitis - adults	169,330	ExternE
Chronic cough - children	240	ExternE
Acute mortality - deaths	1,000,000	European Commission
Asthma attack	40	ExternE
Minor restricted activity day (MRAD)	8	ExternE

Further data: based on the 1998 emission scenario, EU average case

This sheet calculates the number of cases of the various health effects quantified for the EU-15 average, rural emission, case, or for individual countries as specified using the cell shaded pink. Results are scaled up to an emission of 1000 tonnes of the primary pollutant simply to make them easier to read. Impacts to materials and crops are not readily amenable to expression in this way, but information on externalities per tonne emission are given for them in the table that follows. Data on exposure indices are also given, though readers should note that these are specific to the 1998 emission scenario.

RURAL

Number of events of a health effect per 1000 tonne emission, EU average case

	SO2 as SO2	SO2 as SO4	Total SO2	NOx as NO3	NOx as O3	Total NOx	Total PM2.5	Total VOCs
Congestive heart failure		0.30	0.30	0.41		0.41	1.3	
Restricted activity days		2,367	2,367	3,149		3,149	10,471	
Bronchodilator usage - adults		536	536	719		719	2,373	
Cough - adults		552	552	741		741	2,443	
Lower resp symptoms - adults		199	199	269		269	881	
Bronchodilator usage - children		64	64	86		86	281	
Cough - children		110	110	147		147	486	
Lower resp symptoms - children		85	85	114		114	375	
Respiratory hospital admission (RHA)	0.54	0.24	0.79	0.33	-	0.33	1.1	0.98
Cerebrovascular hospital admission		0.59	0.59	0.79		0.79	2.6	
Chronic mortality - deaths		4.8	4.8	6.5		6.5	21	
Chronic mortality - years of life lost (YOLL)		24	24	32		32	107	
Chronic bronchitis - adults		2.2	2.2	3.1		3.1	10	
Chronic cough - children		49	49	65		65	216	
Acute mortality - deaths	1.90		1.90		-	-		1.6
Acute mortality - years of life lost (YOLL)	0.95		0.95		-	-		0.8
Asthma attack					-	-		42
Minor restricted activity day (MRAD)					-	-		2,171

Default damages to materials and crops: externality per tonne of emission (€, price year 2000)

	NOx	VOCs	SO2
	Ozone - crops	Ozone-crops	Acids - materials
Austria		263	321
Belgium		686	287
Denmark		1663	121
Finland	148	113	35
France	160	452	270
Germany		648	224
Greece	260	214	150
Ireland		305	94
Italy		639	185

Netherlands		557	256
Portugal	230	337	110
Spain	150	203	136
Sweden	189	158	62
UK		428	164
EU-15 average		495	189

Exposure indices: rural emissions, data specific to 1998 emission scenario

Country	SO2-SO2	SO2-SO4	NOx-NO3	NOx-ozone	PM2.5	VOC-ozone
Austria	371	98	258		310	180
Belgium	405	107	179		509	385
Denmark	171	45	125		123	935
EU-15 average	266	70	157		312	278
Finland	50	13	33	83	33	64
France	380	101	283	90	345	254
Germany	316	84	154		376	364
Greece	211	56	186	146	179	120
Ireland	133	35	106		94	171
Italy	260	69	268		263	359
Netherlands	360	95	151		414	313
Portugal	154	41	116	129	134	189
Spain	191	51	153	84	181	114
Sweden	88	23	67	106	40	89
UK	232	61	97		222	241

Exposure indices: urban emissions, data specific to 1998 emission scenario

City	SO2-SO2	PM2.5
100,000 people	762	745
500,000 people	3810	3725
1,000,000 people	5715	5587
Many millions	11430	11174