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19

Health Impacts of Emissions from Large Point Sources

Second Edition

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Health Impacts of Emissions from Large Point Sources (Second Edition).

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ISBN: 91-975883-1-8.

ISSN: 1400-4909

Cover illustration: Lars-Erik Håkansson (Lehån).

Published in March 2006 by the Swedish NGO Secretariat on Acid Rain, Box 7005,
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Correction

The methods and data used in this report are subject to regular internal review. During this process, after the release of the first edition of this report, one of the source databases used here was found to substantially overestimate NOx emissions from facilities that process or distribute gas. These plant, including two that had previously been in the top 50 for the region covering the EU, Norway and Switzerland, have thus been removed from the analysis.

This problem highlights the need for future versions of the EPER database, in particular, to be far more comprehensive in their coverage with respect to plant and pollutants than at present. It also highlights a need for a true pan-European emissions database for large point sources, including data from all European countries.

Acknowledgements

This work has been funded by the Swedish NGO Secretariat on Acid Rain, and cofinanced by European Commission DG Research through the Methodex Project.

Summary and conclusions

Analysis under the recent CAFE (Clean Air For Europe) programme of the European Commission highlighted substantial health impacts linked to air pollution. CAFE estimated a loss of 3.6 million life years in the year 2000 attributable to exposure to fine particles in the European Union, which was further estimated to be equivalent to around 350,000 deaths. A further 20,000 deaths were linked to ozone exposure. The CAFE analysis also estimated very significant numbers for cases of ill health linked to air pollution, ranging from lost work days to bronchitis and hospital admissions. Another output of CAFE generated a set of figures expressing damage per tonne emission of five pollutants, including NOx and SO_2, the focus of this study, from each European country. Those results are included in the European IPPC (Integrated Pollution Prevention and Control) Bureau's reference document on Economics and Cross Media Effects and form the basis of the analysis presented here.

This report combines the CAFE health assessment methodology with SENCO's emissions database for European Large Point Sources to assess health related damages linked with emission of NOx and SO_2 on a plant by plant basis. Health impacts have been quantified principally against the sulphate and nitrate aerosols – so-called secondary particles that are formed in the atmosphere following the emissions of SO_2 and NOx. Effects of ozone formation linked to NOx emissions are also included, but these make up a very small contribution to total damage estimates. Emissions of primary particles from large point sources, which in some cases may be significant, were not included in the assessment. The SENCO database covers 7,000 plant in countries throughout Europe, and in countries further east including Turkey and some former USSR countries.

Table (i) Estimated total health impacts of large point sources in the EU25, Norway and Switzerland, linked to emissions of SO_2 and NOx via the formation of sulphate and nitrate aerosols.

Health effect	Total cases	Economic equivalent (euro millions)
Chronic mortality (life years lost, population aged > 30)	790,000	41,000
Chronic mortality (deaths in population aged > 30)	74,000	72,000
Infant mortality (infants aged 1 - 12 months)	130	190
Chronic bronchitis, population aged > 27	35,000	6,500
Respiratory hospital admissions, all ages	13,000	26
Cardiac hospital admissions, all ages	8,100	16
Restricted activity days (RADs) working age population	73,000,000	6,000
Respiratory medication use by adults	6,200,000	6.2
Respiratory medication use by children	750,000	0.75
LRS*, including cough, among adults with chronic symptoms	59,000,000	2,200
LRS* (including cough) among children	39,000,000	1,500
Total (using number of life years lost)		57,000
Total (using number of deaths)		88,000

* Lower respiratory symptoms.

Total estimated health impacts quantified against the large point sources in the region containing the EU25, Norway and Switzerland, are shown in Table (i). It is estimated that the total number of life years lost attributable to emissions from large point sources in the EU25 region is 790,000 per year. Large though these results are, they account for only 21% of the health damage quantified for air pollution emissions for the EU25 in the year 2000 according to the analysis undertaken for the EU's CAFE programme. Other important sources include road transport, shipping, aviation, and the commercial, public and domestic sectors. The CAFE analysis also included damage linked to emissions of ammonia (mainly from agriculture) primary particles (from a diversity of sources) and volatile organic compounds, none of which are considered in this report.

When considering these results and others presented in the report, it is important to be aware of the uncertainties that are present. Not least of these is that some plant have changed emissions since 2001, the latest reporting year for the EPER database, either for operational reasons or in response to legislation. There are also uncertainties in the impact quantification methodology, relating to attribution of damage to specific types of particle (here, sulphate and nitrate aerosols), use of country-average damage estimates, etc. Results should thus be seen as broadly indicative of impact levels, rather than precise measures.

For the EU, Norway and Switzerland, results on a plant by plant basis show that 50% of damage is accumulated by the 120 most damaging plant, and 90% by the 911 most damaging, out of a total of 6,333 plant. The situation seems even more extreme in the non-EU region, for which 50% of damage is estimated to be accumulated by only 20 plant, and 90% by 128, out of a total of 534, though the completeness of the emissions database for this region is questionable.

Table (ii) lists the ten most damaging plant identified in the study in two regions, the EU with Norway and Switzerland, and secondly, all countries outside this region.

Table (ii) The 10 most damaging plant identified in each of the two regions considered, with estimates of annual economic damage and impacts on mortality.

Rank	Country	Plant	Sector	Damage (euro million/ year)	Life years lost/year	Deaths/ year
EU25 Member States, Norway and Switzerland						
1	Spain	Puentes	Electricity	1,400	19,000	1,800
2	Poland	Belchatow	Electricity	1,300	18,000	1,600
3	Spain	Teruel	Electricity	700	9,600	890
4	Poland	Turow	Electricity	690	9,500	890
5	Poland	Adamow	Electricity	600	8,200	760
6	Poland	Patnow	Electricity	540	7,400	690
7	UK	Longannet	Electricity	540	7,400	690
8	UK	Cottam	Electricity	530	7,300	680
9	UK	West Burton	Electricity	510	7,000	660
10	Italy	Porto Tolle	Electricity	500	6,800	630
Countries outside the EU, Norway and Switzerland						
1	Ukraine	Krivorozhskaya	Electricity		14,000	1,300
2	Bulgaria	Maritsa East II	Electricity		14,000	1,300
3	Ukraine	Burshtynskaya	Electricity		13,000	1,200
4	Ukraine	Zmiyevskaya	Electricity		11,000	980
5	Ukraine	Lodyzhinskaya	Electricity		10,000	980
6	Ukraine	Kurakhovskaya	Electricity		9,300	860
7	Ukraine	Pridneprovskaya	Electricity		8,700	810
8	Turkey	Seyitomer Soemtes	Electricity		7,900	740
9	Ukraine	Starobeshevskaya	Electricity		7,600	710
10	Ukraine	Zuevskaya	Electricity		7,400	690

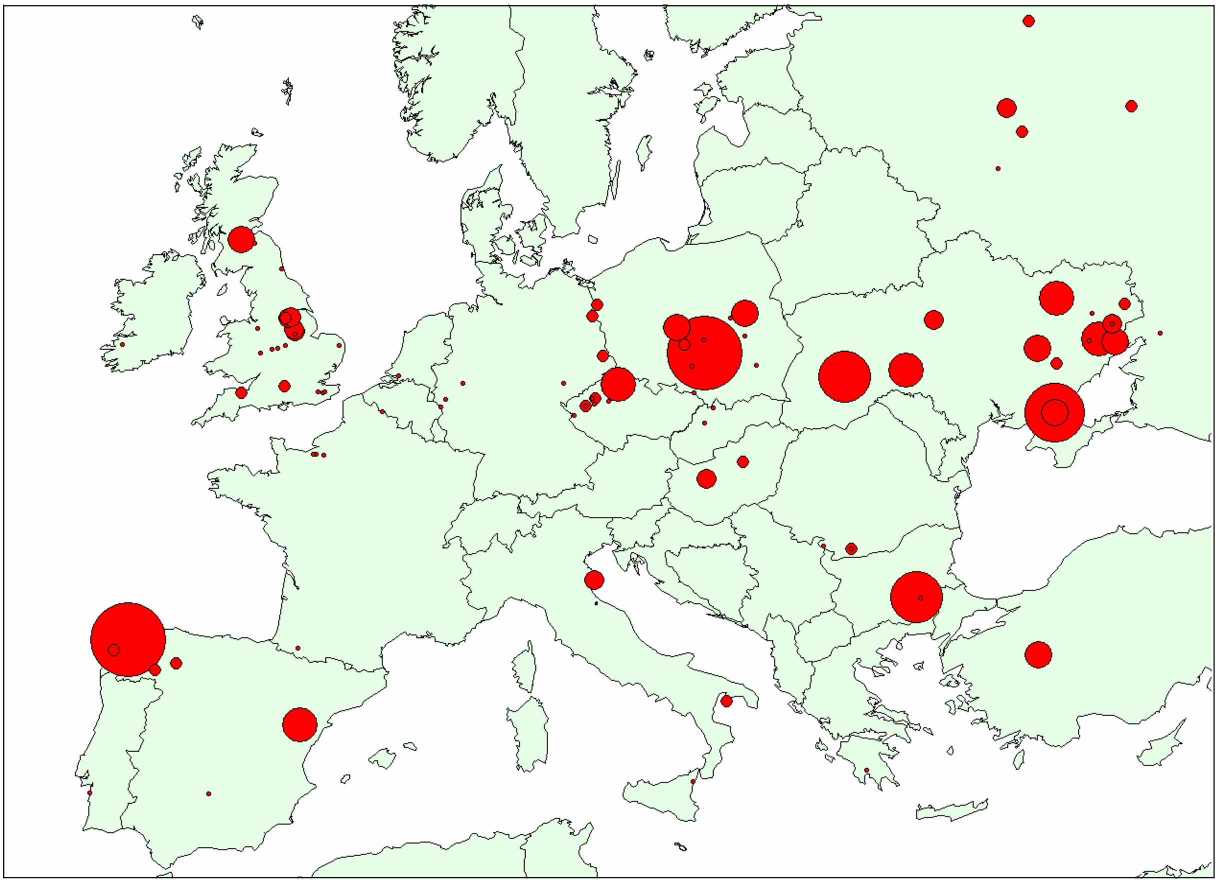

Figure (i). Map showing the location of the large point sources in Europe estimated to cause the greatest health damage due to secondary particles formed from their emissions of SO_2 and NOx. The size of the circles is proportionate to the damage.

The distinction is made between the two groups as results should be considerably more robust for the former than the latter for reasons given in the main text.

The two final columns show loss of life years and the number of deaths – these are simply different ways of expressing mortality impacts rather than separate effects. Loss of life years was the metric preferred by most commentators on the CAFE work, as it can be quantified more robustly. Some commentators, however, prefer to refer to 'deaths' instead, and for that reason both types of result are given. It is important to recognise that impacts are quantified against the formation of sulphate and nitrate aerosols in the atmosphere following the release of SO_2 and NOx. These particles take some time to form, and hence the loss of life expectancy quantified here is not specific to the area around each plant, but is instead spread over distances of several hundred kilometres around each source. Impacts should thus be seen in the context of the overall European pollution climate, not as a local phenomenon.

The economic damage quantified in the table relates only to health impacts, based on the 'willingness to pay' approach used in CAFE. The CAFE approach does not directly provide estimates of willingness to pay outside the EU, so no figures are given in this column for plant in the lower half of the table. The focus of this report on health means that damage to ecosystems and buildings is not included in the estimates shown.

Although the table presented in this summary includes only large point sources whose main purpose is to generate electricity, the analysis covered other source types, such as facilities for manufacture of metals and chemicals, cokeries, etc.

Large power plants dominate the top of the listing, however, simply because of the large quantity of fuel that they use.

Another way to rank plant based on these results involves normalisation of damage against the amount of electricity (or heat, steel, coke, etc.) produced. This type of analysis is presented for power plants in the EU, Norway and Switzerland region. Results provide a different ranking, with a number of smaller plant of apparently much lower efficiency moving to the top of the list. However, results also showed that the plant listed above fall in the top 5% of this second ranking also.

Recommendations are made for improving the transparency of environmental reporting with respect to emissions as follows:

1. The EPER database should be updated annually.
2. Reporting thresholds should be lowered to ensure that a more complete quantification of emissions is provided. For this report it was not possible to quantify damage from primary particle emissions because they are provided for a relatively small number of facilities.
3. Given the trans-boundary nature of air pollution, the database should be extended to cover all European countries, not just those that are members of the European Union.

The report demonstrates that large point sources of SO_2 and NOx generate very significant health impacts across Europe. It is also evident that there is significant variation between plant with respect to levels of damage per unit of electricity generated, due in part to the use of varying levels of emission control. This highlights the potential for substantial benefits for the European population from continued action to reduce emissions of SO_2 and NOx from these sources.

1. Introduction

1.1 Objective

The objective of this work is to estimate health impacts associated with emissions of air pollutants from individual large point sources in Europe. The air pollutants of most interest here are sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and fine particles. Whilst quantifying health impacts, this analysis omits a number of other effects of these pollutants, for example on ecosystems and buildings[1]. A similar exercise has been carried out by analysts in the USA, and is available interactively on the internet[2].

The health impact of most concern is premature mortality as a result of exposure to fine particles. These particles may be emitted directly from combustion and other processes, in which case they are defined as 'primary particles', or formed by chemical reaction in the atmosphere ('secondary particles'). Sulphates and nitrates, formed following the emission of SO_2 and NO_x, fall into this latter category. As data on emissions of primary particles are subject to a markedly higher level of uncertainty than the other pollutants considered, damage from primary emitted particles is excluded from the results presented in the report. The limited analysis of particles that has been carried out in this report indicates that emissions of primary particles from large point sources and associated damage are likely to be relatively small compared to the other pollutants considered here, but this needs further investigation.

1.2 Historical perspectives

In response to health concerns in the mid-20th century, action was taken to reduce air pollution impacts in many countries. This was typically done through controls on the burning of solid fuels and by moving large point sources of emissions away from the most populated areas.

Despite this action, concern over the health effects of air pollution has increased significantly in the last 20 years following research originally in the USA that found relationships between daily air pollutant levels and mortality and hospital admission rates. This research demonstrated impacts at much lower concentrations than had previously been thought relevant to health, and was unable to identify a threshold for impacts, especially for fine particulate matter. Research programmes in Europe found very similar results to those performed in the USA.

The European Commission's ExternE Programme[3], which commenced in 1991, has led work in Europe on the development of a methodology for quantifying the health impacts of air pollutants within an economic framework. Reports issued by the programme in 1995 and since, have demonstrated that, based on available knowledge, air pollution from energy use and transport generates significant costs to society in terms of increased ill health and premature death. These findings have

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[1] Information on the extent of the impacts to ecosystems in the European Union is available on the CAFE website (http://europa.eu.int/comm/environment/air/cafe/general/keydocs.htm) in the section "Maps on Air Pollution Effects".

[2] http://www.cleartheair.org/dirtypower/

[3] Externalities of Energy, http://www.externe.info/

been reinforced by similar work in the USA performed for the Department of Energy (ORNL/RFF, various reports) and the Empire State Electric Energy Research Corporation (Rowe et al, 1995). The ExternE methods have found wide application in the appraisal of European environmental policy relating to air pollution and waste management in particular:

Air quality directives
1st Daughter Directive on fine particles, NO_2, SO_2 and lead (IVM and others; 1997)
2nd Daughter Directive on CO and benzene (AEA Technology; 1998a)
3rd Daughter Directive on ozone (AEA Technology, 1998b).
4th Daughter Directive on PAHs and heavy metals (AEA Technology, 2001; Entec, 2001)

Emission Caps
Gothenburg Protocol (AEA Technology, 1999a)
National Emission Ceilings Directive (AEA Technology, 1999b)

Waste management
Draft Waste incineration directive (AEA Technology, 1997)
Waste management and PVC (AEA Technology, 2000)

More recently, analysis of this type has provided a major input to the development of the European Commission's Thematic Strategy on Air Pollution under the cost-benefit analysis (CBA) of the Clean Air For Europe (CAFE) Programme[4]. The methodology for health impact assessment used by CAFE, and adopted here, was described in detail by Hurley et al (2005). It was developed after extensive consultation with European experts, including groups convened by WHO (World Health Organization), Member State experts, industry and NGOs (Non-Governmental Organisations). A detailed review of the CAFE-CBA methodology was made by UNICE (Union des Industries de la Communauté Européenne), intended as representative of the views of European industry on the benefits methodology. This was critical of a number of decisions made on the methodology, though these were countered in detail by the CAFE-CBA team. Full details of this debate are available on the CAFE-CBA website[4] (AEA Technology and others, 2005e).

1.3 Scope of analysis

The analysis presented in this report is focused on the health impacts of secondary particles formed in the atmosphere following the release of SO_2 and NOx. For large point sources in the EU25, Norway and Switzerland, the monetary equivalent of health impacts has been quantified based on the 'willingness to pay' (WTP) approach (see Hurley et al, 2005). For these countries a single set of values has been applied to all countries (in line with the methods used in the CAFE analysis). For large point sources in other European countries (extending east to Turkey, Russia and the former Soviet Republics) impacts are quantified but not monetised.

Table 1. Mapping primary (emitted) pollutants to impacts.

	NOx	PM2.5	SO_2
Particles: human health	✓	pq	✓
Ozone: human health	✓		
Primary pollutants: human health	✘	pq	✘
Ecosystems: acidification	✘		✘
Ecosystems: eutrophication	✘		
Ecosystems: ozone effects	✘		
Crops: ozone effects	✘		
Materials: material degradation	✘		✘
Materials: soiling		✘	

Key: ✘ identifies impacts unquantified in this report; ✓ identifies quantified impacts; pq = partially quantified. blank cells indicate no link between pollutant and impact.

[4] http://www.cafe-cba.org

Table 1 summarises the pollutants considered, and highlights which impacts are and are not quantified in this report.

The health impacts that have been quantified for this report are listed in detail in Table 2. More information on the impacts omitted from the analysis is given in Table 3. The term 'chronic effects' relates to impacts arising from long-term exposures (for months or years), whilst 'acute effects' are those caused by exposure to elevated pollution levels over a shorter period, typically one or more days.

Table 2. Health impacts quantified in the analysis undertaken for this report.

Burden	Effect	
Human exposure to PM2.5	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

Table 3. Effects omitted from the analysis.

Effect	Comments
Health	
Ozone - chronic mortality	
Ozone - chronic morbidity	No information on possible chronic effects, suspected but not proven
Direct effects of SO_2 and NOx	
Agricultural production	
Direct effects of SO_2 and NOx	Negligible according to past work
Direct ozone impacts on crop yield	
N deposition as crop fertiliser	Negligible according to past work
Visible damage to marketed produce	Locally important for some crops, but insignificant at the European scale
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	CAFE analysis found that these impacts are only a few percent of health damages
Effects on cultural assets, steel in re-inforced concrete	Lack of stock at risk inventory and valuation data
PM and building soiling	
Effects of ozone on paint, rubber	
Ecosystems	
Effects on biodiversity, forest production, etc. from excess ozone exposure, acidification and nitrogen dep.	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

2. Methods and Data

2.1 Overview

The analysis presented here is based principally on two projects:

1. The SENCO database of emissions from large point sources in Europe, covering most member states of UNECE. This database has already been used to rank large point sources of air pollution in Europe according to their emissions (Barrett, 2004), allowing identification of the most and least polluting per unit of useful output.
2. Analysis of health impacts performed for the cost benefit analysis of the Clean Air For Europe (CAFE) programme of European Commission Directorate General Environment (AEA Technology and others, 2004a, b; 2005a, b, c, d; Hurley et al, 2005). This work has also fed directly into the development of the Reference document on Economics and Cross Media Effects produced by the European IPPC Bureau (2005). The underlying methods for this work build on the work of the long-running ExternE Project series of EC DG Research[5], and were developed through extensive debate with stakeholders including representatives of the EU Member States, the World Health Organization (WHO) and other experts, industry and non-governmental organisations (NGOs). Agreement on the methods and functions used is widespread, though not unanimous.

2.2 The SENCO database

The SENCO database is described more completely by Barrett (2004). The following provides an overview of the data contained in it, and the quality of that information.

2.2.1 Data available from the SENCO database

The SENCO database provides an extensive listing of data on emissions and performance of large industrial facilities throughout Europe. It contains information on the names and locations of plant, their purpose and useful outputs, and emissions of SO_2, NOx, PM and CO_2.

2.2.2 Sources of data used by SENCO

The main sources of data for the SENCO database are:

EPER; the European Pollution Emission Register

IEACR; the International Energy Agency Coal Research coal power station database

Platts; the Platts World Electric Power Plant database

IEACO2; a database assembled by the IEA Greenhouse Gas R&D Programme

Information from these databases has been collated for over 7,000 plant from across Europe. Additional data have been sought by SENCO and integrated with the

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

database where necessary and available to give a more complete picture of European plant than would otherwise be possible.

2.2.3 Data quality

The data used in this report are typically from around 2000/2001. Accordingly;

- ❑ Some plant may have shut;
- ❑ Some operators may have retrofitted abatement equipment;
- ❑ Other changes, such as fuel switching, may have occurred;
- ❑ New plant will have come on-line.

In general, these changes will have resulted in reductions in emission because of pressure from National Emission Ceilings, IPPC and LCPD regulation. Accordingly, the results presented here may therefore for some plant (but not all) paint an overly pessimistic view of health damages at the present time. This demonstrates a need for annual updating of emission estimates in databases such as EPER. In addition, plans may already exist at other plant for improved emission control.

Primary particle emissions are reported for relatively few plant in the EPER database, and not at all in the others. To fill this gap, the SENCO database has estimates of particle emissions in many cases, and these estimates are subject to a significant level of uncertainty. As a result, damage associated with primary particle emissions has been excluded from quantification in this report for all but a small number of cases used for illustrative purposes. Provided that effective particle emission controls are in place at any plant this would make only a small difference to the results presented here. However the issue of primary emissions, including those from small sources near or in population centres, needs further examination.

It has been necessary to estimate emissions of SO_2 and NOx in the SENCO database for many plant included in EPER and the other databases as a result of incomplete reporting. Internal review found that the emissions data used for facilities that process or distribute gas in the first edition of this report significantly overestimated true emissions. These plant have been removed from the analysis. Given the need to estimate emissions it is possible that significant errors also affect other plant. This highlights the need for more complete reporting under EPER, particularly.

With these caveats and others described below concerning the impact assessment in mind, the results presented here should only be seen as indicative of likely levels of damage.

2.3 Quantification of health impacts of emissions of NOx, SO_2 and PM

2.3.1 Overview of methods

Analysis contained in this report follows the impact pathway methodology developed in the ExternE Project funded by EC DG Research. Methods for estimating the impacts and economic damage associated with emissions from the EU25 are described by AEA Technology and others (2005b) for development of the updated BeTa (Benefits Table) database. For each country in the EU (excluding Cyprus), BeTa provides average damage estimates in terms of euro/tonne emission of ammonia, NOx, $PM_{2.5}$, SO_2 and VOC. BeTa has already been used to support the development of the IPPC (Integrated Pollution Prevention and Control) Bureau's position on 'Economics and Cross Media Effects' (EIPPC Bureau, 2005).

The impact pathway described by the analysis is as follows:

Emission of pollutants

→ Dispersion and physical/chemical transformation of pollutants

→ Exposure of people

→ Quantification of impacts

→ Valuation of impacts

The method gives two sets of useful data to add to the emission estimates contained in the SENCO database:

1. Information on the number of cases of ill health and loss of life expectancy linked to exposure to emissions of SO_2, NOx and primary PM from large point sources in Europe.
2. Information on the total value attached to these occurrences of ill health, according to surveys performed using economic techniques to assess the 'willingness to pay' (WTP) of members of the public to a change in the risk of being ill or dying early. Some argue that it is unethical to value health in this manner. However, this argument ignores the fact that health is routinely valued by policy makers through the allocation of funds to medical services, foreign aid and so on, though this is rarely done in a way that transparently identifies underlying values, or necessarily reflects the views of the public. The methods used here define a consistent and transparent weighting scheme. Stakeholders who do not accept the values adopted in the analysis are of course free to substitute their own.

2.3.2 Inputs for the BeTa database

The dispersion modelling used in BeTa takes outputs from the EMEP model (Simpson and Wind, 2005). The EMEP model was run many times to quantify the change in pollution climate across the EU25 arising from a 15% change in emission of pollutants including NOx, $PM_{2.5}$ and SO_2 from each country in the year 2010. These impacts on air quality were then scaled back to estimate the change in concentration across Europe arising from emission of 1 tonne of pollutant. The modelling includes assessment of the formation of secondary pollutants such as ozone (from NOx and VOC emissions) and nitrate and sulphate particulates (from NOx and SO_2 emissions respectively).

These changes in pollution concentrations were then combined with population (based on UN data sources) on a 50 x 50 km grid. The "population weighted pollutant concentrations" so derived for each grid cell were then summed and combined with the exposure-response functions adopted under the CAFE programme to quantify the average number of cases or events of death and ill health (following the list in Table 2) associated with the release of 1 tonne of each pollutant in each country. Results were then multiplied by valuation factors to show the economic value of each impact, and summed to give a total damage per unit pollution emission, expressed in euro/tonne.

The key parameters of response function and valuation data are shown for each effect in Table 4. In CAFE the valuation of mortality was performed using four figures – a lower and higher estimate of the value of a life year (VOLY) and a lower and higher estimate for the value of statistical life (VSL). There is roughly a factor four difference between the extremes of the range. Further information on these factors, including the reasons behind their selection for CAFE, is provided by Hurley et al (2005).

For this report the most conservative of these figures, the lower estimate of euro 52,000/VOLY, has been adopted in line with recommendations made under the ExternE Project. ExternE also recommends that it is most meaningful to report mortality in terms of life years lost (LYL). Although estimates of the number of deaths linked to operation of each plant are also provided, these figures should be regarded as less robust, than the reduction in longevity expressed as LYL. Further discussion

Table 4. Response functions and valuation data for quantification of health damages linked to PM and O_3 exposure (based on Hurley et al, 2005).

Effect - pollutant	Response functions: % or absolute change for affected population per 10µg/m³ pollutant	Valuation (euro/case or event)
Chronic mortality (LYL, VOLY valuation) age >30 - PM2.5	6%	52,000
Chronic mortality (deaths, VSL valuation) age >30 - PM2.5	6%	980,000
Infant mortality ages 1 - 11 months - PM10	4%	1,500,000
Chronic bronchitis, population age >27 - PM10	7%	190,000
Respiratory hospital admissions, all ages - PM10	1.14%	2,000
Cardiac hospital admissions, all ages - PM10	0.6%	2,000
Restricted activity days (RADs) ages 18-64 - PM2.5	4.75%	82
Respiratory medication use by asthmatic adults - PM10	0.91	1
Respiratory medication use by asthmatic children - PM10	0.18	1
LRS, including cough, among symptomatic adults- PM10	1.30	38
LRS (including cough) among children - PM10	1.85	38
Acute mortality (VOLY median valuation) - ozone	0.30%	52,000
Respiratory hospital admissions, age >65 - ozone	0.30%	2,000
Minor restricted activity days, ages 18-64 - ozone	1.48%	38
Respiratory medication use by asthmatic adults - ozone	0.73	1

* Life years lost and the number of deaths are different ways of expressing the same impact and their results are therefore not additive.

of these issues is given by Hurley et al (2005) in the report on health methodology for the CAFE-CBA assessment.

2.3.3 Quantification of impacts outside the EU

Country-specific results of modelling of emissions from non-EU countries are not yet available from EMEP. Analysis undertaken for the EC DG Research Methodex Project (Holland, 2006), however, has shown that for the EU countries a good relationship exists between damage and population density within each country for effects of primary particles, SO_2 via sulphate aerosol and NOx via nitrate aerosol but not ozone.

These relationships have therefore been applied to the non-EU countries at the national level, with one exception, Russia. Population density is extremely variable within Russia, ranging from 362 people/km^2 for the administrative subdivisions of Moscow City and Moscow Oblast combined[6] to less than 1 person/km^2 in regions covering more than a third of the country. Given that the area of the various subdivisions of Russia is similar to the range of areas of other entire European countries, extrapolation has been performed by weighting against the population density of the region within which each Russian plant is contained, rather than the country as a whole. Accordingly, the health damage estimated to be caused by emissions from plants in remote regions of the country with a low population density will be significantly lower than that estimated in the more densely populated areas, for example in and around Moscow or St Petersburg. Data are presented in full by Holland (2006).

The fact that some considerable effort has been made to weight Russian emissions by surrounding population density should not be taken to suggest that the results so generated are highly accurate. They are the output of an extrapolation, and have all the uncertainty bound up in that fact. That said, they should be robust

[6] The population density of the city of Moscow approaches 10,000 people/km^2 . However, the method for extrapolation is based on country level data, and it seems appropriate to consider Moscow within an area roughly similar to a more typical European country.

enough to provide an indication of the general magnitude of health damages associated with emissions from each plant.

2.3.4 Data quality

Whilst the EMEP model is widely respected in Europe, there are some caveats relating to its use in this work. Firstly, the results used represent an average for each country, factoring out the specificity of damage relative to the height of emission and the precise location of each plant. To some extent the uncertainty arising from this is reduced here because this analysis focuses on impacts of secondary pollutants (principally sulphate and nitrate aerosols) arising following the release of SO_2 and NOx. These secondary pollutants take some time to form in the atmosphere, making the specificity of site less important. Even so, variability of the order of a factor of 2 around best estimates may be expected within a large country. A much higher degree of variability would be found for primary particles, though they are not included in this analysis.

Turning to the response functions used, in common with other studies in this field, and the advice of WHO given in answers to questions raised by the CAFE stakeholders, the following positions have been adopted:

1. That there is no threshold for the effects of fine particles on health, with the response function being linear down to a concentration of zero. Given a lack of evidence for a threshold, this seems unlikely to introduce a bias to the analysis.
2. That ozone effects are quantified only above a concentration of 35 ppb (parts per billion). This may bias results to underestimation of damage.
3. That all types of particle are equally damaging per unit mass. It is possible that this biases results to overestimation of damage in this study.
4. That there are no separate effects arising from exposure to SO_2 and NO_2, beyond those that might be implicitly accounted for in the quantification of damages from secondary particles. If incorrect, this would bias results to underestimation of damage.

WHO also recommended that impacts of particle exposure on chronic mortality be quantified using a risk rate of 6% per 10 $\mu g/m^3$ for the main analysis, and a lower rate of 4% for sensitivity analysis. Here, only the 6% rate has been used. Impacts based on this lower rate can be obtained simply by reducing the results for the number of LYL or deaths by one third.

3. Results

3.1 Data inputs from the BeTa database

The results in BeTa show significant variation in damage between countries, permitting the present study to take some account of site specificity. The fact that the work does not consider site at a finer resolution within countries does affect the quality of outputs, introducing additional uncertainty. However, this is moderated through the focus on the impacts of SO_2 and NOx via the formation of secondary particles in the atmosphere. Site specificity in damage is much stronger for (e.g.) primary particles which would be considered hazardous from the time of release from a large point source.

3.2 Health impacts from LPS in the SENCO database in the EU25, Norway and Switzerland

3.2.1 Total impacts

Table 5 shows total estimated health impacts and associated economic values arising from emissions of NOx and SO_2 for large point sources for EU Member States, Norway and Switzerland. Damage is mostly linked to secondary aerosol formation, with ozone related impacts adding on average less than 3% to the damage associated with NOx and 1% to the total damage of SO_2 and NOx combined.

The total number of life years lost attributable to emissions from large point sources across the region is 790,000 per year. This represents 21% of the loss of life calcu-

Table 5. Total health impacts and their economic equivalent for emissions of SO_2 and NOx from Large Point Sources in the SENCO database for the EU25, Norway and Switzerland.

Health effect	Total cases	Economic equivalent (euro millions)
Chronic mortality (life years lost, population aged > 30)	790,000	41,000
Chronic mortality (deaths in population aged > 30)	74,000	72,000
Infant mortality (infants aged 1 - 12 months)	130	190
Chronic bronchitis, population aged > 27	35,000	6,500
Respiratory hospital admissions, all ages	13,000	26
Cardiac hospital admissions, all ages	8,100	16
Restricted activity days (RADs) working age population	73,000,000	6,000
Respiratory medication use by adults	6,200,000	6.2
Respiratory medication use by children	750,000	0.75
LRS*, including cough, among adults with chronic symptoms	59,000,000	2,200
LRS* (including cough) among children	39,000,000	1,500
Total (using number of life years lost)		57,000
Total (using number of deaths)		88,000

* Lower respiratory symptoms.

Figure 1. Variation in country-average damage linked to NOx emissions in different EU Member States (AEA Technology and others, 2005b). Mortality valuation based on median VOLY.

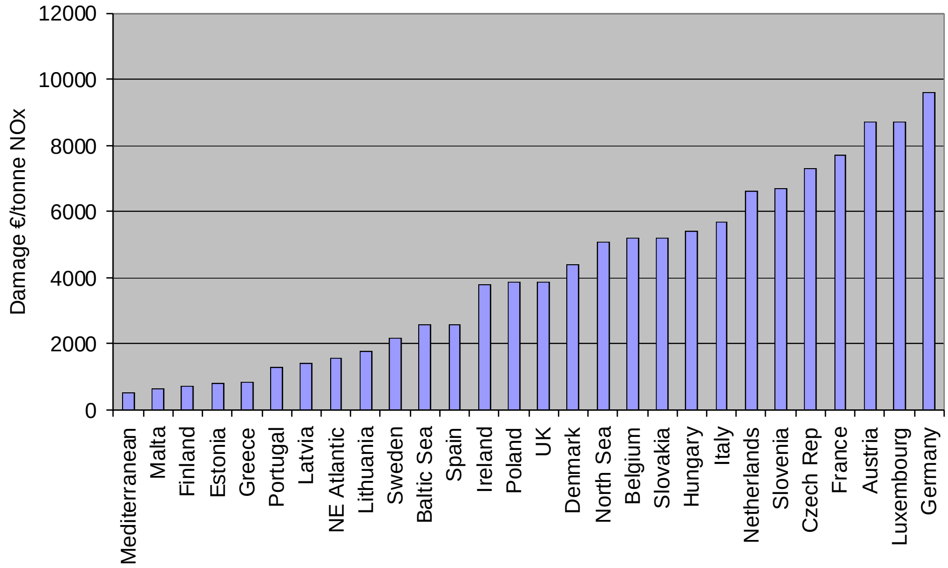
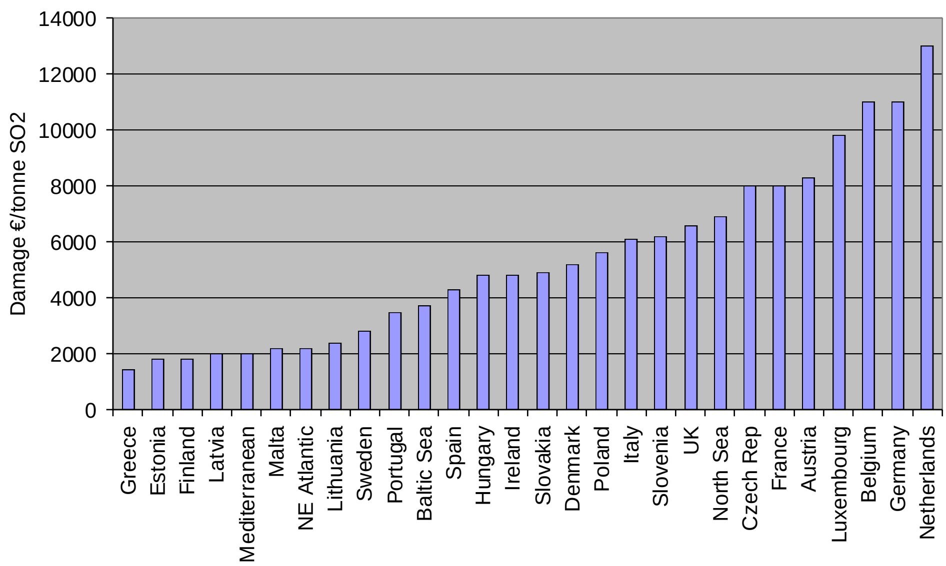


Figure 2. Variation in country-average health damage linked to SO_2 emissions in different EU Member States (AEA Technology and others, 2005b). Mortality valuation based on median VOLY.



lated for the EU in 2000 in the CAFE baseline analysis (AEA Technology and others, 2005a). The remaining 79% can be accounted for by:

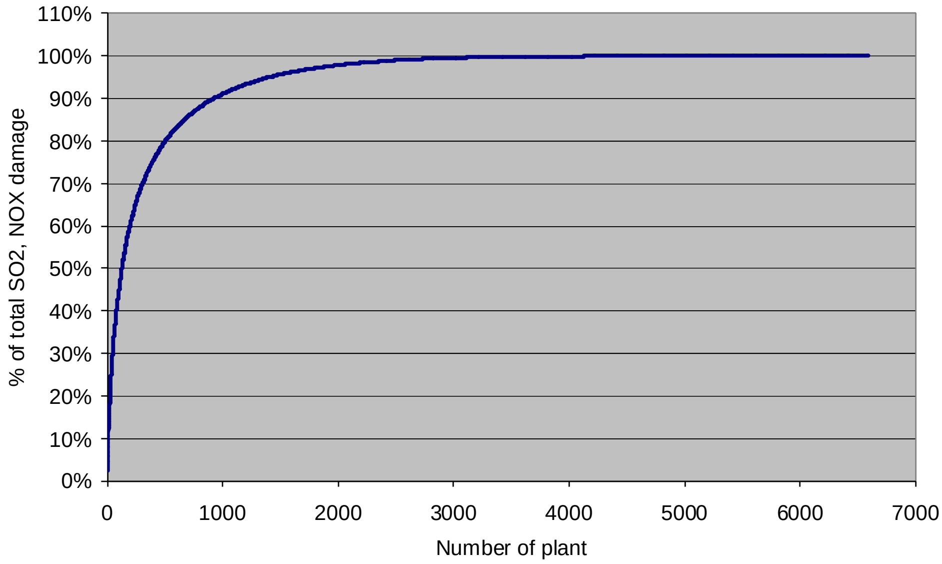
1. Emissions from other sources within the region (from transport, the domestic sector, smaller industrial facilities, natural sources, etc.);
2. Effects of emissions of $PM_{2.5}$, NH_3 and VOCs;
3. Emissions from outside the countries considered in this part of the analysis.

Total damage is in the order 57 billion euro/year based on use of the value of a life year (VOLY) approach for mortality valuation. This corresponds to the lower end of the CAFE range, and is in line with estimates based on the ExternE Project methodology. A higher value is also given, 88 billion euro/year, based on mortality valuation using the alternative approach of value of statistical life. Both of these estimates are based on use of median estimates from the observed distribution of responses to 'willingness to pay' questionnaires. Given a highly skewed distribution of the responses, the median is regarded by a number of economists as more representative of societal preference than the mean, though of course it pays little regard to the views of those who proclaim a very high willingness to pay. Use of the mean value of statistical life (in line with the upper end of the CAFE estimates) would roughly double the VSL based estimate to 170 billion euro/year. These issues of valuation of course have no effect on the number of cases or health events estimated here.

3.2.2 Cumulative distribution of impacts

The cumulative distribution of damage for SO_2 and NOx emissions from the LPS in EU25, Norway and Switzerland recorded in the SENCO database is shown in Figure 3. The steepness of the curve in its initial phase is striking, with 50% of damage accumulated by the 120 most damaging plant, and 90% by the 911 most damaging (out of a total of 6,333 plant).

Figure 3. Cumulative distribution of damage by number of plant in the EU25, Norway and Switzerland.



The situation seems even more extreme in the non-EU region, for which 50% of damage is estimated to be accumulated by only 20 plant, and 90% by 128, out of a total of 534. However, the factor 10 disparity in the total number of sources identified in the two regions requires further investigation.

3.2.3 Plant with the largest impacts in the EU25, Norway and Switzerland

Table 6 lists the 200 plant in the region containing the EU25, Norway and Switzerland that generate the highest health damage, according to the CAFE-CBA methodology and the information contained in the SENCO database. A number of caveats should be considered:

1. Methods and input variables are prone to uncertainty, including the attribution of health impacts to secondary particles formed following the release of NOx and SO_2.
2. No account has been taken of the impacts of pollutants other than SO_2 and NOx.

3. Emissions data are also prone to uncertainty, and may not bear a close relation to current plant performance, for example, where plant have been upgraded since 2001. In addition, new plant may have been opened since 2001 – these will not be included in the listing. Shading in the tables highlights those plant not included in EPER, for which emissions data are likely to be less reliable. However, for many plant included in EPER it was necessary to estimate SO_2 and/or NOx emissions.
4. Some of the plant listed may be far more efficient in terms of production per unit damage than smaller plant that are not included on this list simply because of their size, rather than a good standard of environmental control.

The results shown include total economic damages linked to the health impacts, the number of life years and the corresponding number of deaths. The figures for deaths are less robust than the figures for life years lost. Indeed, some experts in the field argue very strongly against quantification of deaths (e.g. A. Rabl, personal communication, 2005). The economic estimates given in Table 6 are based on the median estimate of the VOLY, and hence link to the lower estimate shown in Table 5. Use of the median estimate of the VSL would increase damage by about 50%. Use of the mean VSL would further double damage. Uncertainty generally is discussed in more detail in Sections 2.2.3, 2.3.4 and 4.1.

The fuel codes used in Table 6 are described in the box below, noting that for some plant a variety of coals may be used.

Fuel codes used in the tables

S_ Solid fuel	
S_Coa	undefined coal
S_CoaAnt	anthracite
S_CoaBit	bituminous coal
S_CoaHar	hard coal
S_CoaLig	lignite
S_CoaSub	subbituminous coal
S_OilSha_Estonia	Oil shale
S_PeaMil	Peat
L_ Liquid fuel	
L_LigDis	light distillate oil
L_FO	fuel oil
L_FOHea	heavy fuel oil
G_ Gaseous fuel	
G_BlaFur	blast furnace gas
G_Nat	natural gas
X unknown fuel	

Table 6. The 200 LPS in the EU25, Norway and Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation. Shading highlights plant not included in the EPER database.

	Plant	Country	NACE sector	Main fuel	Damage (million euro/yr)	Life years lost/yr	Deaths /year
1	Puentes	Spain	Electricity	S_Coa	1,400	19,000	1,800
2	Belchatow	Poland	Electricity	S_CoaLig	1,300	18,000	1,600
3	Teruel	Spain	Electricity	S_Coa	700	9,600	890
4	Turow	Poland	Electricity	S_CoaLig	700	9,500	890
5	Adamow	Poland	Electricity	S_CoaLig	600	8,200	760
6	Patnow	Poland	Electricity	S_CoaLig	540	7,400	690
7	Longannet	UK	Electricity	S_Coa	540	7,400	690
8	Cottam	UK	Electricity	S_Coa	530	7,300	680
9	West Burton A	UK	Electricity	S_Coa	510	7,000	660
10	Porto Tolle	Italy	Electricity	L	500	6,800	630
11	Eggborough	UK	Electricity	S_Coa	450	6,100	570
12	Oroszlany	Hungary	Electricity	S_CoaSub	440	6,000	560
13	Drax	UK	Electricity	S_Coa	420	5,700	540
14	Prunerov I	Czech Rep.	Electricity	S_CoaLig	410	5,600	520
15	Ferrybridge C	UK	Electricity	S_Coa	380	5,200	480
16	Pomorzany	Poland	Electricity	S_CoaBit	370	5,100	470
17	Taranto	Italy	Iron&steel	X	370	5,100	470
18	Jänschwalde	Germany	Electricity	S_Coa	360	5,000	460
19	Belfast West	UK	Electricity	S_Coa	360	4,900	460
20	Compostilla	Spain	Electricity	S_CoaAntBit	350	4,700	440
21	Matra	Hungary	Electricity	S_CoaLig	330	4,600	430
22	Krakow	Poland	Electricity	S_CoaBit	330	4,500	420
23	Didcot A	UK	Electricity	S_Coa	330	4,500	420
24	Meirama	Spain	Electricity	S_Coa	330	4,400	420
25	Ledvice II	Czech Rep.	Electricity	S_CoaLig	310	4,300	400
26	La Robla	Spain	Electricity	S_CoaBitAnt	300	4,100	380
27	Aberthaw	UK	Electricity	S_Coa	290	4,000	370
28	Schwedt	Germany	Coke, other fuels	X	290	3,900	370
29	Rugeley	UK	Electricity	S_Coa	280	3,900	360
30	Kingsnorth	UK	Electricity	S_Coa	280	3,800	360
31	Rybnik	Poland	Electricity	S_CoaBit	270	3,800	350
32	Pernis Rotterdam	Netherlands	Coke, other fuels	X	260	3,600	330
33	Ironbridge	UK	Electricity	S_Coa	250	3,500	320
34	Novaky B	Slovakia	Electricity	S_CoaLig	250	3,400	320
35	Litvinov	Czech Rep.	Electricity	S_CoaBit	240	3,300	310
36	Lippendorf	Germany	Electricity	S_Coa	240	3,300	310
37	High Marnham	UK	Electricity	S_Coa	240	3,300	310
38	Tisova I	Czech Rep.	Electricity	S_CoaLig	240	3,300	310
39	Moneypoint	Ireland	Electricity	S_Coa	230	3,200	300
40	Megalopolis	GRC	Electricity	S_Coa	230	3,100	290
41	Fiddlers Ferry	UK	Electricity	S_Coa	230	3,100	290
42	Gravenchon	France	Coke, other fuels	X	220	3,100	290
43	Grain	UK	Electricity	L	220	3,000	280
44	Lynemouth	UK	Electricity	S_Coa	220	3,000	280
45	Setubal	Portugal	Electricity	L	220	3,000	280
46	Melnik III	Czech Rep.	Electricity	S_CoaLig	210	2,900	270
47	Pocerady	Czech Rep.	Electricity	S_CoaLig	200	2,800	260
48	Weisweiler	Germany	Electricity	S_Coa	200	2,800	260
49	Frimmersdorf	Germany	Electricity	S_Coa	200	2,700	250
50	San Filippo	Italy	Electricity	L	190	2,700	250

Table 6 (continued). The 200 LPS in the EU25, Norway and Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation. Shading highlights plant not included in the EPER database.

	Plant	Country	NACE sector	Main fuel	Damage (million euro/yr)	Life years lost/yr	Deaths /year
51	Ratcliffe on Soar	UK	Electricity	S_Coa	190	2,600	250
52	Puertollano	Spain	Coke, other fuels	X	190	2,600	240
53	Lodz IV	Poland	Electricity	S_CoaBit	190	2,600	240
54	Westfalen	Germany	Iron&steel	X	190	2,600	240
55	Tilbury	UK	Electricity	S_Coa	180	2,500	240
56	Gonfreville	France	Coke, other fuels	X	180	2,500	230
57	Zeran	Poland	Electricity	S_CoaBit	180	2,400	220
58	Tusimice I	Czech Rep.	Electricity	S_CoaLig	170	2,300	220
59	Cockenzie	UK	Electricity	S_Coa	170	2,300	220
60	Ruien	Belgium	Electricity	S_Coa	170	2,300	220
61	Le Havre	France	Electricity	S_Coa	170	2,300	220
62	Siersza	Poland	Electricity	S_CoaBit	170	2,300	220
63	Drakelow B	UK	Electricity	S_Coa	170	2,300	210
64	Kozienice	Poland	Electricity	S_CoaBit	170	2,300	210
65	Ostroleka A	Poland	Electricity	S_CoaBit	170	2,300	210
66	Elektrownia III	Poland	Electricity	S_CoaBit	160	2,200	210
67	Bergheim	Germany	Electricity	X	160	2,200	210
68	Konin	Poland	Electricity	S_CoaLig	160	2,200	210
69	Sines	Portugal	Electricity	S_Coa	160	2,200	210
70	Gelsenkirchen/Scholven	Germany	Electricity	S_Coa	160	2,200	210
71	Skawina	Poland	Electricity	S_CoaBit	160	2,200	210
72	Gela/Ref	Italy	Coke, other fuels	X	160	2,100	200
73	Alberto	Spain	Inorg. Chemicals	X	160	2,100	200
74	Cordemais	France	Electricity	S_Coa	150	2,100	200
75	Chvaletice	Czech Rep.	Electricity	S_CoaLig	150	2,000	190
76	Fos Sur Mer	France	Iron&steel	X	150	2,000	190
77	Borsod	Hungary	Electricity	S_CoaSub	150	2,000	190
78	Dunamenti	Hungary	Electricity	L_FuOHea	150	2,000	190
79	Kilroot Power Station	UK	Electricity	S_Coa	140	2,000	180
80	Priolo Gargallo Nord	Italy	Coke, other fuels	X	140	2,000	180
81	Krakow Leg	Poland	Electricity	S_CoaBit	140	1,900	180
82	Sicilia	Italy	Electricity	L_LigDis/FueO	140	1,900	180
83	Detmarovice	Czech Rep.	Electricity	S_CoaBit	140	1,900	180
84	Amer	Netherlands	Electricity	S_CoaBit	140	1,900	180
85	Emil Huchet	France	Electricity	S_Coa	140	1,900	170
86	Boxberg	Germany	Electricity	S_Coa	140	1,900	170
87	Esso Antwerpen	Belgium	Coke, other fuels	X	140	1,800	170
88	Tarbert	Ireland	Electricity	L	130	1,800	170
89	Aboño	Spain	Electricity	S_Coa	130	1,800	170
90	Almeria	Spain	Electricity	S_Coa	130	1,800	170
91	Fawley Refinery	UK	Coke, other fuels	X	130	1,800	170
92	Anllares	Spain	Electricity	S_Coa	130	1,800	160
93	Vojany I	Slovakia	Electricity	S_CoaHar	130	1,800	160
94	La Casella	Italy	Electricity	L	130	1,700	160
95	Piombino	Italy	Electricity	L	130	1,700	160
96	Brindisi/Federico	Italy	Electricity	X	130	1,700	160
97	Escucha	Spain	Food	X	130	1,700	160
98	FINA Antwerpen	Belgium	Coke, other fuels	X	120	1,700	160
99	Tapada	Portugal	Electricity	S_Coa	120	1,700	160
100	Guardo	Spain	Electricity	S_CoaBit	120	1,700	160

Table 6 (continued). The 200 LPS in the EU25, Norway and Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation. Shading highlights plant not included in the EPER database.

	Plant	Country	NACE sector	Main fuel	Damage (million euro/yr)	Life years lost/yr	Deaths /year
101	Maasvlakte	Netherlands	Energy	S_Coa	120	1,700	160
102	Soto de Ribera	Spain	Electricity	S_Coa	120	1,700	160
103	Neurath	Germany	Electricity	S_Coa	120	1,700	150
104	Pecs Power Plant	Hungary	Electricity	S_CoaSubHar	120	1,700	150
105	Bremen/Hafen	Germany	Electricity	S_Coa	120	1,600	150
106	Imola	Italy	Electricity	G_Nat	120	1,600	150
107	Hemweg	Netherlands	Electricity	S_CoaBit	120	1,600	150
108	Fort Dunlop	UK	Electricity	G_Nat	120	1,600	150
109	Kosciuszko	Poland	Electricity	S_CoaBit	120	1,600	150
110	Wilhelmshaven	Germany	Electricity	S_Coa	120	1,600	150
111	Blenod/Pont a Mousson	France	Water	S_Coa	120	1,600	150
112	Excatron	Spain	Electricity	S_Coa	110	1,600	150
113	San Martin	Spain	Coke, other fuels	X	110	1,500	140
114	Banhida	Hungary	Electricity	S_CoaSub	110	1,500	140
115	Dolna Odra	Poland	Electricity	S_CoaBit	110	1,500	140
116	Trebovice	Czech Rep.	Electricity	S_CoaBit	110	1,500	140
117	Gibraltar	Spain	Coke, other fuels	X	110	1,500	140
118	Schwarze Pumpe	Germany	Electricity	S_Coa	110	1,500	140
119	Ajaccio	France	Electricity	L	110	1,500	140
120	Fusina	Italy	Electricity	S_CoaBit	110	1,500	140
121	Rotterdam/Darcy	Netherlands	Coke, other fuels	X	110	1,500	140
122	Venezia/Mal	Italy	Electricity	X	110	1,500	140
123	Dillingen	Germany	Iron&steel	X	110	1,400	130
124	Dunkerque	France	Iron&steel	X	110	1,400	130
125	Brugge	Belgium	Electricity	S_Coa	100	1,400	130
126	Ljubljana	SVN	Electricity	S_CoaLig	100	1,400	130
127	Genova	Italy	Electricity	S_Coa	100	1,400	130
128	La Mede	France	Coke, other fuels	X	100	1,400	130
129	Opatovice	Czech Rep.	Electricity	S_CoaLig	100	1,400	130
130	Woippy	France	Electricity	S_Coa	99	1,400	130
131	Sarroch	Italy	Coke, other fuels	X	98	1,300	130
132	Petit Couronne	France	Coke, other fuels	X	97	1,300	120
133	Los Barrios	Spain	Electricity	S_Coa	97	1,300	120
134	Berre L'Etang	France	Organic chemicals	X	95	1,300	120
135	Deuna	Germany	Cement	X	95	1,300	120
136	Hodonin	Czech Rep.	Electricity	S_CoaLigBit	94	1,300	120
137	Ijmuiden/Laura	Netherlands	Electricity	X/G_BlaFur	93	1,300	120
138	Seraing	Belgium	Iron&steel	X	93	1,300	120
139	Augusta	Italy	Coke, other fuels	X	93	1,300	120
140	Mol	Belgium	Electricity	S_Coa	93	1,300	120
141	Torrevaldaliga Nord	Italy	Electricity	L	93	1,300	120
142	HKM Duisburg	Germany	Iron&steel	X	92	1,300	120
143	Voerde	Germany	Electricity	S_Coa	91	1,300	120
144	Narcea	Spain	Electricity	S_Coa	91	1,300	120
145	Ijmuiden/ Laura	Netherlands	Iron&steel	X	91	1,200	120
146	Wroclaw	Poland	Electricity	S_CoaBit	89	1,200	110
147	Rhode	Ireland	Electricity	S_PeaMil	88	1,200	110
148	Eesti	Estonia	Electricity	S_OilSha_Est	87	1,200	110
149	Mainz	Germany	Cement	X	87	1,200	110
150	Monfalcone	Italy	Electricity	S_Coa	85	1,200	110

Table 6 (continued). The 200 LPS in the EU25, Norway and Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation. Shading highlights plant not included in the EPER database.

	Plant	Country	NACE sector	Main fuel	Damage (million euro/yr)	Life years lost/yr	Deaths /year
151	Balti	Estonia	Electricity	S_OilSha_Est	85	1,200	110
152	Aughinish	Ireland	Inorg chemicals	X	83	1,100	110
153	Nieuwdorp	Netherlands	Coke, other fuels	X	83	1,100	110
154	Mendonk	Belgium	Iron&steel	X	83	1,100	110
155	Lacq	France	Gas, oil extraction	X	82	1,100	110
156	Wesseling	Germany	Organic chemicals	X	81	1,100	100
157	Cercs	Spain	Electricity	S_CoaBitLig	80	1,100	100
158	Meyreuil	France	Electricity	X	80	1,100	100
159	Laziska	Poland	Electricity	S_CoaBit	79	1,100	100
160	Gdansk II	Poland	Electricity	S_CoaBit	79	1,100	100
161	Donges	France	Coke, other fuels	X	78	1,100	100
162	Milazzo	Italy	Electricity	S_Coa	77	1,100	99
163	Tisza	Hungary	Electricity	L_FuOHea	77	1,100	98
164	Donges	France	Coke oven prods	X	77	1,100	98
165	Ensdorf	Germany	Electricity	S_Coa	76	1,000	98
166	Blachownia	Poland	Electricity	S_CoaBit	76	1,000	97
167	Pleinting	Germany	Electricity	L_FuOLig	76	1,000	97
168	Carregado	Portugal	Electricity	L	76	1,000	97
169	Gent	Belgium	Iron&steel	X	75	1,000	96
170	Lindsey	UK	Coke, other fuels	X	75	1,000	96
171	Koln/ Godorf	Germany	Coke, other fuels	X	75	1,000	96
172	Tarragona Repsol	Spain	Coke, other fuels	X	75	1,000	96
173	Stanlow	UK	Coke, other fuels	X	73	1,000	93
174	Pego	Portugal	Electricity	S_CoaBit	72	990	92
175	Weiher	Germany	Electricity	S_Coa	72	990	92
176	Saarbrucken	Germany	Energy	S_Coa	72	980	91
177	Priolo Gargallo Sud	Italy	Coke, other fuels	X	72	980	91
178	Feyzin	France	Coke, other fuels	X	71	980	91
179	Grangemouth	UK	Coke, other fuels	X	71	980	91
180	Loon Plage	France	Coke, other fuels	X	71	970	91
181	Noyelles Godault	France	Non-ferrous metals	X	70	960	89
182	Bydgoszcz II	Poland	Electricity	S_CoaBit	69	950	88
183	Lada	Spain	Electricity	S_Coa	69	950	88
184	Mannheim	Germany	Electricity	S_Coa	69	950	88
185	Puertollano	Spain	Electricity	S_Coa	69	950	88
186	Elektrenai	Lithuania	Electricity	L_FuOHea	69	940	88
187	Schilling	Germany	Electricity	L_FueOil	69	940	88
188	Livorno	Italy	Electricity	L	69	940	88
189	Porto Torres/ Fiume	Italy	Electricity	L	68	930	87
190	Westfalen	Germany	Electricity	S_Coa	68	930	87
191	Brindisi Sud	Italy	Electricity	S_Coa	66	910	85
192	Raffinerie de Berre	France	Coke, other fuels	X	66	910	85
193	Ostiglia	Italy	Electricity	G_Nat	65	890	83
194	Buschhaus, Schöningen	Germany	Electricity	S_Coa	64	880	82
195	Pembroke	UK	Coke, other fuels	X	64	880	82
196	Santurce	Spain	Electricity	L_FuOH/FueOl	64	870	81
197	Refinería de Castellón	Spain	Coke, other fuels	L	63	870	81
198	ISPAT, Duisburg	Germany	Iron&steel	X	63	870	81
199	Marchienne	Belgium	Iron&steel	X	63	870	81
200	Lagisza	Poland	Electricity	S_CoaBit	63	860	80

3.3 Efficiency of plant operation relative to impacts

The results shown in Table 6 highlight the most damaging plant, according to the estimates made for this report. However, it is possible for an efficient plant to feature on the list simply because of its size, whereas a smaller plant that is far less efficient does not appear. To account for this, another-approach to the ranking is to consider damage per unit of useful output.

A major problem for this part of the work is that production statistics are not reported in the main source databases that feed into the SENCO database. For consistency within the calculations it has been necessary to use emissions as well as output calculated by the SENCO database to generate the euro cent/kWh estimates. Given the inevitable uncertainty that results from the need to estimate emissions and outputs, Table 7 lists only the 12 power plants that were identified above as having the highest total damage to health from emissions of SO_2 and NOx via secondary pollutant formation. The first column shows the position of each plant in the list given in Table 6, whilst the second column (on which the table as a whole is ordered) shows the ranking of these plant in terms of damage per unit output (eurocent/kWh). For plant that generate heat as well as electricity, outputs of the two streams have simply been added together.

Table 7. Comparison of ranking systems for power plants, taking the 12 plant in the EU, Norway and Switzerland with the highest estimated damage as quantified here, and normalising against useful energy output.

Rank by estimated damage	Rank by eurocent /kWh	Country	Plant	Output (PJ)	Output (GWh)	Calc eurocent /kWh
5	1	Poland	Adamow	10	2,894	20.6
11	2	Hungary	Oroszlnany	11	3,193	13.7
10	3	UK	Eggborough	19	5,353	11.4
1	4	Spain	Puentes	38	10,484	10.0
6	5	Poland	Patnow	26	7,150	7.6
7	6	UK	Cottam	25	7,071	7.1
4	7	Poland	Turow	47	12,987	5.3
2	8	Poland	Belchatow	100	27,909	4.6
9	9	Italy	Porto Tolle	23	6,315	4.5
3	10	Spain	Teruel	25	6,881	2.4
8	11	UK	West Burton	34	9,326	2.0
12	12	UK	Drax	76	21,213	1.8

The following are particularly evident from this table:

1. The estimated damage in eurocent/kWh for several plants is greater than typical prices charged per kWh of electricity.
2. The ranking changes significantly, for example, Belchatow drops from 2^{nd} to 8^{th}. If the list included all power plants these changes would be more significant.
3. Even though the plant listed are all amongst the most damaging according to the estimates made in this report, there is a factor 10 difference in cost per kWh shown in the list between the extremes – Adamow and Drax. Overall, the range in estimates per kWh would be even broader, with gas fired plant tending to have significantly lower damage per kWh, and some older plant having even higher damage per kWh.

3.4 Total health impacts from LPS in the SENCO database in other European countries

The analysis has been repeated for other European countries (those outside the EU and not including Norway and Switzerland). Results for these countries are reported separately for the following reasons:

1. Emission estimates are likely to be less robust;
2. Quantification of impacts is also less robust, being based on extrapolation from result for the EU25.
3. Given a lack of empirical data on willingness to pay for these countries, an economic evaluation of health damage has not been attempted.

Results are shown in Table 8. Again, readers are referred to Sections 2.2.3, 2.3.4 and 4.1 for a discussion of the robustness of results.

Table 8. Total health impacts associated with emissions of SO_2 and NOx from Large Point Sources in the SENCO database outside the region containing the EU25, Norway and Switzerland.

Health effect	Cases or events per life year lost	Total cases
Chronic mortality (life years lost, population aged > 30)	1.00	300,000
Chronic mortality (deaths in population aged > 30)	0.093	28,000
Infant mortality (infants aged 1 - 12 months)	0.00016	49
Chronic bronchitis, population aged > 27	0.044	13,000
Respiratory hospital admissions, all ages	0.017	5,000
Cardiac hospital admissions, all ages	0.010	3,000
Restricted activity days (RADs) working age population	93	28,000,000
Respiratory medication use by adults	7.9	2,400,000
Respiratory medication use by children	0.95	290,000
LRS*, including cough, among adults with chronic symptoms	75	23,000,000
LRS* (including cough) among children	49	15,000,000

* Lower respiratory symptoms.

Again, results reveal a high level of damage, with around 300,000 life years lost annually, contrasting with the 790,000 life years lost estimated for plant in the EU, Norway and Switzerland.

3.5 Estimates of damage for non-EU European LPS

A ranking of large point sources outside the EU, Norway and Switzerland, starting with that estimated to be most damaging to health, is shown in Table 9. Fuel codes are given on page 22. Economic damage estimates are not given for this set of plant, due to the need for extrapolation from the CAFE data. Such extrapolation could be carried out, transferring valuations using purchasing power parity (PPP).

As was the case for plant in the region covering the EU25, Norway and Switzerland (see Section 3.2.2), most of the total damage arises from operation of a relatively small number of sources. Here, 50% of damage is estimated to be accumulated by only 20 plant, and 90% by 128, out of a total number of sources contained in the database for this region of 534. It is noted that the total of 534 sources seems low when compared to the EU25, Norway and Switzerland total of more than 6,000 sources, raising the possibility that a significant number of plant in this region are omitted from the databases considered during development of the SENCO database. None of the plants listed in Table 9 are included in the EPER database.

Table 9. The 200 European LPS outside the EU25+Norway+Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation.

	Plant	Country	Sector	Main fuel	Life years lost/yr	Deaths /year
1	Krivorozhskaya	Ukraine	Electricity	S_CoaBit	14,000	1,300
2	Maritsa East II	Bulgaria	Electricity	S_CoaLig	14,000	1,300
3	Burshtynskaya	Ukraine	Electricity	S_CoaBit	13,000	1,200
4	Zmiyevskaya	Ukraine	Electricity	S_CoaBit	11,000	980
5	Lodyzhinskaya	Ukraine	Electricity	S_CoaBit	10,000	980
6	Kurakhovskaya	Ukraine	Electricity	S_CoaBit	9,300	870
7	Pridneprovskaya	Ukraine	Electricity	S_CoaBit	8,700	810
8	Seyitomer Soemtes	Turkey	Electricity	S_CoaLig	7,900	740
9	Starobeshevskaya	Ukraine	Electricity	S_CoaBit	7,600	710
10	Zuevskaya	Ukraine	Electricity	S_CoaBit	7,400	690
11	Mosenergo 22	Russian Fed.	Electricity	S_CoaBit	6,300	590
12	Uglegorskaya	Ukraine	Electricity	S_CoaBit	6,100	570
13	Tripolskaya	Ukraine	Electricity	S_CoaBit	6,000	560
14	Zaporozhskaya	Ukraine	Electricity	S_CoaBit	5,600	530
15	Mosenergo 4	Russian Fed.	Electricity	S_CoaBitAnt	5,400	510
16	Luganskaya	Ukraine	Electricity	S_CoaBit	5,300	500
17	Craiova II	Romania	Electricity	S_CoaLig	4,100	390
18	Troitskaya	Russian Fed.	Electricity	S_CoaSub	4,100	390
19	Kostroma-1	Russian Fed.	Electricity	G_Nat	4,000	370
20	Maritsa East I	Bulgaria	Electricity	S_CoaLig	3,900	360
21	Uglegorsk	Ukraine	Electricity	L_FueOil	3,600	330
22	Zaporizhzhya	Ukraine	Electricity	L_FueOil	3,500	330
23	Afsin Elbistan A	Turkey	Electricity	S_CoaLig	3,500	330
24	Turceni	Romania	Electricity	S_CoaLig	3,500	320
25	Drobeta-Turnu Severin	Romania	Electricity	S_CoaLig	3,300	310
26	Cherepetskaya	Russian Fed.	Electricity	S_CoaBit	3,100	290
27	Slavyanskaya	Ukraine	Electricity	S_CoaBit	3,100	290
28	Novocherkasskaya	Russian Fed.	Electricity	S_CoaAnt	3,100	290
29	Kangal	Turkey	Electricity	S_CoaLig	2,400	230
30	Tuncbilek B Tutes B	Turkey	Electricity	S_CoaLig	2,300	220
31	Hrazdan	Armenia	Electricity	L_FueOil	2,300	210
32	Moscow_Central Fuel Co.	Russian Fed.	Coke, other fuels	X	2,200	210
33	Bobovdol	Bulgaria	Electricity	S_CoaLig	2,200	210
34	Lukoml	Belarus	Electricity	L_FuOHea	2,200	200
35	Novo-Moskovskaya	Russian Fed.	Electricity	X	2,100	200
36	Moscow-26	Russian Fed.	Electricity	G_Nat	2,000	190
37	Kostroma-Gres2	Russian Fed.	Electricity	S_Pea	2,000	190
38	Varna	Bulgaria	Electricity	S_CoaAnt	1,900	180
39	Starobeshev	Ukraine	Electricity	L_FuOHea	1,900	170
40	Voskresenskcement	Russian Fed.	Cement	X	1,800	170
41	Soma	Turkey	Electricity	S_CoaLig	1,800	170
42	Kiev 5	Ukraine	Electricity	L_FuOHea	1,800	160
43	Catalagzi B [Yates B]	Turkey	Electricity	S_Coa	1,700	160
44	Ryazanskaya	Russian Fed.	Electricity	S_CoaSubLig	1,700	160
45	Kemerkoey	Turkey	Electricity	S_CoaLig	1,600	150
46	Maritsa East III Dimo Ditchev	Bulgaria	Electricity	S_CoaLig	1,600	150
47	Ryazan Sdeps	Russian Fed.	Electricity	L_FuOHea	1,600	150
48	Moscow-23	Russian Fed.	Electricity	G_Nat	1,500	140
49	Govora	Romania	Electricity	S_CoaLig	1,500	140
50	Brasov	Romania	Electricity	S_CoaLig	1,400	130

Table 9 (continued). The 200 European LPS outside the EU25+Norway+Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation.

	Plant	Country	Sector	Main fuel	Life years lost/yr	Deaths /year
51	Moscow-21	Russia	Electricity	G_Nat	1,400	130
52	Yatagan Yates	Turkey	Electricity	S_CoaLig	1,400	130
53	Kostolac	Serbia - Mont.	Electricity	X/_	1,300	120
54	Moscow-25	Russia	Electricity	G_Nat	1,200	110
55	Dobrotvorskaya	Ukraine	Electricity	S_CoaBit	1,200	110
56	Moscow-05 Shatura	Russia	Electricity	G_Nat	1,100	110
57	Suceava	Romania	Electricity	S_CoaLig	1,100	100
58	Krivorozhstal Works	Ukraine	Iron and steel	X	1,100	99
59	Tiraspol	Moldavia	Electricity	L_FuOHea	1,000	96
60	Pervomoiskaya 14	Russia	Electricity	S_CoaBit	1,000	94
61	Paroseni	Romania	Electricity	S_Coa	980	91
62	Yenikoey Yentes	Turkey	Electricity	S_CoaLig	970	90
63	Galati	Romania	Iron and steel	X	970	90
64	Shcurovsky Cement	Russia	Cement	X	950	89
65	Moscow-05 Kashira	Russia	Electricity	G_Nat	950	88
66	Giurgiu	Romania	Electricity	S_CoaLigBit	930	87
67	Trypilya	Ukraine	Electricity	L_FuOHea	900	84
68	Kramatorskaya	Ukraine	Electricity	S_CoaBit	890	83
69	Novomoscovsk Gres	Russia	Electricity	G_Nat	830	77
70	Republica I	Bulgaria	Electricity	S_Coa	800	75
71	Iasi II	Romania	Electricity	S_CoaLig	740	69
72	Kremenchug_Refinery	Ukraine	Coke, other fuels	X	740	69
73	Ilyicha	Ukraine	Iron and steel	X	730	68
74	Kirishi_Refinery	Russia	Coke, other fuels	X	720	67
75	Moscow-03 Klasson	Russia	Electricity	G_Nat	720	67
76	Moscow-20	Russia	Electricity	G_Nat	720	67
77	Svishtov	Bulgaria	Electricity	S_CoaBit	700	65
78	Pskov Gres	Russia	Electricity	S_Pea	670	62
79	Borzesti II	Romania	Electricity	S_CoaLig	660	62
80	Lisichansk_Refinery	Ukraine	Coke, other fuels	X	650	61
81	Moscow-08	Russia	Electricity	G_Nat	650	61
82	Alumina	Russia	Cement	X	630	59
83	Lipetskyi	Russia	Iron and steel	X	610	57
84	Sisak	Croatia	Electricity	L_	600	56
85	Asovstal	Ukraine	Iron and steel	X	590	55
86	Podolsky Cement	Ukraine	Cement	X	590	55
87	Burshytn	Ukraine	Electricity	G_Nat	580	54
88	Gardabani	Georgia	Electricity	L_FuOHea	580	54
89	Balakleysky Cement Plant	Ukraine	Cement	X	580	54
90	Vladimirskaya	Russia	Electricity	S_CoaBit	550	52
91	Nikel	Russia	Metals		520	48
92	Kstovo_Refinery	Russia	Coke, other fuels	X	510	48
93	Nikolayevsky Cement	Ukraine	Cement	X	500	47
94	Rousse	Bulgaria	Electricity	S_CoaBit	500	47
95	Izmit_Refinery	Turkey	Coke, other fuels	X	500	46
96	Aliaga_Refinery	Turkey	Coke, other fuels	X	500	46
97	Polotsk 2	Belarus	Electricity	L_FuOHea	500	46
98	Smolenskaya	Russia	Electricity	X	490	45
99	Doncement	Ukraine	Cement	X	490	45
100	Kherson_Refinery	Ukraine	Coke, other fuels	X	480	45

Table 9 (continued). The 200 European LPS outside the EU25+Norway+Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation.

	Plant	Country	Sector	Main fuel	Life years lost/yr	Deaths /year
101	Rijeka	Croatia	Electricity	L_Die/L_FuOHea	460	43
102	Novi Sad	Serbia - Mont.	Electricity	L_FuOHea	450	41
103	Ploiesti_Refinery	Romania	Coke, other fuels	X	440	41
104	Borzesti	Romania	Electricity	L_FueOil	440	41
105	Moscow 12	Russia	Electricity	G_Nat	430	40
106	Oskolcement	Russia	Cement	X	420	39
107	Mozyr_Refinery	Belarus	Coke, other fuels	X	410	38
108	Fier	Albania	Electricity	L_FueOil	400	37
109	Adana	Turkey	Cement	X	400	37
110	Hereke Izmit	Turkey	Cement	X	400	37
111	TG Jiu	Romania	Cement	X	400	37
112	Cayirhan A	Turkey	Electricity	S_CoaLig	400	37
113	Alesd	Romania	Cement	X	400	37
114	Mironovskaya	Ukraine	Electricity	S_CoaBit	390	37
115	Kirishi Sdeps	Russia	Electricity	G_Nat	390	36
116	Slavyansk	Ukraine	Electricity	G_Nat	390	36
117	Isalnita	Romania	Electricity	S_CoaLig	380	35
118	Medgidia	Romania	Cement	X	370	34
119	Vidin	Bulgaria	Electricity	S_CoaAnt	360	34
120	Büyükçekmece	Turkey	Cement	X	360	34
121	Rovinari	Romania	Electricity	S_CoaLig	350	32
122	Zdolbunov	Ukraine	Cement	X	340	31
123	Volgodonsk-2	Russia	Electricity	L_FuOHea	340	31
124	Mahmudiye	Turkey	Cement	X	340	31
125	Belaya Tserkov	Ukraine	Electricity	X/_	330	31
126	Mogilev 1	Belarus	Electricity	L_FuOHea	330	31
127	Iskenderun Works	Turkey	Electricity	L_FuOHea	330	31
128	Zaporozhye	Ukraine	Iron and steel	X	330	31
129	Orhaneli	Turkey	Electricity	S_CoaLig	330	31
130	Devnya	Bulgaria	Electricity	S_CoaBit	330	30
131	Kdz. Eregli	Turkey	Iron and steel	X	320	30
132	Zagreb Te-To	Croatia	Electricity	L_FuOHea	320	30
133	Dzerzhinsk	Russia	Electricity	L_FuOHea	320	30
134	Novocherkassk Sdeps	Russia	Electricity	G_Nat	320	29
135	Oradea I	Romania	Electricity	S_CoaLigBit	310	29
136	Aliaga Refinery	Turkey	Electricity	L_FuOHea	300	28
137	St Petersburg 05	Russia	Electricity	G_Nat	300	28
138	Hoghiz	Romania	Cement	X	300	28
139	Devnenski Cement	Bulgaria	Cement	X	300	27
140	Yaroslavl_Refinery	Russia	Coke, other fuels	X	290	27
141	Isikkent	Turkey	Cement	X	290	27
142	Zaporizhzhya	Ukraine	Electricity	G_Nat	290	27
143	Bursa Ovaakca	Turkey	Electricity	G_Nat	290	27
144	Uglegorsk	Ukraine	Electricity	G_Nat	290	27
145	Ryazan_Refinery	Russia	Coke, other fuels	X	290	27
146	Sisak_Refinery	Croatia	Coke, other fuels	X	290	27
147	Bicaz	Romania	Cement	X	280	26
148	Deva	Romania	Cement	X	280	26
149	Stavropol Sdeps	Russia	Electricity	G_Nat	280	26
150	Pancevo_Refinery	Serbia - Mont.	Coke, other fuels	X	280	26

Table 9 (continued). The 200 European LPS outside the EU25+Norway+Switzerland estimated to have the largest health damages from emissions of SO_2 and NOx via secondary pollutant formation.

	Plant	Country	Sector	Main fuel	Life years lost/yr	Deaths /year
151	Bornova, Izmir	Turkey	Cement	X	270	25
152	Palas	Romania	Electricity	L_FueOil	270	25
153	Kestel	Turkey	Cement	X	270	25
154	Moscow 11	Russia	Electricity	G_Nat	260	25
155	Belgorodsky Cement	Russia	Cement	X	260	24
156	Isparta	Turkey	Cement	X	260	24
157	Cherepovetskaya	Russia	Electricity	S_CoaBitLig	260	24
158	Hamitabat	Turkey	Electricity	G_Nat	260	24
159	Moscow 16	Russia	Electricity	G_Nat	250	24
160	Calarasi	Romania	Iron and steel	X	250	23
161	Beocinska	Serbia - Mont.	Cement	X	250	23
162	Cimpulung	Romania	Cement	X	250	23
163	Kirkkale_Refinery	Turkey	Coke, other fuels	X	250	23
164	Bitola	Macedonia	Electricity	S_CoaLig	240	23
165	Iskenderun	Turkey	Iron and steel	X	240	22
166	Midia_Refinery	Romania	Coke, other fuels	X	230	22
167	Darica	Turkey	Cement	X	230	21
168	Rybnitsa	Moldavia	Cement	X	230	21
169	Novi Popovac	Serbia - Mont.	Cement	X	230	21
170	Gaydurt	Turkey	Cement	X	230	21
171	Mersin_Refinery	Turkey	Coke, other fuels	X	220	20
172	Novopolotsk_Refinery	Belarus	Coke, other fuels	X	220	20
173	Bourgas_Refinery	Bulgaria	Coke, other fuels	X	200	19
174	Minsk 2	Belarus	Electricity	G_Nat	200	19
175	Olshansky Cement Plant	Ukraine	Cement	X	200	18
176	Ambarli CC	Turkey	Electricity	G_Nat	200	18
177	Ploiesti	Romania	Electricity	L_FueOil	200	18
178	Tekkeköyü	Turkey	Cement	X	190	18
179	Batumi_Refinery	Georgia	Coke, other fuels	X	190	18
180	Moscow-17 Stupino	Russia	Electricity	G_Nat	190	18
181	Tiraspol	Moldavia	Electricity	G_Nat	190	18
182	Moscow 09	Russia	Electricity	G_Nat	190	18
183	Yerevan	Armenia	Electricity	G_Nat	190	18
184	Monchegorsk	Russia	Metals		190	17
185	SeverstalWorks	Russia	Electricity	X/G_BlaFur	180	17
186	Rijeka_Refinery	Croatia	Coke, other fuels	X	180	17
187	Mozyr	Belarus	Electricity	L_FuOHea	180	17
188	Nesvetay	Russia	Electricity	S_CoaAnt	180	17
189	Fieni	Romania	Cement	X	180	17
190	Bastas	Turkey	Cement	X	180	17
191	Zenica	Bosnia - Herz.	Iron and steel	X	180	16
192	Sofia-Botounetz	Bulgaria	Iron and steel	X	170	16
193	Girne	Turkey	Electricity	L_Die/L_FuOHea	170	16
194	Kavkazcement	Russia	Cement	X	170	16
195	Bobruysk 1&2	Belarus	Electricity	L_FuOHea	170	16
196	Nevinnomyssk Sdeps	Russia	Electricity	G_Nat	170	16
197	Mersin	Turkey	Electricity	L_FuOHea	170	15
198	Krasnodar-3	Russia	Electricity	G_Nat	170	15
199	Pitesti_Refinery	Romania	Coke, other fuels	X	160	15
200	Denizli	Turkey	Cement	X	160	15

4. Discussion

4.1 Validation of estimates

The results presented here cannot be validated in the strict sense of measuring the number of deaths around each plant linked to operation of that plant. Part of the reason for this is that the impacts described here are linked to the formation of secondary particles and ozone in the atmosphere, following release of SO_2 and NOx. These particles may form at great distances from the emission source, with the result that anticipated impacts are mediated via the overall pollution climate of Europe, rather than through local air quality.

Direct evidence that reducing pollutant emissions reduces the incidence of ill-health is available through 'intervention studies' that typically examine death rates or hospital admissions in restricted areas where some specific action has suddenly been taken to reduce emissions. A famous example concerns the banning of coal burning in Dublin. Unfortunately, these studies are useful for validation of the impact of primary pollutants only.

In the context of this report, a partial validation of the results has been carried out in two stages. The first stage concerns the methods, and the second, their application. Validation that the methods used are in line with the accepted state of the art in Europe comes through the fact that they have been widely reviewed through the CAFE process, and have closely followed recommendations made by WHO and expert groups convened by it. ExternE (2005) recommends a broadly similar approach, though differing in some detail (see below). A critique by UNICE challenged the CAFE-CBA methodology, though this was responded to by the CAFE-CBA team (see AEA Technology and others, 2005e, for both the UNICE critique and the response).

In considering validation of the results presented here, it must be remembered that the emissions database used is specific to data for each plant for a single year, typically 2001. Since that time it is possible that emissions will have changed, perhaps in line with the fitting of additional flue gas control equipment under Integrated Pollution Prevention and Control (IPPC), or through plant closures. It is also possible, of course, that additional plant will have been opened, or that plant are missing from the SENCO database (though great effort has gone to make it as complete as possible).

Whilst validation is not possible against direct measurements of health incidence, it is possible at least to check that results are consistent with those quantified elsewhere. In this respect, the estimate that emissions of SO_2 and NOx from large point sources in the EU, Norway and Switzerland provide 21% of the damage quantified for the year 2000 in work carried out for the EU's CAFE programme seems reasonable, given that this analysis excludes emissions of primary particles and ammonia, and many sources of air pollution, including transport.

Recent work in the ExternE project carried out for EC DG Research provides estimates of total damage from the power plants in the EU25. These are compared with results from this study in Table 10 and show a high level of consistency at the aggregate level. Disaggregated results would show more significant differences –

ExternE for example treats nitrate aerosol as less damaging than sulphate and primary particles (ExternE, 2005) whereas here they are treated as being equally harmful per unit mass, but it is still reassuring that the final outcomes of the two analyses, undertaken independently, are broadly consistent.

Table 10. Comparison of total damage from this study and the ExternE study (Friedrich, 2005) for power plants in the EU25.

Study	Total life years lost	Economic damage (euro billion)
This report	516,000	38
Friedrich (2005)	474,000	35
Difference	8.3%	6.4%

Results expressed per kWh in Table 7 also provide results that are broadly consistent with those quantified in the ExternE Project series (ExternE-Pol, 2005).

For ease of presentation this report has focused on best estimates of impacts and their monetary value. However, it is necessary to recognise that there are uncertainties in the quantification process. These are discussed in detail in AEA Technology (2004b) which indicates 95% confidence intervals around the best estimates of +/- 70%, taking account of statistical uncertainty.

For the results for individual plant the uncertainty in taking country-average damage factors, rather than making original estimates based on site-specific modelling for each plant should also be considered.

A more fundamental issue of concern for validation of these estimates is that the basis for attribution of the effects observed in epidemiological studies to individual types of particle as opposed to the overall mix of particles in the atmosphere is relatively weak. Experts convened by WHO refused to differentiate between particles, instead (implicitly) regarding them all as equally harmful. At the present time there is no empirical basis to do otherwise. It is certainly an area requiring further research in the near future, to be sure that air quality policy is focused on the most damaging pollutants.

4.2 Who is affected by air pollution?

Other than in extreme cases it is not possible to attribute the death or ill health of any individual living around a power plant or other large point source to air pollutant emissions from the operation of that facility. These ‘extreme’ cases would really only be applicable in the event of major industrial accidents, and so are outside the scope of this study which instead deals with ‘routine’ emissions from the operation of plant.

It is to be expected that emissions will affect most directly those people whose health is already compromised in some way, perhaps because they are very old or young or have an existing health condition. Until recently there was a view that those likely to be affected would lose a relatively short period of life, days, weeks or months at worst. The evidence of the Pope et al (1995) study and others since based around the American Cancer Society cohort has, however, led to a change in views. Applying the results of these studies, as has been done in the CAFE (Clean Air For Europe) Programme suggests a much more substantial loss of longevity than indicated by the earlier work.

4.3 Improving the models

4.3.1 Emissions and other industrial data

Considerable effort has gone into the development of the SENCO database, pulling together information from a number of different sources to provide a Europe-wide emission inventory extending across the European UNECE domain, and including various additional information beyond that provided by EPER to describe inputs and energy or material outputs.

However, there were notable limitations on the quantity and quality of data available for this exercise. The following recommendations are made for improving the EPER database and its successor (from 2009), the European Pollutant Release and Transfer Register (EPRTR):

1. Consider whether it is necessary to collate information on a larger number of plant than at present. The SENCO database is supplemented by data from other sources (IEACO_2, IEACR, Platts) in order to provide a reasonably comprehensive view of industrial emissions.
2. Provide complete information on emissions from each plant. In this study the paucity of data on PM emissions has largely prevented estimation of damage related to primary PM emissions. This is needed in order to gain a better understanding of priorities for control.
3. In respect of [2], reconsider the reporting thresholds for pollutants currently used by EPER. The importance of small plant near populations should be accounted for.
4. Update information more frequently (it is understood that this will be done annually for the EPRTR, but not before 2009). The data used in this report are generally from 2001/2. It may be expected that emissions from many plant will have changed in this period for various reasons:
   a. Heightened regulation, for example under the directives on IPPC (Integrated Pollution Prevention and Control), LCP (Large Combustion Plants, NEC (National Emission Ceilings), and the daughter directives on air quality.
   b. Heightened awareness of environmental responsibilities may have led operators to better manage their plant (e.g. via EMAS).
   c. Plant alterations (e.g. enlargement).
   d. Fuel switching.
   e. Closure of older plant.
   f. Development of new plant.
5. Provide information not solely on pollutant outputs, but also on the quantity of useful output (electricity, heat, clinker, glass, etc.), technologies used, abatement equipment in place, etc., in order that the efficiency of production per unit emission can be quantified, and performance properly understood.
6. Provide a better framework for extracting, comparing and using data than is currently available directly through the internet.

Some, though not all, of these issues were noted in the first EPER review[7], and hopefully will be addressed to a significant extent when 2004 data become available. Barrett (2004) also discusses database enhancement.

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[7] http://www.eper.cec.eu.int/eper/documents/Summary%20of%20first%20EPER%20Review%20Report.pdf

4.3.2 Dispersion modelling

The analysis conducted here has used outputs from the EMEP model for the year 2010 specific to each of the EU25 Member States. Ideally, further data will be available in the near future for alternative situations:

1. For other years (e.g. 2000, 2005, 2020).
2. For all UNECE Member States, noting the special case of Russia, for which a series of analyses would be preferred, to account for its large size and the extreme variability of population density within the country.

These factors introduce some uncertainty to the analysis, but this may well be limited in contrast to other uncertainties that are present (e.g. with respect to PM emissions).

4.3.3 Quantifying pollutant impacts and monetary damages

Requirements for improvement in this part of the analysis were identified in the methodology reports produced for the cost-benefit analysis of the Clean Air For Europe (CAFE) Programme (AEA Technology, 2004a, b; Hurley et al, 2005). Important issues include:

1. Further work on the valuation of air-pollution related mortality.
2. Establishment of a larger base of European data on air pollution epidemiology, and better information on the incidence of ill health in the European population.
3. Closer integration of damage to health and other monetised impacts, with those that cannot currently be monetised, such as damage to ecosystems.
4. Research on attribution of harm to specific types of particle.

Some of this work is already underway, though some aspects may well take a number of years before conclusions are reached.

4.4 Overview of the results

The results presented in this report demonstrate that large point sources still provide a significant level of damage to the European population despite the effects of legislation introduced over the last 25 years. Combining results for both of the regions considered here, more than a million life years are estimated to be lost annually in Europe to emissions of SO_2 and NOx from large point sources, with many additional cases of ill health to add to this (see Table 5 and Table 8).

It is particularly notable that 50% of the quantified health impact is attributable to a relatively small number of sources in the region covering the EU, Norway and Switzerland, 120 out of 6,333, whilst 90% of the damage can be attributed to only 911 plants. A broadly similar level of bias is seen in results for the second region considered in the report (i.e. European countries excluding those just mentioned).

Wide variation is noted in the damage per unit output in the electricity sector, reflecting in part differing standards with respect to fuel quality and the level of emission abatement adopted. The results presented in this report strongly suggest that substantial benefits would accrue to the European population if action were taken to reduce this variability.

The importance of other pollutants and other sectors is also recognised, by virtue of the results quantified for the large point sources representing only about 21% of the total damage quantified for the EU in the CAFE Programme. Effective control will thus require action across a range of sources, not just those included here.

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This study combines the health impact assessment methodology used by EU's CAFE programme with an emissions database for European large point sources, to assess health damage linked to emissions of nitrogen oxides and sulphur dioxide on a plant by plant basis.

It finds that the emissions from large point sources in Europe could be responsible for more than one million life years lost in Europe every year. Some of the worst polluting plants may each be responsible for the annual loss of between 10,000 and 20,000 life years.

This study has been commissioned by the Swedish NGO Secretariat on Acid Rain as a contribution to the debate on European air quality policy in general, and on the review and revision of EU air pollution control legislation in particular.

The Swedish NGO Secretariat on Acid Rain

The essential aim of the Swedish NGO Secretariat on Acid Rain is to promote awareness of the problems associated with air pollution, and thus, in part as a result of public pressure, to bring about the needed reductions in the emissions of air pollutants. The aim is to have those emissions eventually brought down to levels – the so-called critical loads – that the environment can tolerate without suffering damage.

In furtherance of these aims, the secretariat

- Keeps up observation of political trends and scientific developments.
- Acts as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
- Produces information material.
- Supports environmentalist bodies in other countries in their work towards common ends.
- Participates in the lobbying and campaigning activities of European environmentalist organizations concerning European policy relating to air quality and climate change, as well as in meetings of the Convention on Long-range Transboundary Air Pollution and the UN Framework Convention on Climate Change.

The work of the secretariat is largely directed on the one hand towards eastern Europe, especially Poland, the Baltic States, Russia, and the Czech Republic, and on the other towards the European Union and its member countries.

As regards the eastern European countries, activity mostly takes the form of supporting and cooperating with the local environmentalist movements. Since 1988, for instance, financial support has been given towards maintaining information centres on energy, transport, and air pollution. All are run by local environmentalist organizations.

The Secretariat has a board consisting of one representative from each of the following organizations: Friends of the Earth Sweden, the Swedish Anglers' National Association, the Swedish Society for Nature Conservation, the Swedish Youth Association for Environmental Studies and Conservation, and the World Wide Fund for Nature Sweden.

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