Assessment of the costs and benefits for the UK of adopting ceilings under the NECD.

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Executive Summary

This report considers the costs and benefits for the UK of different scenarios considered in the context of three actions:

1. The UNECE's Gothenburg Protocol to Abate Acidification, Eutrophication and Ground Level Ozone under the Convention on Long-Range Transboundary Air Pollution, signed in Gothenburg in December 1999.
2. The EU's National Emission Ceilings Directive (NECD) on which a common position was reached in June 2000.
3. The EU's Ozone Directive.

The report follows previous analysis for DETR during 1999 and 2000. The analysis starts with the definition of a 'business as usual' scenario, here named UKREF4. Emissions for this scenario are as follows:

UK emissions:
SO_2 – 612 kt/year, NO_x – 1167 kt/year, VOC – 1152 kt/year, NH_3, – 297 kt/year
Emissions from other European countries:
EU Member States – as specified in the Common Position on the NECD
Non-EU UNECE Members – as specified in the Gothenburg Protocol.

The baseline figure of 1152 kt VOC/year is significantly lower than estimated in previous analysis. Revisions have been made following discussion with the British Coatings Federation (BCF) with respect to emissions from the use of paints and inks, and with the UK Petroleum Industry Association (UKPIA), with respect to onshore emissions from the oil industry. This causes a substantial reduction in the cost of further VOC abatement under the Protocol and Directives as the following table shows:

Table 1. Estimated costs of abatement of VOCs (£M/year) specific to the NECD and Gothenburg Protocol.

Scenario	Emission, kt	Costs (£M)
1990	2445	-
Gothenburg Protocol, Common Position	1200	0
UKREF4 for 2010	1152	0
VOC1150	1150	0.4
VOC1100	1100	11
VOC1050	1050	23
VOC1000	1000	47
H1[1]	964	72

Note: 1 the H1 scenario defined the Commission's original proposal for the NECD.

The reference emission for SO_2 is taken as 612 kt/year, in line with DTI Energy Projections from March 2000. Costs for attaining different emission ceilings are shown in Table 2. A sensitivity analysis was conducted to demonstrate the potential error that might arise from over-estimation of the efficiency of sulphur abatement technologies. This was found to make a negligible difference to the costs of attaining a 585 kt/year ceiling, and a £3million/year increase to the costs of attaining a ceiling of 497 kt/year (costs rising from £25million/year to £28million/year).

Table 2. Costs of emission reductions for SO_2 (£M/year) specific to the NECD and Gothenburg Protocol.

Scenario	Emission, kt	Cost				
		UK	England	N Ireland	Scotland	Wales
1990	3756	-	-	-	-	-
UKREF4 for 2010	612	-	-	-	-	-
Gothenburg Protocol	625	0	0	0	0	0
Common Position	585	6	5	0	1	0
H1[1]	497	25	21	1	2	1

Note: 1 the H1 scenario defined the Commission's original proposal for the NECD.

This report does not consider costs or benefits for changes in NO_x or ammonia, as ceilings for these are unchanged from the Gothenburg Protocol.

Within this report the results for benefits concentrate on a set of headline indicators, as follows:

- Change in critical levels exposure for ozone
- Crop and forest damage (£/year)
- Materials damage (£/year)
- Number of cases of premature mortality linked to short-term pollutant exposures
- Number of respiratory hospital admissions linked to short-term pollutant exposures.

These are only a sub-set of the full range of environmental damages caused by the pollutants of interest here. Results for the benefits to the UK, of abatement by the UK of SO_2 and VOC emissions are shown in Tables 3 and 4. Actual benefit to the UK from implementation of the Directives and Protocol will be higher, given that the *incremental* benefits to the UK of abatement in other countries are not presented.

Separate consideration was given to the transboundary influence of emissions from and to the UK. This revealed the following:

- The UK is responsible for about 75% of sulphur and nitrogen deposition within the UK. Of the rest, the main contributors are Ireland, France and Germany.
- The UK is responsible for only 54% of secondary particle exposure within the UK. Of the rest the main contributors are Germany, France and the Netherlands. The difference against sulphur and nitrogen deposition arises because of the time taken for secondary particles to form in the atmosphere.
- A substantial amount of the UK's emissions are deposited in the North Sea and NE Atlantic. The other main destinations are (in order) Germany, France, Norway, Sweden and Ireland, though in no case does more than 5% of UK emission land in any other single country. Germany heads the list because of size and prevailing wind directions.

Table 3. Annual benefits to the UK of abatement of SO_2 by the UK. Costs (as given above in Table 2) are included for comparison.

Scenario and annual SO_2 emission	UKREF4 612 kt/year	Common Position 585 kt/year	H1[2] 497 kt/year
Costs of abatement (£M/year)	0	6	25 - 28
Reduction in materials damage (£M/year) compared to UKREF4	-	1.2	5.5
Reduction in the number of cases of acute mortality linked to SO_2 and sulphate exposure, compared to UKREF4	-	42	179
Reduction in the number respiratory hospital admissions linked to SO_2 and sulphate exposure, compared to UKREF4	-	20	85

Note 1: the H1 scenario defined the Commission's original proposal for the NECD.

Table 4. Annual benefits to the UK of abatement of VOCs by the UK. Costs (as given above in Table 1) are included for comparison.

Scenario and annual VOC emission	UKREF4 1152 kt/year	1150 kt/year	1100 kt/year	1050 kt/year	1000 kt/year	H1[1] 964 kt/year
Costs of abatement (£M/year)	0	0.4	11	23	47	72
AOT40 – 1000 km^2 excess ppm.hours (a measure of the risk of exposure to ozone for vegetation)	122	122	117	112	107	104
AOT60 – million people excess ppm.hours (a measure of the risk of exposure to ozone for health)	60	60	58	56	53	51
Reduction in crop damage (£M/year) compared to UKREF4	-	0.09	2.3	4.6	7.0	8.4
Reduction in forest damage (£M/year) compared to UKREF4	-	0.002	0.06	0.12	0.18	0.22
Reduction in the number of cases of acute mortality linked to ozone exposure, compared to UKREF4	-	1	15	30	47	58
Reduction in the number respiratory hospital admissions linked to ozone exposure, compared to UKREF4	-	1	19	38	60	74

Note 1: the H1 scenario defined the Commission's original proposal for the NECD.

Contents

1 Introduction

1.1 BACKGROUND

This report provides details of analysis conducted for DETR following agreement on the Common Position for the National Emission Ceilings Directive (NECD) proposed by the European Commission. The work is also relevant to the UNECE Protocol to Abate Acidification, Eutrophication and Ground-level Ozone signed in Gothenburg in December 1999, and the forthcoming Ozone Directive. It follows an earlier report for DETR carried out by the same team (Holland *et al*, 2000), examining the consequences for the UK of the latest agreements on emission ceilings across Europe, and of alternative (UK) emission ceilings.

It should be noted from the outset that the costs and benefits of the Directives and Protocol should not be regarded in isolation from other legislation that is currently agreed but yet to take full effect, and for which the overall consequences are, as yet, uncertain. These include:
- the IPPC Directive
- the Kyoto Protocol
- the National Air Quality Strategy (NAQS).

Many of the measures to be taken to ensure compliance with the IPPC Directive and the Kyoto Protocol will assist in meeting the legislation considered here. A good example concerns improvements in energy efficiency, given that combustion processes are major sources of SO_2, NO_x and VOCs. The Gothenburg Protocol and the Ozone and NEC Directives should reduce the costs of attaining the limit values of the NAQS by acting to control emissions internationally. The review of the NAQS (DETR, 1999) demonstrated that the targets for PM_{10} and ozone will be extremely difficult to meet without significant action in other European countries.

1.2 OVERVIEW OF THE METHODS USED IN THIS REPORT

The methodology used here for estimating the costs and benefits to the UK of meeting specified emissions abatement targets follows the methods used in Holland *et al* (2000), and is organised in the following steps:
- compilation and mapping of 'baseline' emissions projections disaggregated by sector for the target year (2010);
- identification of cost-effective abatement techniques and estimation of costs associated with the application of these to reduce projected emissions to the prescribed target levels;
- mapping of emissions disaggregated by sector for alternative emission scenarios for the target year;
- modelling of the dispersion and chemical transformation of the mapped emissions to generate maps of associated air quality and deposition for each alternative scenario;

- comparison of the deposition maps against critical loads maps to determine the degree of ecological protection attributable to the prescribed level of emissions abatement[1];
- assessment of the exposure of sensitive receptors (people, buildings, etc.) for each scenario, by combining maps of pollution levels with maps of (e.g.) population distribution;
- quantifying impacts by combining data on exposures with dose-response functions to provide estimates of changes in hospital admissions, premature deaths, rate of material degradation, crop yields, etc.
- comparison of results between the baseline and alternative scenarios to assess the incremental change in impacts arising from emissions abatement;
- estimation of the monetary value of the benefits attributed to emissions abatement.

Estimates of UK emissions were based on the National Atmospheric Emissions Inventory (NAEI). For the purposes of mapping these were disaggregated between Scotland, Wales, Northern Ireland and England using existing information held within the NAEI database on the location of point and area sources. Many of the important sources, such as power stations, large combustion plant, ports, airports, and process plant, were defined as point sources and, therefore, could easily be assigned to one of the four countries. Emissions from road transport on major roads were defined as line sources and could also be assigned to the individual countries. Remaining sources, such as domestic and small industrial combustion plant, agriculture, off-road vehicles, and military vehicles were treated as area sources, and were disaggregated using surrogate statistics, such as regional population, fuel use or employment.

Emissions data were presented in map form using a 10 km x 10 km grid, to act as input for the modelling of their dispersion and chemical transformation within the atmosphere. This was undertaken firstly using the HARM model, to determine sulphur and nitrogen deposition and concentrations, and the ELMO model for ground level ozone concentrations. These models take account of the complex chemical reactions taking place in the atmosphere, the changing chemical composition of the air as it moves away from one source area and into another, and the impact of a range of meteorological parameters. ELMO and HARM have both been run for a number of different scenarios. Late on in this work it became necessary to consider some additional scenarios for VOC emissions. Ozone concentrations for these were assessed using the web version of IIASA's RAINS model[2]. To check the consistency of analysis comparison was made between benefits estimated using ELMO and RAINS.

The benefits analysis for impacts on health, crops and materials was based around the ALPHA and ALPHA-UK models, used previously in analysis of the Gothenburg Protocol and the NECD, and also the National Air Quality Strategy. Deposition/concentration maps were overlaid onto data showing the distribution of 'stock at risk' (people, buildings, crops etc.) and information on the sensitivity of the stock (death rates, age structure of the population, type of ecosystem etc.). This provided information on exposure, to which could be applied exposure-response functions, to derive estimates of the impact of the changes in pollution concentration and deposition, in biological and physical terms.

Impacts were monetised to the extent possible. For some effects, such as changes in crop yield, this can simply be done using data from relevant markets. In other cases, particularly for effects

[1] Analysis of critical loads exceedences have been excluded from this report due to ongoing work to refine the calculation of the contribution of ammonia to acidification and eutrophication.
[2] http://www.iiasa.ac.at/Research/TAP/docs/TAP_Home.html

on human health, alternative methods were necessary, based, for example, on the contingent valuation technique. The UK government is currently funding research on monetisation of health effects, and will reach an agreed position once that work is complete. In the absence of such an agreed position, an extended sensitivity analysis is supplied in Appendix I to indicate how the balance of costs and benefits changes under different sets of assumptions, not just on monetisation, but also at other stages of the analysis.

1.3 SCENARIOS

The scenarios considered in this report are as follows. Estimated reference scenario emissions are again lower than in our previous reports. The progressive decline in baseline emissions is discussed below.

1. Baseline (UKREF4):
Annual UK emissions: SO_2 - 612 kt, NOx - 1167 kt, VOCs - 1152 kt, NH_3 - 297 kt, based on Gothenburg Protocol and available projections where emissions are expected to be below the Gothenburg ceiling.

UK emissions for this scenario are based on the lower of projected emissions and the ceilings agreed under the Gothenburg Protocol. Emissions of SO_2 and NOx are largely based on the energy scenario analysis of DTI (2000). Baseline emissions of VOCs are reduced from those adopted in the earlier analyses in this series. This follows recent submissions from the British Coatings Federation (BCF) and the UK Petroleum Industry Association (UKPIA), both of which indicated that the earlier estimates were too pessimistic.

Emissions for other countries were assumed to follow the Common Position on the NECD (for EU Member States), and the Gothenburg Protocol (for other European countries). These emissions were held constant across all the scenarios of variation in UK emissions. Total (non-UK) emissions of the four pollutants are shown in Table 1. Further details, providing a country by country breakdown are presented in Table 2.

Table 1. Emissions of the four Protocol/Directive pollutants: reference scenario for countries other than the UK.

Scenario	Region	SO_2 (kt)	NO_x (kt)	NH_3 (kt)	VOCs (kt)
NECD	EU (excl. UK)	3,265	5,352	2,813	5,310
Gothenburg	Non-EU UNECE	9,930	7,327	3,151	6,990
	Total	**13,195**	**12,679**	**5,964**	**12,300**

Without detailed analysis it is not clear how reliable the emissions estimates for other countries should be regarded. As analysis in the UK has demonstrated, the emissions data in IIASA's RAINS model do contain some very significant uncertainties. In the context of this analysis it is only effects of emissions in other countries on pollution abatement benefits in the UK that are important. Given the limited contribution of other individual countries to the UK's pollution problems averaged over the period of a year (see Section 3.3), it seems unlikely that errors in estimating emissions outside the UK will have a significant effect on the analysis of costs and benefits as presented here[3].

Table 2. Emission ceilings for countries except the UK under the NECD (EU Member States) and Gothenburg Protocol (non-EU UNECE) in 2010 (kt/year).

Country	SO_2	NOx	VOC	NH_3
Austria	39	103	159	66
Belgium	99	176	139	74
Denmark	55	127	85	69
Finland	110	170	130	31
France	375	810	1050	780
Germany	520	1051	995	550
Greece	523	344	261	73
Ireland	42	65	55	116
Italy	475	990	1159	419
Luxembourg	4	11	9	7
Netherlands	50	260	185	128
Portugal	160	250	180	90
Spain	746	847	662	353
Sweden	67	148	241	57
Total EU excluding UK	**3265**	**5352**	**5310**	**2813**
Albania	55	36	41	35
Belarus	480	255	309	158
Bosnia-H	415	60	48	23
Bulgaria	856	266	185	108
Croatia	70	87	90	30
Czech_Rep.	283	286	220	101
Estonia	175	73	49	29
Hungary	550	198	137	90
Latvia	107	84	136	44
Lithuania	145	110	92	84
Norway	22	156	195	23
Poland	1397	879	800	468
Moldova	135	90	100	42
Romania	918	437	523	210
Russia	2352	2653	2786	894
Slovakia	110	130	140	39
Slovenia	27	45	40	20
Switzerland	26	79	144	63
Macedonia	81	29	19	16
Ukraine	1457	1222	797	592
Yugoslavia	269	152	139	82
Atlantic	641	911	0	0
Baltic	43	80	0	0
North_Sea	264	639	0	0
Total UNECE excluding EU	**10878**	**8957**	**6990**	**3151**
Grand total- excluding UK	**14143**	**14309**	**12300**	**5964**

[3] It is acknowledged that emissions from other countries could have a significant effect on exceedence of air quality standards, but this is problem is not investigated specifically in this study.

2. Common Position (CP):
Full attainment of the NECD, in line with the Common Position – i.e. all emissions held the same as in UKREF4 except those for the UK, which decline to 585 kt/year for SO_2.

3 – 7. VOC1150, VOC 1100, VOC1050, VOC1000, VOC964
As scenario CP, but with annual VOC emissions further reduced as indicated (e.g., for VOC1150, VOC emissions in 2010 are 1150 kt). Costs have been assessed for all of these scenarios, benefits only for VOC1150, VOC1100 and VOC964.

1.4 VARIATION OVER TIME IN ESTIMATES OF EMISSIONS FOR THE REFERENCE SCENARIO

During the series of analyses undertaken by the present study team and by IIASA (for the EC and UNECE) of the NECD and the Gothenburg Protocol there has been a significant fall in estimates of the baseline (reference) emissions of SO_2 and VOCs for the UK. Past and present estimates for 2010 are reviewed in Table 3. Further information regarding the decline in emissions, particularly for SO_2 and VOCs, is given below the Table.

Table 3. Reductions in estimates of emissions (kt/year) under the 2010 reference scenario.

Scenario	SO_2	NOx	VOC	NH_3	Reasons for change
1990 (numerous IIASA reports to UNECE and EC)	3805	2839	2667	329	-
IIASA Reference (as above)	980	1186	1351	297	Implementation of various national and EU regulations on emissions.
UKREF (Holland *et al*, 2000)	784	1187	1336	319/297	Fall in emissions based on draft of DTI Working Paper. Range for NH_3 reflects uncertainty.
UKREF2 (first draft of this report)	612	1167	1252	319/297	Emissions revised following new DTI energy projections (DTI, 2000).
UKREF3 (second draft of this report)	612	1167	1200	297	VOCs, NH_3 reduced to Gothenburg Protocol ceilings.
UKREF4 (this report)	612	1167	1152	297	VOCs further reduced following discussions with BCF and UKPIA.

SO_2
UK SO_2 emissions were reduced twice during the analysis from the IIASA baseline, by a total of 38% (368 kt/year). The first reduction was based on an early draft of the revised energy projections undertaken by DTI; the second on the results of the Working Paper 'Energy Projections for the UK' released in March 2000. In all cases the emissions adopted were based on the Central growth, High energy price scenario (referred to as "Central/High"). The main reasons for the change are the reduced use of coal and increased FGD capacity. The reliability of the latest reference case SO_2 emission is rated at ±10%.

NH_3
There is considerable uncertainty regarding the emission inventory and projections for NH_3. There is concern over growing emissions from non-agricultural sources, particularly transport, in the UK and other countries. Inventories are constantly being revised and updated, with MAFF concentrating on agricultural sources and DETR investigating potential abatement measures for the non-agricultural sources and their associated costs.

NOx
Estimated emissions of NOx have remained steady throughout the analysis. There is just a small decline between UKREF and UKREF2, linked to the new UK energy projections given by the DTI (2000). Under these projections it is anticipated that the UK will meet its agreed ceiling for NOx, and, indeed, improve on the ceiling proposed by the analysis carried out for the European Commission, without the need for additional measures. Reliability of emission projections for NOx is rated at ±25%.

VOCs
Our original analysis for DETR (Holland *et al*, 2000), using the UKREF scenario, started with VOCs at a level similar to that adopted by IIASA. This fell by 100 kt/year once the new DTI energy projections were taken into account (DTI, 2000). However, following discussion with two trade bodies - the British Coatings Federation (BCF) representing the paint and ink sector, and the UK Petroleum Industry Association (UKPIA, representing the onshore oil industry) - it became apparent that earlier estimates of baseline emissions were still too pessimistic. The UKPIA accepted a 10 kt/year reduction in baseline emissions, reflecting new practices in the industry and the closure of some plant. The BCF argued for a 90 kt/year reduction in emissions for three reasons. Firstly, the earlier sales forecasts for the period from 1990 to the present needed to be reduced. Secondly, BCF consider that insufficient account had been taken of the industry trend away from paints and inks based on organic solvents. Thirdly, BCF believe that there will be a far higher penetration of 'end-of-pipe' abatement technologies than earlier assumed. The effect of these amendments for the coatings sector is shown in Table 4.

Table 4. Comparison of VOC emission estimates from the use of paints and inks.

Year	Original estimate, kt/y	BCF estimate, kt/y
1990	255	221
1998	190	156
2010	179	87

Together, changes in these two sectors reduce total estimated emissions by 100 kt/year from the UKREF2 position, and (at 1152 kt/year) to a level 200 kt/year below IIASA's reference scenario. According to the new estimate, the UK will go beyond meeting its agreed emission ceiling for VOCs for the Gothenburg Protocol, with no cost specifically attributable to the Protocol.

A brief review of emissions of VOCs in other sectors has been undertaken. Overall it is felt that there is now balance between those sectors for which emissions may be overestimated and those for which emissions are likely to be underestimated. Reliability of the total emissions estimate is assessed as being ±25%.

It must be stressed that the figures applied here are best estimates, and, like any data, are subject to uncertainties that we have sought to quantify in percentage terms. For VOCs potential errors relate to a number of factors, including:

- activity drivers that are used to predict future sales (which could lead to either over- or under-estimation of emissions).
- further development of new coatings that are less dependent on organic solvents (which will potentially reduce emissions).
- development of new applications for VOCs (which have the potential to increase emissions).

2 Assessment of Abatement Costs

2.1 RESULTS - SO_2

Cost estimates for abating SO_2 emissions are given in Table 5. Results for scenario H1 (based on the Commission's original proposal for the NECD) and emissions data for 1990 are shown for reference. The measures required to meet the limits are listed in Table 6.

Table 5. Costs of emission reductions for SO_2 (£M/year) specific to the NECD and Gothenburg Protocol.

Scenario	Emission, kt	Cost				
		UK	England	N Ireland	Scotland	Wales
1990	3756	-	-	-	-	-
UKREF4 for 2010	612	-	-	-	-	-
Gothenburg Protocol	625	0	0	0	0	0
Common Position	585	6	5	0	1	0
H1	497	25	21	1	2	1

Table 6. Measures used to achieve reductions in SO_2.

SO_2 emission (ktonnes)	Sector	Measure	Marginal cost (£/tonne)	Total cost (£M/yr)
625 (Gothenburg Protocol)	-	-	-	0
585 (Common Position)	Power generation	FGD	213	6
497 (H1)	Power generation	FGD	213	25

The standard SO_2 cost curve is based on the assumption that FGD has an efficiency of 95%. In contrast, the reference position is based on FGD with a lower efficiency being fitted to most stations. Thus, a second version of the cost curve has been developed which attempts to reflect the UK's position more accurately. The assumptions are:

- 90% of coal is burnt in stations fitted with FGD. This FGD plant has an efficiency of 80%
- 10% of coal is burnt in stations not fitted with FGD but which use lower sulphur coal compared with the situation in 1990. FGD fitted to these stations would have an efficiency of 75%.

The costs and measures required for meeting various ceilings on the basis of lower FGD efficiency are shown in Table 7. Overall there is little effect on the costs which remain the same for reaching 585 kt/year at £6M/year, and for 497 kt/year rise by only £3M to £28M/year. The similarity arises because of the narrow range in marginal abatement costs for different technologies over the range of interest.

Table 7. Measures used to achieve reductions in SO_2 (assuming lower efficiency FGD)

SO_2 emission (ktonnes)	Fuel	Sector	Measure	Marginal cost (£/tonne)	Total cost (£M/yr)
625	-	-	-	-	0
600	None	Industrial processes [a]	Various controls, 40% efficiency	233	3
585	None	Industrial processes [a]	Various controls, 40% efficiency	233	6
564	None	Industrial processes [a]	Various controls, 40% efficiency	233	11
550	Coal	Industrial boilers	Low sulphur (0.6%) coal	245	15
541	Coal	Industrial boilers	Low sulphur (0.6%) coal	245	17
536	Coal	Industrial furnaces	Low sulphur (0.6%) coal	245	18
525	Coal	non FGD power plant	Low sulphur (0.6%) coal	245	20
509	Coal	non FGD power plant	Low sulphur (0.6%) coal	245	25
509	Coke	Industrial boilers	Low sulphur (0.6%) coke	260	25
502	Coal	Residential combustion	Low sulphur (0.6%) coal	260	27
500	Coke	Residential combustion	Low sulphur (0.6%) coke	260	27
500	Coke	Fuel conversion [b]	Low sulphur (0.6%) coke	262	27
499	Fuel oil	Power generation	Low sulphur (0.6%) fuel oil	288	27
497	Fuel oil	Industrial boilers	Low sulphur (0.6%) fuel oil	288	28

a – processes in cement production, lime production, oil production, oil refining, iron and steel industry, non-ferrous metals production, and sulphuric acid manufacture. Due to the diverse nature of this sector, specific control measures are not used, however it is estimated that a 40% reduction in emissions from the sector can be achieved at a cost of £233 per tonne abated. Control options would include waste gas scrubbing.
b – The fuel conversion sector can include refineries, and producers of fuel gases, coke, and other solid smokeless fuel.

2.2 RESULTS – VOCS

The incremental costs beyond the UKREF4 position for meeting various emission ceilings for VOCs are shown in Table 8. These are substantially reduced compared to our previous estimates. Table 9 lists the measures that would be implemented to meet ceilings at least cost.

Table 8. Costs of emission reductions for VOC (£M/year) specific to the NECD and Gothenburg Protocol.

Scenario	Emission kt	Cost UK	England	N Ireland	Scotland	Wales
1990	2445	-	-	-	-	-
UKREF4 for 2010	1152	-	-	-	-	-
Gothenburg Protocol, Common Position	1200	0	0	0	0	0
VOC1150	1150	0.4	0.2	0.0	0.1	0.1
VOC1100	1100	11	3	0	3	1
VOC1050	1050	23	7	0	8	1
VOC1000	1000	47	29	0	10	2
H1	964	72	50	1	12	3

It is interesting to compare these results with those calculated by IIASA (Amann *et al*, 1999a, b). Starting at a baseline of 1352 kt/year, they calculated the following costs for reducing UK VOC emissions:

- £114 million (for 1200 kt/year, to meet the Protocol)
- £235 million/year (for 1101 kt/year, the original ceiling proposed for the UK by the UNECE's Working Group on Strategies under the Gothenburg Protocol, based on the RAINS analysis)
- £684 million/year (for 964 kt/year, the original ceiling proposed for the UK under the NECD by the Commission, based on the RAINS analysis).

Additional analysis was performed in earlier work under the present study to see whether significant savings could be made by using an alternative strategy for VOCs, weighting emissions within the cost-curve by their capacity to generate ozone. Emissions were, in theory, reduced to a level that would give an equivalent reduction in ozone concentration as the required reduction in total mass emission of VOC. Going to 964 kt/year (the target in the original proposal for the NECD) the difference was under 5% of total costs. At lower ceilings the difference was negligible. For the new analysis, which includes significant cost reductions it would appear likely that the difference at the 964 kt/year level is also now negligible. It was therefore concluded that within the likely ambition range the savings to be made from an alternative abatement strategy were not significant. However, it was noted that this may not be the case at the level of individual plant.

Table 9. Measures used to achieve reductions in VOC emissions from the UKREF4 scenario.

VOC emission (ktonnes)	Sector	Measure	Marginal cost (£/tonne)	Total cost (£M/yr)
1150	Refineries	Covered oil-water separators and flaring	179	0
1124	Refineries	Covered oil-water separators and flaring	179	5
1100	Oil production and distribution	Vapour balancing during loading	229	11
1062	Oil production and distribution	Vapour balancing during loading	229	19
1056	Industrial adhesives	Housekeeping & substitution	276	21
1052	Refineries	Incineration	319	22
1051	Dry cleaning	Conventional closed circuit machines	364	23
1050	Organic chemicals manufacture	Incineration	439	23
1014	Organic chemicals manufacture	Incineration	439	39
1002	Off-road machinery	Oxidation catalysts	600	46
1000	Motorcycles	Oxidation catalysts	600	47
983	Motorcycles	Oxidation catalysts	600	57
983	Products incorporating solvent	Reformulation	649	58
981	Industry – other solvent	Substitution	791	58
964	Industrial paints	Substitution	803	72

3 Analysis of Benefits

3.1 RESULTS: HEADLINE INDICATORS

Results in this section are restricted to the set of headline indicators quantified by Holland *et al* (2000). These were as follows:

- Change in critical levels exposure for ozone
- Crop and forest damage (£/year)
- Materials damage (£/year)
- Number of cases of premature mortality linked to short-term pollutant exposures
- Number of respiratory hospital admissions linked to short-term pollutant exposures.

This is not a comprehensive listing of the effects of the Protocol/Directive pollutants on health and the environment (see Table 10). Recent developments (e.g. Hurley *et al*, 2000, and the latest results from the APHEA air pollution epidemiology study [Katsouyanni, personal communication]) would appear to suggest that a wider quantification is warranted, a matter currently under discussion within the Department of Health and DETR. Results for some of these effects are given in Appendix I, following the format used in earlier reports.

SO_2, NO_x and NH_3 all contribute to acidification, and NO_x and NH_3 to eutrophication. At the present time the cost benefit analysis of ammonia is under review. When this is complete, results for exceedence of critical loads will be made available.

Results deal with benefits to the UK from abatement by UK sources. Previous analysis has investigated benefits to the UK from the reduction in emissions in other countries (Holland *et al*, 2000).

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Information on exceedence of AOT40 and AOT60 is provided in Table 11 and Table 12 respectively. Economic benefits are shown in Table 13.

Table 10. Effects of abatement of emissions of SO_2, NO_x, NH_3 and VOCs. An assessment (albeit partially subjective) of the likely importance of each effect following a reduction in emissions is shown in the final column: '+++' benefit from reduction, very important, through to '–' slight cost from abatement (e.g. through reduced fertilisation of crops with S or N). '?' denotes effects for which particular uncertainty exists, for example concerning the existence of chronic effects of air pollutants on morbidity, or the importance of visibility reductions.

Effect	Importance of effects
Health	
Ammonium sulphate and nitrate aerosols	
acute – mortality	+++
chronic – mortality	+++?
acute – morbidity	++
chronic – morbidity	++?
Ozone	
acute – mortality	+++
acute – morbidity	++
chronic – morbidity	?
SO_2	
acute – mortality	+++
acute – morbidity	++
chronic – morbidity	?
Direct effects of VOCs on mortality and morbidity	++?
Direct effects of NO_2 on mortality and morbidity	++?
Altruistic effects of the above health impacts	+++?
Impacts on competitiveness of businesses linked to the above health effects via	
changes in rates of absenteeism	++?
demand for pharmaceutical products	–
consumer demand via changes in mortality rates	+
Materials	
SO_2 / acid effects on utilitarian buildings	++
Effects on cultural assets	+++?
Effects on steel in re-inforced concrete	+
Effects of O_3 on paint	no significant effect
Effects of ozone on rubber	+
Macroeconomic effects	++?
Crops	**++?**
Direct effects of SO_2 and O_3 on crop yield	
Indirect SO_2 and O_3 effects on livestock	+
N deposition as fertiliser	--
Interactions between pollutants, with pests and pathogens, climate...	--/++
Acidification/liming	+
Macroeconomic effects	++?
Forests	
O_3 effects on timber production	+?
Non-O_3 effects	++?
Non-timber benefits of forests	++?
Exceedence of critical load for eutrophication	++?
Exceedence of critical load for acidification	++?
Other ecosystems	
Exceedence of O_3 critical level	++
Exceedence of critical load for eutrophication	+?
Exceedence of critical load for acidification	+++
Visibility	
Change in amenity	++?
Secondary effects of pollution abatement measures on pollutants not considered under the Directive/Protocol (e.g. greenhouse gases)	--/+++

Table 11. Data on AOT40 under each scenario, including benefits to UNECE from abatement in the UK.

	UK		UNECE	
Scenario/ VOC emission kt/year	**Average excess ppm hours**	**1000 km^2 excess ppm hours**	**Average excess ppm hours**	**1000 km^2 excess ppm hours**
UKREF4 (1152 kt/year)	1.5	122	2.2	11976
1150 kt/year	1.5	122	2.2	11975
1100 kt/year	1.4	117	2.2	11945
1050 kt/year	1.4	112	2.2	11915
1000 kt/year	1.3	107	2.2	11884
H1 (964 kt/year)	1.3	104	2.2	11863

Within the range shown in Table 11 each 50 kt reduction in UK VOC emissions leads to roughly a reduction of 5,000 km^2 excess ppm.hours in the UK (4% of the UKREF4 total), and 30,000 km^2 excess ppm.hours across the whole of the UNECE (0.25% of the UKREF4 total).

Table 12. Data on AOT60 under each scenario, including benefits to UNECE from abatement in the UK.

	UK		UNECE	
Scenario	**Average excess ppm hours**	**Million people excess ppm hours**	**Average excess ppm hours**	**Million people excess ppm hours**
UKREF4 (1152 kt/year)	1.0	60	0.7	460
1150 kt/year	1.0	60	0.7	459
1100 kt/year	1.0	58	0.7	455
1050 kt/year	1.0	56	0.7	451
1000 kt/year	0.9	53	0.7	446
H1 (964 kt/year)	0.9	51	0.7	443

Within the range shown in Table 12 each 50 kt reduction in UK VOC emissions leads to a reduction of roughly 2.5 million people ppm.hours in the UK (4% of the UKREF4 total), and 4 million people excess ppm.hours across the whole of the UNECE (0.9% of the UKREF4 total).

Table 13. Benefits (£M) in terms of increased crop and forest production in the UK through reduced exposure to ozone, as a result of reducing VOC emissions in the UK.

Receptor	Emission, kt/year	Benefit, £M/year
Crops	1150	0.09
	1100	2.3
	1050	4.6
	1000	7.0
	964	8.4
Forests	1150	0.002
	1100	0.06
	1050	0.12
	1000	0.18
	964	0.22

From extrapolation of analysis based on the ELMO model, benefits to crop production would be spread as follows: 90% to England, 9% to Wales and 1% to Scotland. Northern Ireland is not included in this part of the analysis, but would not change the total benefits significantly. For forests, 66% of the benefits would arise in England and 33% in Wales. A detailed assessment for each country under each scenario is not possible for results based on the RAINS model.

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Estimated changes in damage via acid deposition to building materials are shown in Table 14. These estimates include only damages to materials in what may be described as 'utilitarian applications'. They therefore exclude damage to cultural monuments and buildings, effects of ozone on rubber and damage to fine art materials.

Table 14. Estimated change in materials damage against the baseline UKREF4 scenario.

	Benefit (£M)
Common Position (585 kt/year)	1.2
H1 (497 kt/year)	5.5

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Acidification is caused by sulphur dioxide, nitrogen oxides and ammonia, whilst eutrophication is caused by deposition of nitrogen oxides and ammonia. Exceedence of critical loads for acidification and eutrophication (essentially the thresholds for damage) are likely to lead to damaging impacts on ecosystems. Full results of the analysis of areas of the UK exceeding critical load in 2010 are not yet available, as calculations are currently being revised in the light of recent developments in deposition modelling and evaluation of critical loads[4]. However, the

[4] UK experts are currently reviewing critical loads for nutrient nitrogen set to protect ecosystems from eutrophication. In addition, the deposition modelling is being refined to improve the calculation of wet deposition of sulphate, nitrate and ammonium, and of the total deposition of ammonia.

agreed ceilings for SO_2 and NO_x will afford substantially greater protection to ecosystems in the UK, particularly with respect to acidification.

3.1.4 Acute effects of Protocols and Directive air pollutants on mortality and respiratory hospital admissions

Estimates of health effects for SO_2 and secondary particles have been made by combining the results of HARM modelling with the following exposure-response functions. Functions are also given for ozone, for which a threshold of 50 ppb has been assumed here. This reflects the lack of appropriate models for assessment of mean ozone concentrations rather than a preference for the existence of a threshold. The quantification of effects of ozone on health combines the results given by COMEAP with the data given above on AOT40 and AOT60.

Table 15. Functions for assessment of health effects.

Pollutant	% change in mortality rate per μg/m^3	% change in rate of respiratory hospital admissions (RHAs) per μg/m^3
SO_2	0.060%	0.050%
Secondary particles	0.075%	0.080%
Ozone	0.060%	0.070%

Results are shown in the following Tables.

Table 16. Estimated reduction in health impacts regarding premature mortality and respiratory hospital admissions (in terms of the number of events) from reducing UK SO_2 emissions from the reference position of 612 kt/year.

	England	N. Ireland	Scotland	Wales	Total
585 kt/year					
Acute effects on mortality	37	1	2	2	42
Acute effects on respiratory hospital admissions	18	0	1	1	20
497 kt/year					
Acute effects on mortality	157	4	9	9	179
Acute effects on respiratory hospital admissions	77	0	4	4	85

Table 17. Estimated annual reduction in the health effects of ozone under scenarios of diminishing UK VOC emission, assuming a threshold for effects of 50 ppb.

Emission (kt/year)	Acute effects on mortality	Acute effects on respiratory hospital admissions
UKREF4 (1152 kt/year)	-	-
1150	1	1
1100	15	19
1050	30	38
1000	47	60
H1 (964 kt/year)	58	74

Here, as before, we follow the advice currently available from COMEAP (1998) on selection of health exposure-response functions for the core estimates of damages presented in the main text of this report. A recent paper by Schwartz (2000) has cast doubt on the direct role of SO_2 in damage to health. The lower bound for effects of acute exposures to SO_2 on mortality is therefore set to zero in the sensitivity analysis presented in Appendix I, to reflect this uncertainty.

Other recent developments operate in favour of including the chronic effects of particles, including sulphate aerosols, on mortality in the headline estimates. These include the completion of a report by Hurley *et al* (2000), which developed a more robust methodology for application of the results of the available exposure-response functions than was previously available, and re-analysis of the data in the relevant papers (particularly Pope *et al*, 1995) carried out by the Health Effects Institute in the USA. This information is currently under consideration within COMEAP.

Overall, therefore, the latest information on benefits suggests that there may be overestimation in some parts of this analysis, but underestimation in others. Section 3.2 and Appendix I provide some insight on the relative importance of the issues identified.

3.2 SENSITIVITY ANALYSIS

Analysis of a number of additional endpoints, particularly for health, with some monetisation is presented in Appendix I. The purpose of that work is to investigate whether it is *possible* for the benefits of abating UK emissions to exceed or not to exceed the associated costs of abatement. Given the uncertainties that affect this work and strong differences in the views of different commentators, the ranges of various parameters adopted in the Appendix are extremely broad. These ranges are indeed broader than the study team believes to be the case[5]. However, given the current level of debate it seems inappropriate for the study team to bias the analysis to their own viewpoint, and so a pragmatic position is adopted, seeking to develop an inclusive debate in the field. The analysis demonstrates that estimated costs lie in the current range for the monetary value of 'quantifiable' benefits. It also demonstrates that the inclusion of health effects not currently included in the COMEAP guidance *could* have a substantial effect on the analysis.

Further guidance on some of these issues may soon be available, following consideration of the recent report completed for the Department of Health and referred to already above (Hurley *et al*, 2000).

3.3 POLLUTION TRANSFER MATRIX ANALYSIS

Analysis of the contribution of different countries in Europe to pollution problems in the UK, and vice-versa is described in detail in a separate paper produced under the project (R. Warren, 2000). This section is largely a summary of the main results of that work. The contributions of European countries to acidification, N deposition, and the concentration of secondary particles in the UK are shown in Figures 1 to 3. Results show that the following countries are the largest

[5] Specifically, we regard the upper end of the range for mortality valuation recommended by EAHEAP to be excessive.

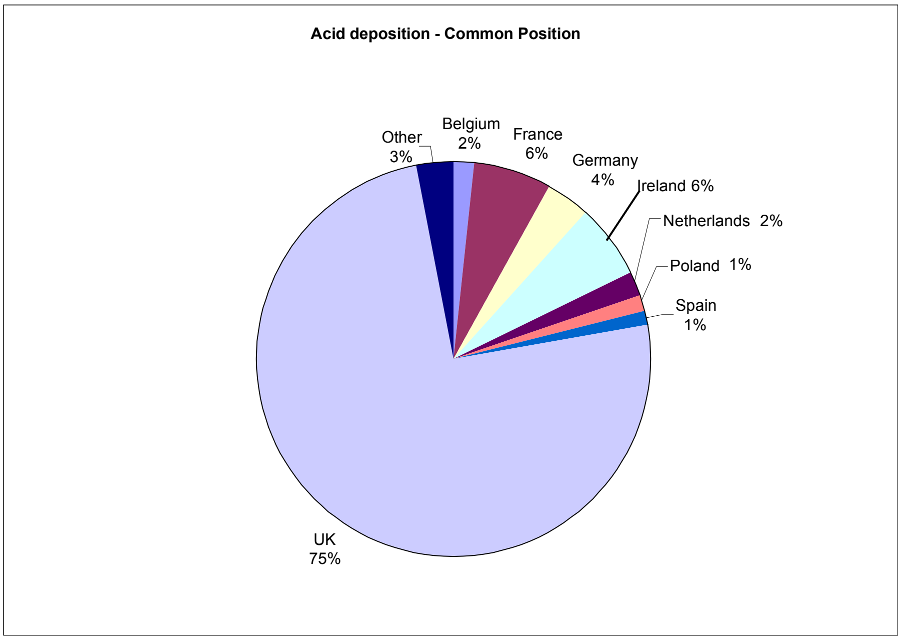
contributors to deposition and secondary particle concentration in the UK: Belgium, France, Germany, Ireland, Netherlands, Poland, Spain and finally of course, the UK itself. Of these, the largest contributions come from:

- Ireland, because of its proximity to the UK, and prevailing wind directions
- Germany, because of the size of its emissions
- The UK and France, because of both size and proximity

The contribution of the UK is notably smaller for secondary particle concentration than for N or acidic deposition by about 25%. This difference is related to the time taken for particles to form following emission of the primary species.

The countries most affected by the UK (in approximate order of *the percentage* of the total deposition in each country originating from the UK) are the UK itself, Iceland, Ireland, Denmark, Norway, the Netherlands, Belgium, Sweden, Germany and France.

Table 18shows that a substantial amount of the UK's emissions are deposited in the North Sea and NE Atlantic. The other main destinations are (in order) Germany, France, Norway, Sweden and Ireland, though in no case does more than 5% of UK emissions land in any other single country. Germany heads the list because of size and prevailing wind directions.



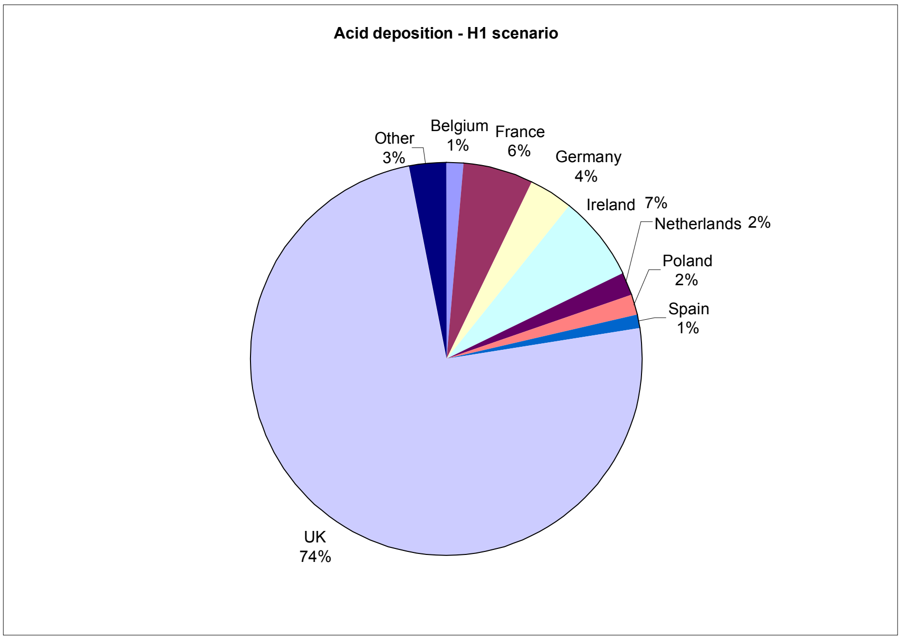


Figure 1. Contribution of neighbouring countries to acidic deposition in the UK.

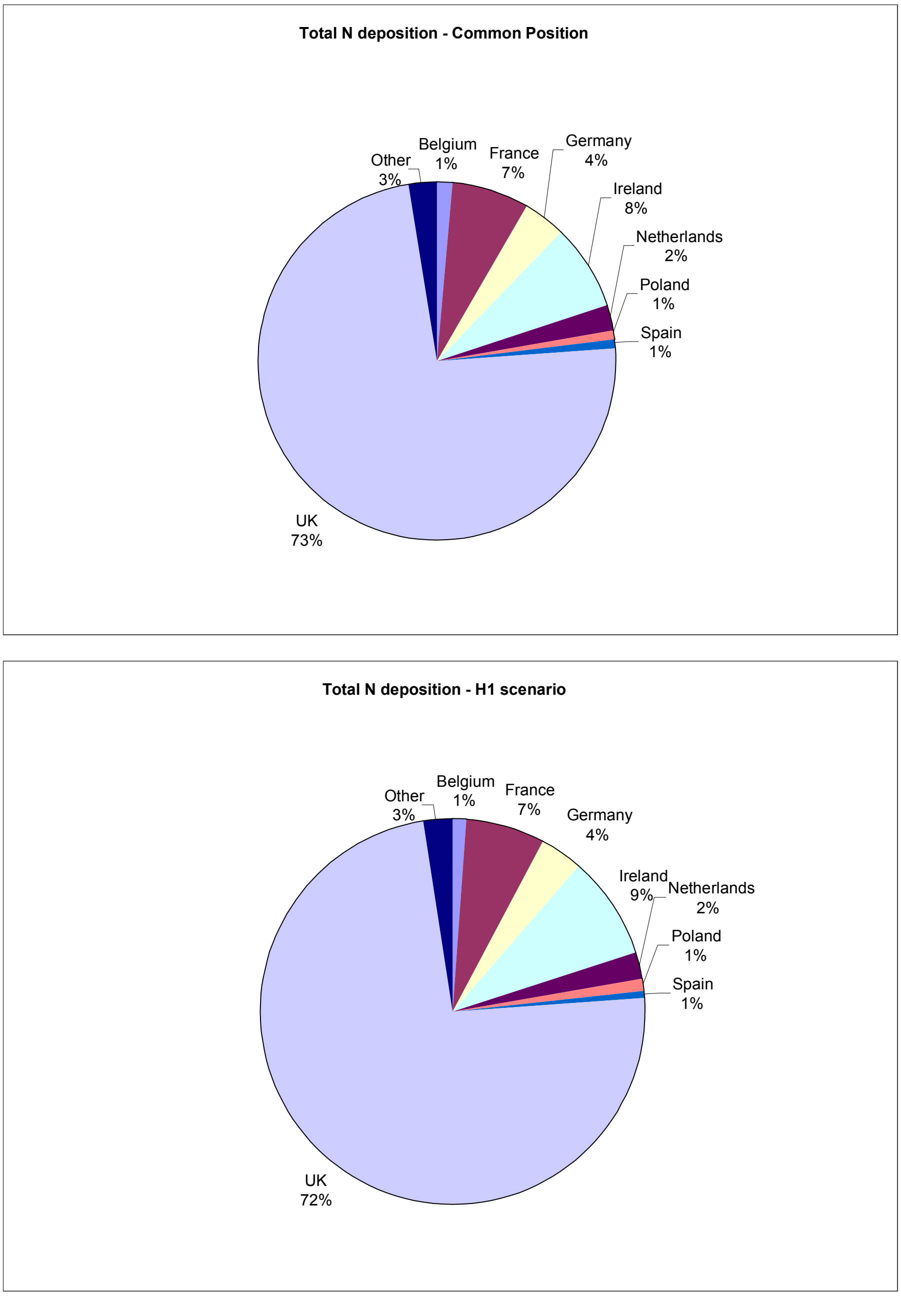
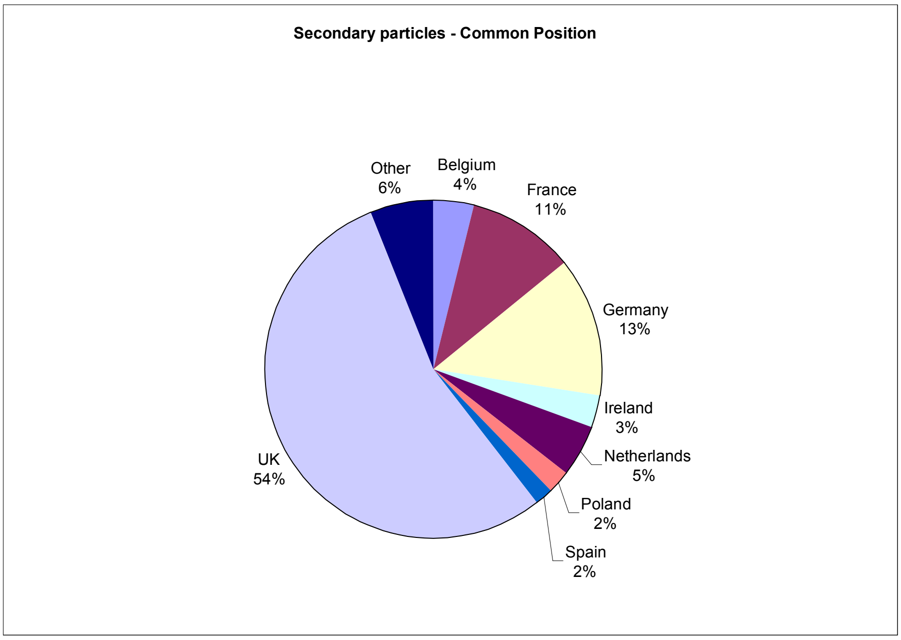


Figure 2. Contribution of neighbouring countries to total N deposition in the UK.



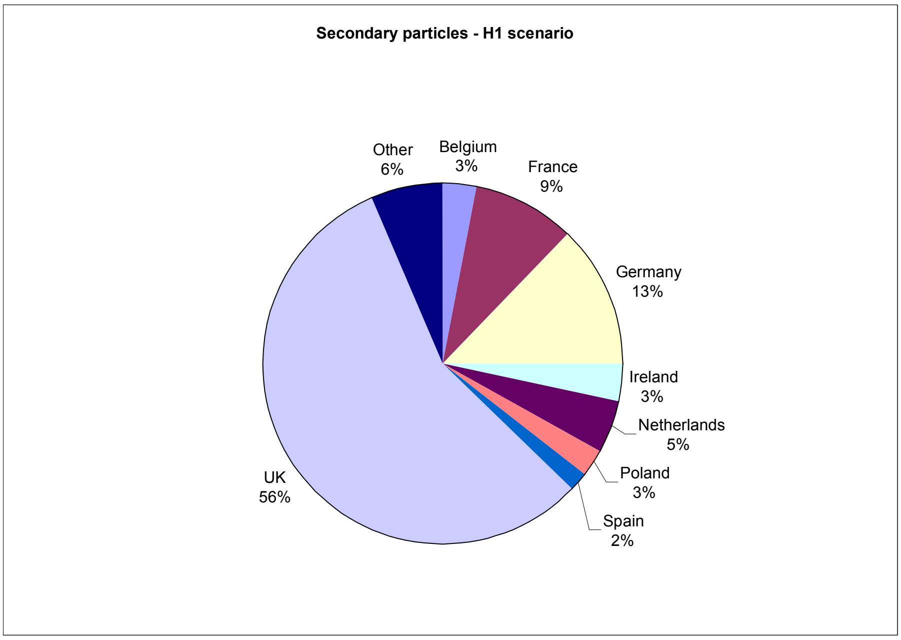


Figure 3. Contribution of neighbouring countries to secondary particle (ammonium, sulphate, nitrate) concentration in the UK.

Table 18. % of total UK emissions deposited in each country within the area accounted for by EMEP. All countries shown.

	Sulphur	Oxidised N
Austria	0.22%	0.25%
Belgium	0.39%	0.87%
Bulgaria	0.05%	0.06%
Denmark	0.54%	1.21%
Finland	0.30%	0.46%
France	2.14%	4.53%
Germany	2.42%	4.80%
Greece	0.02%	0.10%
Hungary	0.06%	0.10%
Iceland	0.21%	0.40%
Ireland	1.08%	2.00%
Italy	0.17%	0.37%
Luxembourg	0.02%	0.04%
Netherlands	0.49%	1.08%
Norway	1.23%	2.25%
Poland	0.80%	1.48%
Portugal	0.01%	0.08%
Romania	0.15%	0.19%
Spain	0.16%	0.54%
Sweden	1.14%	2.06%
Switzerland	0.15%	0.15%
Turkey	0.11%	0.23%
UK	32.28%	31.07%
Byelorus	0.26%	0.33%
Ukraine	0.32%	0.44%
Moldova	0.01%	0.02%
Russia (European part)	1.30%	1.68%
Latvia	0.14%	0.27%
Lithuania	0.18%	0.37%
Czech Republic	0.20%	0.33%
Slovakia	0.05%	0.08%
Slovenia	0.01%	0.02%
Croatia	0.04%	0.06%
Bosnia-Herzogovina	0.06%	0.08%
Yugoslavia	0.09%	0.12%
Macedonia	0.01%	0.02%
Cyprus	0.00%	0.00%
Armenia	0.00%	0.00%
Malta	0.00%	0.00%
Remaining land areas	0.27%	1.00%
Baltic Sea	1.28%	1.73%
North Sea	29.30%	16.35%
NE Atlantic Ocean	21.74%	22.00%
Mediterranean Sea	0.49%	0.62%
Black Sea	0.11%	0.12%

4 Conclusions

1. Previous estimates of the costs of abating VOCs from the UK to the levels under consideration in developing legislation on emission ceilings are found to be too high. The reason for this was overestimation of emissions in the reference (baseline) case for 2010 (compared to current best estimates) by 8%.

2. Although this difference sounds small in percentage terms, it has important implications when combined with the cost curve for UK VOCs. According to the results presented here, the emission ceiling agreed for the UK under the Common Position and the Gothenburg Protocol (1200 kt/year) can be met without the introduction of measures additional to those already agreed. For lower emission ceilings costs would be much reduced in comparison to earlier estimates.

3. Without specific analysis for other countries it is unclear to what extent they may have over- or under-estimated their own emissions. Experience in the UK would suggest that others may be taking an overly-pessimistic view of what will be achieved in the future. This may apply to all countries with respect to VOCs, and for SO_2 particularly to those countries for which coal use played a strong role in the energy sector in the 1990s.

4. The benefits presented in this report focus on improvements to health in the UK as a consequence of UK emissions. Ecosystem benefits are not presented in this report as they are currently being revised in the light of developments in the areas of ammonia emissions, abatement and dispersion modelling.

   Moving from UKREF4 to the Common Position for SO_2 is estimated to reduce cases where acute exposure influences mortality and respiratory hospital admissions by 42 and 20 cases per year (respectively) across the UK. For ozone there is no additional benefit under the current proposals for moving to the Common Position, as this should be met under existing regulation and market trends (see paragraph 2). However, for each reduction of 50 kt/year it is estimated that there will be a reduction of about 15 cases of premature mortality linked to ozone and 19 respiratory hospital admissions each year, assuming a threshold for effects of 50 ppb ozone. The threshold assumption is used here because of a lack of appropriate models for prediction of mean exposures. The Department of Health's advisory committee in this field, COMEAP, recommends an alternative, no-threshold approach.

5. Consideration of the origin of the pollutants deposited and otherwise affecting the UK demonstrates that the UK is, not surprisingly, the dominant source of its own pollution problems. Three quarters of the sulphur and nitrogen deposited in the UK is of UK origin. However, only a little over half of the exposure of the UK population to secondary particles arises through UK emissions. The difference arises partly because of the time taken for secondary particles to form in the atmosphere.

   Much of the pollution emitted in the UK is deposited in the surrounding seas. The other main destinations are (in order) Germany (because of its size and the prevailing wind directions), France, Norway, Sweden and Ireland, though in no case does more than 5% of UK emissions land in any other single country.

APPENDIX I: Glossary and abbreviations

ALPHA	Atmospheric Long-range Pollution Health/environment Assessment model
AOT40	Accumulated concentration of ozone over a threshold of 40 ppb
AOT60	Accumulated concentration of ozone over a threshold of 60 ppb
BCF	British Coatings Federation
CBA	Cost-benefit analysis
COMEAP	Committee on the Medical Effects of Air Pollutants
CLRTAP	Convention on Long Range Transboundary Air Pollution
CP	Common Position on the NECD
Critical level	Concentration of a pollutant in the air above which environmental harm is anticipated
Critical load	Deposition of a pollutant to land or water above which environmental harm is anticipated
DETR	UK Department of the Environment, Transport and the Regions
DH	UK Department of Health
DTI	UK Department of Trade and Industry
EAHEAP	Economic Appraisal of the Health Effects of Air Pollution
EC	European Commission
ELMO	Edinburgh/Lancaster Model for Ozone
EMEP	European Monitoring and Evaluation Programme
EU	European Union
FGD	Flue gas desulphurisation
H1	Scenario containing emission ceilings as originally proposed by the European Commission
ha	Hectares
HARM	Hull Acid Rain Model
IGCB	Inter-departmental Group on Costs and Benefits
IIASA	International Institute for Applied Systems Analysis
kt	Thousand tonnes
NAEI	National Atmospheric Emissions Inventory
NAQS	National Air Quality Strategy
NEC(D)	National Emission Ceilings (Directive)
NH_3	Ammonia
NO_x	Oxides of nitrogen (NO and NO_2, but not N_2O)
O_3	Ozone
PM_{10}	Fine particles less than 10 μm in diameter
RAD	Restricted activity day
RAINS	Regional Air Pollution Information and Simulation Model
(IIASA) Reference	IIASA reference scenario
RHA	Respiratory hospital admissions
SO_2	Sulphur dioxide
UKPIA	United Kingdom Petroleum Industry Association

UKREFx	A series of scenarios used in AEA Technology's reports on the Gothenburg Protocol and NECD to define UK emissions under a scenario of no further action. The baseline scenario used for this report is referred to as UKREF4.
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compound
VOCx	Series of scenarios used in this report to define UK VOC emissions intermediate between the Common Position and H1 scenario. 'x' refers to VOC emission in kt.
WFGD	Wet flue gas desulphurisation
YOLL	Years of life lost

Appendix II: Sensitivity Analysis of Benefits

The results given in this appendix demonstrate the effect of quantifying benefits more widely, particularly for health, and of monetising quantified impacts. The ranges shown are extremely broad, though could probably be reduced given some of the latest developments in epidemiology and valuation.

AEA Technology.
Analysis by Katie King, Mike Holland and Charles Walker

Version 11.0

Scenario: VOC @ 1150 kt/year

Colour key:	
	Physical/biological impacts
	Monetary valuations

£ conversions Rate = 1.5euro/pound

Guide to grouping of effects
Group I: Effects quantified and reported for the IGCB report on the NAQS
Group II: Results of application of exposure-response functions reported by COMEAP but not used by IGCB
Group III: Monetisation of aute effects on mortality and RHAs following EAHEAP
Group IV: Monetisation of effects for which COMEAP gave functions, but EAHEAP did not give valuation.
Monetisation based on ExternE values.
Group V: Quantification and monetisation of chronic effects on mortality based on Hurley et al (1999) (forthcoming)
Group VI: Additional effects quantified for UNECE Task Force on Economic Aspects of Abatement Strategies
and European Commission DGXI

NOTE: All calculations shown here are based on the assumption of a threshold of 50 ppb.

Group	Effect		Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	High
I	Crop damage		Monetary	Market valuations	O3	0.09	0.1	0.1
I	Acute mortality	-lc	Threshold	0.030%	O3	1		
		-mid		0.060%	O3	1		
		-high		0.080%	O3	1		
I	RHA		Threshold	0.025%	O3	0		
		-mid		0.070%	O3	1		
		-high		0.120%	O3	2		
III	Acute mortality - low		Threshold	0.0021	O3	0.00	0.1	
	Acute mortality - intermediat		Threshold	0.088	O3	0.1		
	Acute mortality - high		Threshold	1.12	O3	1		1.6
III	RHA - low		Threshold	0.000	O3	0.00	0.1	
	RHA - high		Threshold	0.0026	O3	0.00		1.6
VI	Forests			Market values	O3	0.00	0.1	1.6
VI	Asthma attacks		Pers.days - threshold	4.29E-03	O3	781		
			Threshold	0.000022	O3	0.02	0.1	1.6
VI	MRADS		Person days - Threshold	9.76E-03	O3	1776		
			Threshold	0.0000045	O3	0.01	0.1	1.6

AEA Technology.
Analysis by Katie King, Mike Holland and Charles Walker

Version 11.0

Scenario: VOC @ 1100 kt/year

Colour key:	Physical/biological impacts
	Monetary valuations

£ conversions Rate = 1.5euro/pound

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Group VI: Additional effects quantified for UNECE Task Force on Economic Aspects of Abatement Strategies
and European Commission DGXI

NOTE: All calculations shown here are based on the assumption of a threshold of 50 ppb.

Group	Effect		Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	High
I	Crop damage		Monetary	Market valuations	O3	2.33	2	2
I	Acute mortality	-lc	Threshold	0.030%	O3	8		
		-mid		0.060%	O3	15		
		-high		0.080%	O3	20		
I	RHA		Threshold	0.025%	O3	7		
		-mid		0.070%	O3	19		
		-high		0.120%	O3	33		
III	Acute mortality - low		Threshold	0.0021	O3	0.02	2	
	Acute mortality - intermediat		Threshold	0.088	O3	1.3		
	Acute mortality - high		Threshold	1.12	O3	22		25
III	RHA - low		Threshold	0.000	O3	0.00	2	
	RHA - high		Threshold	0.0026	O3	0.08		25
VI	Forests			Market values	O3	0.06	2	25
VI	Asthma attacks		Pers.days - threshold	4.29E-03	O3	11708		
			Threshold	0.000022	O3	0.26	3	25
VI	MRADS		Person days - Threshold	9.76E-03	O3	26637		
			Threshold	0.0000045	O3	0.12	3	25

AEA Technology.
Analysis by Katie King, Mike Holland and Charles Walker

Version 11.0

Scenario: VOC @ 1050 kt/year

Colour key: Physical/biological impacts
Monetary valuations

£ conversions Rate = 1.5euro/pound

Guide to grouping of effects

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Monetisation based on ExternE values.
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Group VI: Additional effects quantified for UNECE Task Force on Economic Aspects of Abatement Strategies
and European Commission DGXI

NOTE: All calculations shown here are based on the assumption of a threshold of 50 ppb.

Group	Effect		Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	High
I	Crop damage		Monetary	Market valuations	O3	4.60	5	5
I	Acute mortality	-lc	Threshold	0.030%	O3	15		
		-mid		0.060%	O3	30		
		-high		0.080%	O3	40		
I	RHA		Threshold	0.025%	O3	14		
		-mid		0.070%	O3	38		
		-high		0.120%	O3	65		
III	Acute mortality - low		Threshold	0.0021	O3	0.03	5	
	Acute mortality - intermediat		Threshold	0.088	O3	2.6		
	Acute mortality - high		Threshold	1.12	O3	45		49
III	RHA - low		Threshold	0.000	O3	0.00	5	
	RHA - high		Threshold	0.0026	O3	0.17		50
VI	Forests			Market values	O3	0.12	5	50
VI	Asthma attacks		Pers.days - threshold	4.29E-03	O3	23417		
			Threshold	0.000022	O3	0.52	5	50
VI	MRADS		Person days - Threshold	9.76E-03	O3	53274		
			Threshold	0.0000045	O3	0.24	6	50

AEA Technology.
Analysis by Katie King, Mike Holland and Charles Walker

Version 11.0

Scenario: VOC @ 1000 kt/year

Colour key:	Physical/biological impacts
	Monetary valuations

£ conversions Rate = 1.5euro/pound

Guide to grouping of effects
Group I: Effects quantified and reported for the IGCB report on the NAQS
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Monetisation based on ExternE values.
Group V: Quantification and monetisation of chronic effects on mortality based on Hurley et al (1999) (forthcoming)
Group VI: Additional effects quantified for UNECE Task Force on Economic Aspects of Abatement Strategies
and European Commission DGXI

NOTE: All calculations shown here are based on the assumption of a threshold of 50 ppb.

Group	Effect		Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	High
I	Crop damage		Monetary	Market valuations	O3	7.00	7	7
I	Acute mortality	-lc	Threshold	0.030%	O3	24		
		-mid		0.060%	O3	47		
		-high		0.080%	O3	63		
I	RHA		Threshold	0.025%	O3	21		
		-mid		0.070%	O3	60		
		-high		0.120%	O3	103		
III	Acute mortality - low		Threshold	0.0021	O3	0.05	7	
	Acute mortality - intermediat		Threshold	0.088	O3	4.1		
	Acute mortality - high		Threshold	1.12	O3	70		77
III	RHA - low		Threshold	0.000	O3	0.00	7	
	RHA - high		Threshold	0.0026	O3	0.27		77
VI	Forests			Market values	O3	0.18	7	78
VI	Asthma attacks		Pers.days - threshold	4.29E-03	O3	36686		
			Threshold	0.000022	O3	0.81	8	78
VI	MRADS		Person days - Threshold	9.76E-03	O3	83463		
			Threshold	0.0000045	O3	0.38	8	79

Analysis by Katie King, Mike Holland and Charles Walker

Scenario: VOC @ 964 kt/year

Colour key:	Physical/biological impacts	
	Monetary valuations	£ conversions Rate = 1.5euro/pound

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and European Commission DGXI

NOTE: All calculations shown here are based on the assumption of a threshold of 50 ppb.

Group	Effect	Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	High
I	Crop damage	Monetary	Market valuations	O3	8.40	8	8
I	Acute mortality -lc	Threshold	0.030%	O3	29		
	-mid		0.060%	O3	58		
	-high		0.080%	O3	77		
I	RHA	Threshold	0.025%	O3	26		
	-mid		0.070%	O3	74		
	-high		0.120%	O3	127		
III	Acute mortality - low	Threshold	0.0021	O3	0.06	8	
	Acute mortality - intermediat	Threshold	0.088	O3	5.1		
	Acute mortality - high	Threshold	1.12	O3	87		95
III	RHA - low	Threshold	0.000	O3	0.00	8	
	RHA - high	Threshold	0.0026	O3	0.33		95
VI	Forests		Market values	O3	0.22	9	96
VI	Asthma attacks	Pers.days - threshold	4.29E-03	O3	45272		
		Threshold	0.000022	O3	1.00	10	97
VI	MRADS	Person days - Threshold	9.76E-03	O3	102996		
		Threshold	0.0000045	O3	0.46	10	97

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Colour key:	
	Physical/biological impacts
	Monetary valuations

Scenario: SO2 @ 585 kt/year

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Group V: Quantification and monetisation of chronic effects on mortality based on Hurley et al (1999) (forthcoming)
Group VI: Additional effects quantified for UNECE TFEAAS and EC DG ENV.
Note 1: Chronic effects on mortality not added to the running high total as only lower bound and intermediate values available.

Group	Effect	Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	£M Totals High
I	Materials damage	Monetary	Market valuations	Total	1.20	1.20	1.20
I	Acute mortality -lc	Premature deaths	0.060%	SO4	5		
	-mid		0.075%	SO4	6		
	-high		0.085%	SO4	7		
	-low		0.000%	SO2	0		
	-mid		0.060%	SO2	36		
	-high		0.070%	SO2	42		
I	RHA	Hospital admission	0.050%	SO4	3		
	-mid		0.080%	SO4	5		
	-high		0.110%	SO4	7		
	-low		0.000%	SO2	0		
	-mid		0.050%	SO2	15		
	-high		0.090%	SO2	27		
II	Cardiovascular disease	Hospital admission	0.100%	SO4	4		
II	Congestive Heart Failure	Hospital admission	1.85E-05	SO4	2		
II	Ischaemic Heart Disease	Hospital admission	1.75E-05	SO4	2		
II	Cerebrovascular Hospital Ac	Hospital admission	5.04E-06	SO4	2		
II	Bronchodilator Usage	Person days	0.163,0.078	SO4	6439		
II	Asthmatics and Cough	Person days	0.168,0.133	SO4	7475		
II	Lower respiratory Symptoms	Person days	0.061,0.103	SO4	3586		
III	Acute mortality - low		0.0021	SO4	0.010		
			0.0021	SO2	0.000		
			0.0021	Total	0.010	1	
	Acute mortality - intermediate		0.088	SO4	0.5		
			0.088	SO2	3		
			0.088	Total	4		
	Acute mortality - high		1.12	SO4	7.6		
			1.12	SO2	47		
			1.120	Total	55		56
III	RHA - low		0.000	SO4	0		
			0.000	SO2	0		
			0.000	Total	0	1	
	RHA - high		0.0026	SO4	0.018		
			0.0026	SO2	0.07		
			0.0026	Total	0.09		56
IV	Cardiovascular disease		0.0014	SO4	0.005	1	
IV	Congestive Heart Failure		0.0014	SO4	0.003		56
IV	Ischaemic Heart Disease		0.0014	SO4	0.003		56
IV	Cerebrovascular Hospital Admissions		0.0014	SO4	0.003	1	56
IV	Bronchodilator Usage		0.0000045	SO4	0.03	1	56
IV	Asthmatics and Cough		0.0000045	SO4	0.03		56
IV	Lower respiratory Symptoms		0.0000045	SO4	0.016		56
V	Chronic mortality	Low	1.71E-04	SO4	135		
		Mid	2.24E-04	SO4	176		
	Chronic mortality - low	Monetary	0.025	SO4	3	5	
	Chronic mortality - intermediate		0.088	SO4	15		Note 1
VI	Chronic Bronchitis adults	Incidence	4.90E-05	SO4	35		
		Monetary - low	0.00016	SO4	0.006	5	
		Monetary - high	0.063	SO4	2.2		58
VI	Chronic Bronchitis children	Episodes	1.61E-03	SO4	253		
		Monetary	0.00016	SO4	0.04	5	58
VI	Chronic cough	Episodes	2.07E-03	SO4	330		
		Monetary	0.00013	SO4	0.04	5	58
VI	RADs	Days	0.025	SO4	15938		
		Monetary - low	0.0000045	SO4	0.07	5	
		Monetary - high	0.000045	SO4	0.7		59

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Colour key: Physical/biological impacts / Monetary valuations

Scenario: SO2 @ 497 kt/year

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Group V: Quantification and monetisation of chronic effects on mortality based on Hurley et al (1999) (forthcoming)
Group VI: Additional effects quantified for UNECE TFEAAS and EC DG ENV.
Note 1: Chronic effects on mortality not added to the running high total as only lower bound and intermediate values available.

Group	Effect	Quantification	Function/values £M 1990	Pollutant	UK to UK	£M Totals Low	£M Totals High
I	Materials damage	Monetary	Market valuation	Total	5.50	5.50	5.50
I	Acute mortality	Premature deaths	0.060%	SO4	18		
	-mid		0.075%	SO4	22		
	-high		0.085%	SO4	25		
	-low		0.000%	SO2	0		
	-mid		0.060%	SO2	157		
	-high		0.070%	SO2	183		
I	RHA	Hospital admission:	0.050%	SO4	13		
	-mid		0.080%	SO4	21		
	-high		0.110%	SO4	29		
	-low		0.000%	SO2	0		
	-mid		0.050%	SO2	64		
	-high		0.090%	SO2	115		
II	Cardiovascular disease	Hospital admission:	0.100%	SO4	13		
II	Congestive Heart Failure	Hospital admission:	1.85E-05	SO4	7		
II	Ischaemic Heart Disease	Hospital admission:	1.75E-05	SO4	7		
II	Cerebrovascular Hospital /	Hospital admission:	5.04E-06	SO4	7		
II	Bronchodilator Usage	Person days	0.163,0.078	SO4	23610		
II	Asthmatics and Cough	Person days	0.168,0.133	SO4	27408		
II	Lower respiratory Symptor	Person days	0.061,0.103	SO4	13149		
III	Acute mortality - low		0.0021	SO4	0.037		
			0.0021	SO2	0.000		
			0.0021	Total	0.037	6	
	Acute mortality - intermediate		0.088	SO4	1.9		
			0.088	SO2	14		
			0.088	Total	16		
	Acute mortality - high		1.12	SO4	27.9		
			1.12	SO2	205		
			1.120	Total	233		239
III	RHA - low		0.000	SO4	0		
			0.000	SO2	0		
			0.000	Total	0	6	
	RHA - high		0.0026	SO4	0.075		
			0.0026	SO2	0.30		
			0.0026	Total	0.37		239
IV	Cardiovascular disease		0.0014	SO4	0.018	6	
IV	Congestive Heart Failure		0.0014	SO4	0.010		239
IV	Ischaemic Heart Disease		0.0014	SO4	0.010		239
IV	Cerebrovascular Hospital Admissions		0.0014	SO4	0.010	6	239
IV	Bronchodilator Usage		0.0000045	SO4	0.11	6	239
IV	Asthmatics and Cough		0.0000045	SO4	0.12		239
IV	Lower respiratory Symptoms		0.0000045	SO4	0.059		239
V	Chronic mortality	Low	1.71E-04	SO4	494		
		Mid	2.24E-04	SO4	646		
	Chronic mortality - low	Monetary	0.025	SO4	12	18	
	Chronic mortality - intermediate		0.088	SO4	57		Note 1
VI	Chronic Bronchitis adults	Incidence	4.90E-05	SO4	128		
		Monetary - low	0.00016	SO4	0.021	18	
		Monetary - high	0.063	SO4	8.1		247
VI	Chronic Bronchitis childrer	Episodes	1.61E-03	SO4	927		
		Monetary	0.00016	SO4	0.15	18	248
VI	Chronic cough	Episodes	2.07E-03	SO4	1210		
		Monetary	0.00013	SO4	0.16	18	248
VI	RADs	Days	0.025	SO4	58440		
		Monetary - low	0.0000045	SO4	0.26	19	
		Monetary - high	0.000045	SO4	2.6		250

APPENDIX III: References

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