

Evaluation of the costs and benefits of the implementation of the IPPC Directive on Large Combustion Plant

European Commission DG ENV.C.5

ED48763

Issue Number 3

July 2007

Title	Evaluation of the costs and benefits of the implementation of the IPPC Directive on Large Combustion Plant
Customer	European Commission DG Environment C.5
Customer reference	
Confidentiality, copyright and reproduction	
File reference	
Reference number	ED48763 – IPPC Issue 3

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Executive Summary

Introduction

This report presents the cost-benefit analysis (CBA) of scenarios developed by IIASA using the GAINS model to assess the impact of different emission levels resulting from variation in the interpretation and implementation of BAT on Large Combustion Plant under the IPPC Directive.

Two scenarios have been considered in this analysis:

- Implementation of the upper end of BAT associated emission levels (AEL) range i.e. **least stringent**
- Implementation of the lower end of BAT associated emission levels (AEL) range i.e. **most stringent**

Both scenarios were compared to the 2020 baseline scenario (outlined in NEC Scenario Analysis Report Nr. 3, Amann et al. 2007). This baseline includes current legislation and uses Member State national energy and agricultural projections. This baseline includes the impact and costs of Euro 5/6 implementation.

Emission reductions and abatement costs

The emission reductions due to IPPC implementation and associated abatement costs are presented in this report. They have been provided by IIASA, as outputs of the GAINS model. The abatement costs are an important input into the assessment of costs and benefits. Some Member States realise negative costs where assumptions about the current implementation of controls in their baseline projections is more stringent than what is proposed under the IPPC implementation cases e.g. Sweden.

Approach to benefits estimation

The cost-benefit analysis takes data on emissions, dispersion and abatement costs derived using the GAINS model¹ as its starting point. The analysis presented here quantifies a variety of health impacts associated with exposure to fine particles and ozone, and converts them to their monetary equivalent, for the EU27.

The methods used for this were developed previously following extensive consultation with WHO and other expert groups, Member States, industry and NGOs, and were subject to independent peer review². The benefits and costs of each scenario are compared at EU27 and Member State levels.

Reduced impacts on ecosystems (freshwater and terrestrial, including forests) are also reported in terms of exceedance of critical loads/levels drawing directly on the outputs of GAINS, but without monetisation. It has not been possible to quantify the damages to crops or materials; therefore, the overall benefits numbers are slightly underestimated.

Overall cost and benefits of IPPC implementation

The information given above on monetised benefits of the two implementation scenarios has been compared against the costs estimated by GAINS. Results in Table i) are expressed in terms of net benefits (i.e. the total level of benefit achieved) and the benefit-cost ratio (essentially the effectiveness of each scenario in achieving benefits) in relation to the NEC (national projections) baseline. At this point, no account is taken of uncertainty other than in mortality valuation (which generates the Low-High ranges shown).

¹ <http://www.iiasa.ac.at/rains/index.html>

² In particular, see Holland et al (2005a,b) and Hurley et al 2005

Table i) Comparison of annual costs and benefits for the EU27 under the two IPPC scenarios relative to the NEC baseline (€billion/year) in 2020

	Upper end of BAT AEL range	Lower end of BAT AEL range
EU27 Annual monetised benefits (health only)		
Low estimate	9.4	20.4
High estimate	29.7	65.2
EU27 Annual Total Costs		
Total	2.1	6.5
Net benefits (Monetised Benefits minus Total Costs)		
Low estimate	7.3	13.9
High estimate	27.5	58.7
Benefit to Cost Ratio		
Low estimate	4.4	3.2
High estimate	13.9	10.1

The main finding from this analysis is that the benefits are higher than the costs, even if the more conservative (low) valuation estimate is used. The highest B-C ratios are estimated under the upper end of BAT AEL range case (of between 4.4-13.9). The lower end case has a B-C ratio range of 3.2 to 10.1. Uncertainty analysis has been applied in line with the methods used for appraisal of the costs and benefits of the Thematic Strategy on Air Pollution. This suggests a probability in excess of 98% that benefits are indeed greater than costs.

Acknowledgements

The authors want to thank all their colleagues who have contributed to this analysis, especially other members of the CAFE-CBA team who were involved in the development of the methods used here – in particular Paul Watkiss, Fintan Hurley and Alistair Hunt - and the team at IIASA (International Institute for Applied Systems Analysis) under the leadership of Markus Amann, in particular Janusz Cofala and Chris Heyes.

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1 Introduction

In the context of the current review of the IPPC Directive, the Commission requested an assessment of the costs and benefits of the implementation of the IPPC Directive in 2020. This report describes the costs and benefits associated with two different interpretations of the requirements of the Directive, and compares these to the baseline being used in the NEC revision analysis.

The following two scenarios were considered:

- Implementation of the upper end of BAT associated emission levels (AEL) range i.e. **least stringent**
- Implementation of the lower end of BAT associated emission levels (AEL) range i.e. **most stringent**

To enable the elaboration of the above scenarios, the Commission provided IIASA with the so-called IPPC control strategies based on interpretation of the LCP BREF for the LCP sector, taking into account the modeling constraints of GAINS.

Both scenarios were compared to the 2020 *National* baseline scenario (outlined in NEC Scenario Analysis Report Nr. 3, Amann et al. 2007). This baseline includes current legislation and uses Member State national energy and agricultural projections and includes the impacts and costs of Euro 5/6 implementation.

2 Impact on emissions and control costs

Using the GAINS model, IIASA calculated the impact on emissions and control costs for the two different interpretations of the IPPC Directive implementation on the LCP sector.³

2.1 Impact on emissions

The following figures illustrate the change in emissions for SO₂, NO_x and PM_{2.5} relative to the NEC baseline. For the majority of countries across all three pollutants, a reduction in emissions is observed relative to the baseline. In the *lower end of the BAT AEL range* case, the reductions are of course much more significant. Increases relative to the baseline indicate that the actual abatement controls assumed under the baseline are more stringent than what is being implemented under the two BAT AEL scenarios.

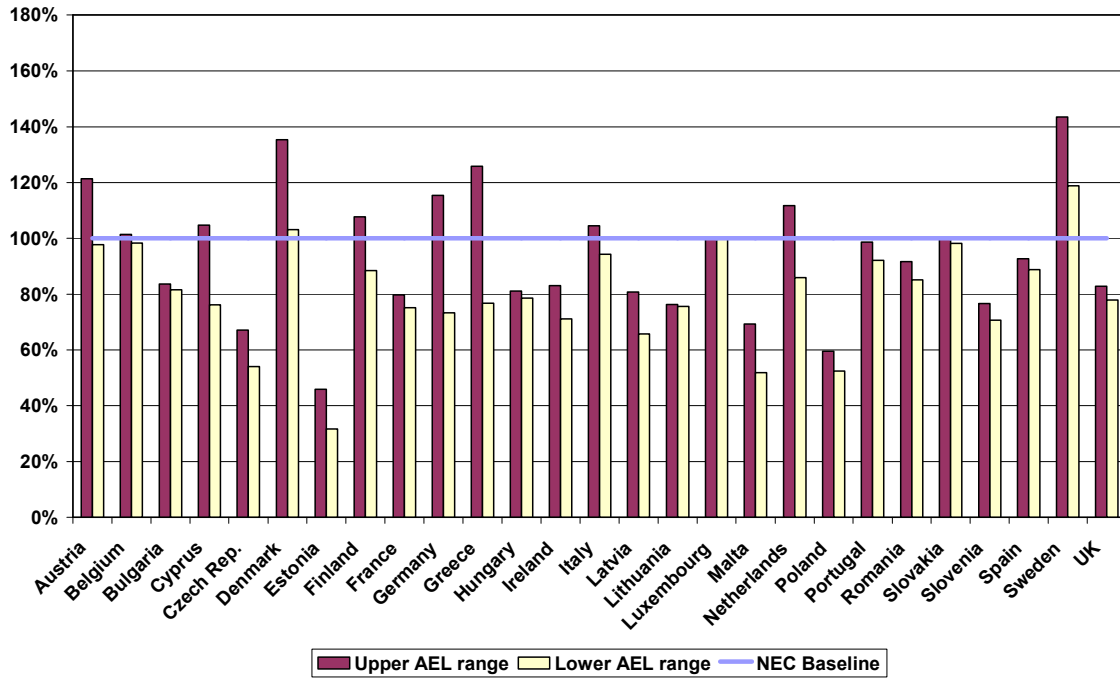
It is important to note that 2020 baselines are based on Member States' own projections; some Member States suggest that baseline controls are more stringent than those implemented in the *upper end of the BAT AEL range* case. In other words, they are already undertaking action that is at least as effective (if not more effective) for the reduction of emissions from large combustion plant. Some careful interpretation of the analysis is required to consider implementation of controls *on the ground* as opposed to the modelled situation.

For SO₂ (as shown in Figure 2.1)

- Emissions increase for both Sweden and Denmark under the *lower end of the BAT AEL range* case, reflecting stringent controls already in place under the baseline.
- For Finland, Germany, Greece, Italy, and Netherlands, the analysis suggests that national controls are between both interpretations of the Directive, with emission increases under the upper end case and reductions under the lower end case.
- Czech Republic, Estonia, Malta and Poland realise the largest relative reductions under both IPPC cases, reflecting that assumed current controls in place are less stringent than the IPPC implementation cases considered here.

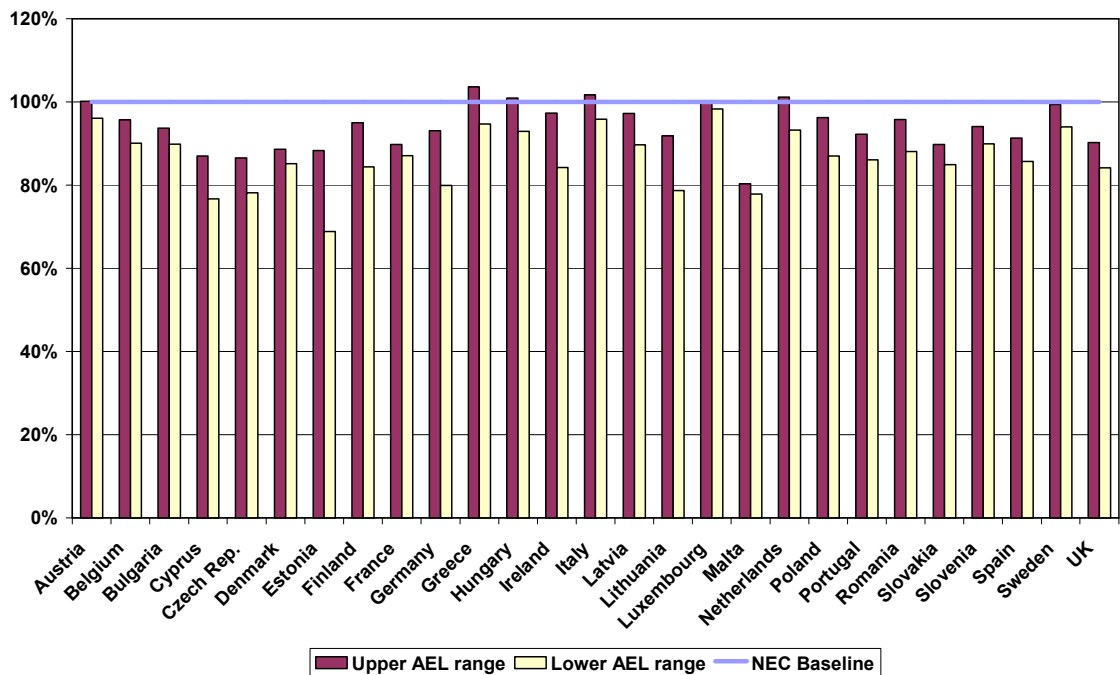
³ Data on costs and emissions supplied by IIASA (J. Cofala) on 30th May 2007

Figure 2.1 Changes in emissions of SO₂ relative to the NEC baseline under both IPPC implementation cases



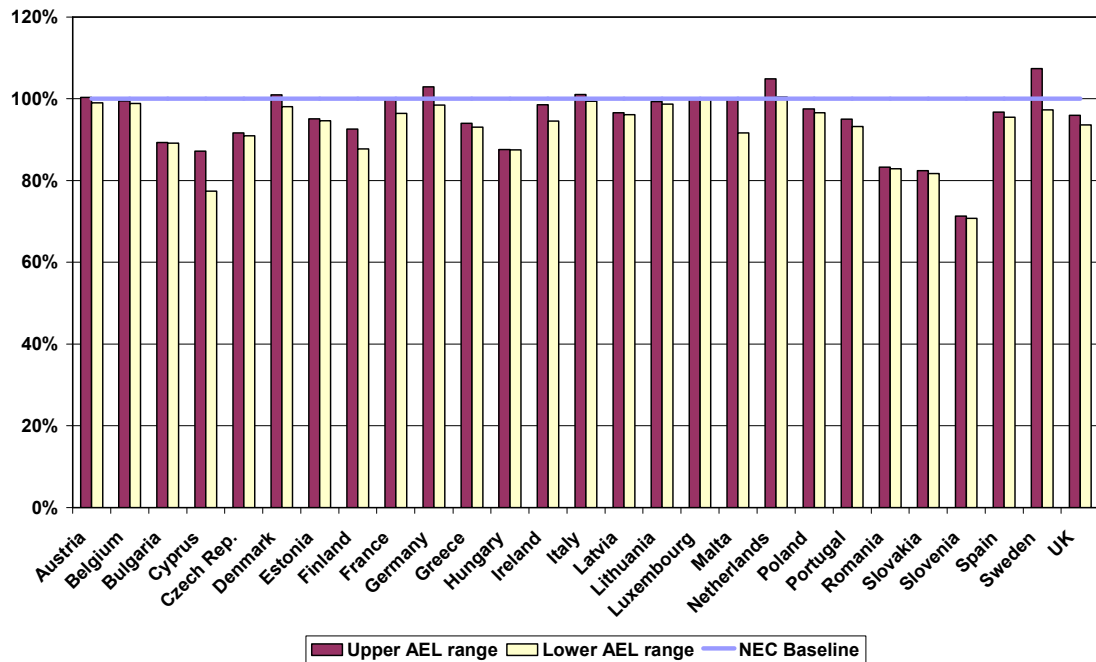
In the case of NO_x, most Member States see reductions under both scenarios. The Netherlands, Italy, Greece and Hungary have small increases in emissions under the upper BAT AEL range case.

Figure 2.2 Changes in emissions of NO_x relative to the NEC baseline under both IPPC implementation cases



For PM_{2.5}, most Member States see reductions under both scenario cases. Sweden, Italy, Denmark, Netherlands and Germany have small increases in emissions under the upper BAT AEL range case.

Figure 2.3 Changes in emissions of PM_{2.5} relative to the NEC baseline under both IPPC implementation cases



2.2 Impact on abatement costs

The analysis undertaken in GAINS has assessed the increase (or in some cases reduction) in abatement costs associated with meeting BAT associated emission levels for LCP plant, either through implementation of AELs at the lower or upper end of the BAT range.

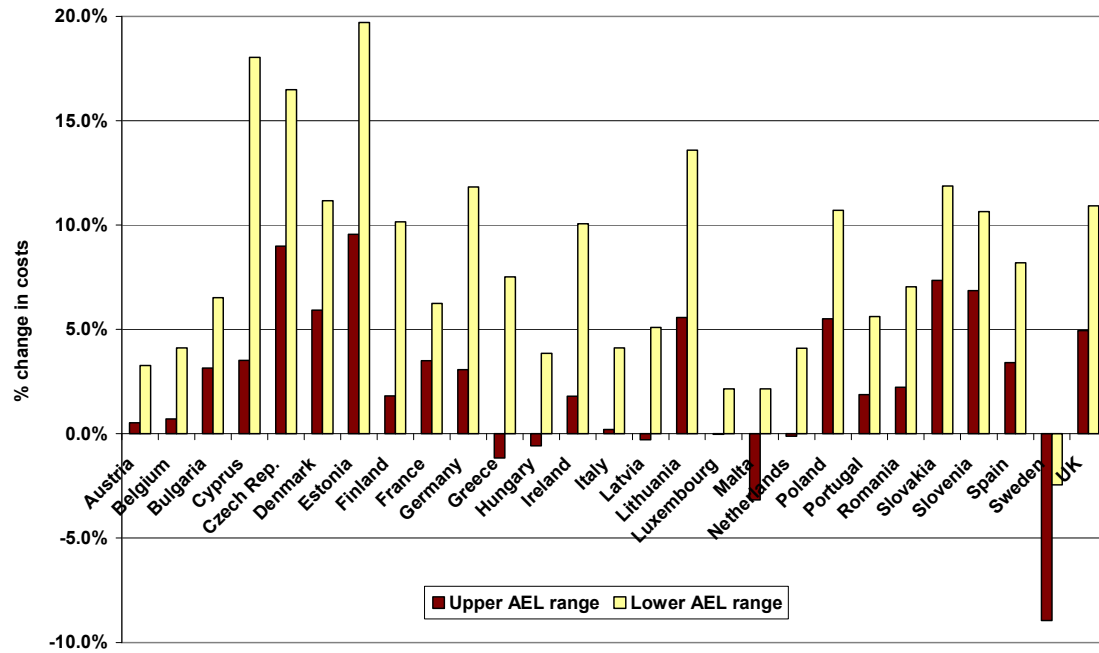
Table 2.1 shows that for all countries under the *lower BAT AEL range* case, except for Sweden, additional costs for abatement controls are incurred. The level of additional costs indicates how much further Member States need to invest in abatement controls to meet the two IPPC interpretations.

Table 2.1 Additional costs (Eur Million/yr) resulting from the implementation of IPPC BAT AELs at the lower and upper end of the range

Member State	NEC baseline costs	Annual increase in overall costs	
		Upper BAT AEL range	Lower BAT AEL range
Austria	1720	9	56
Belgium	2102	15	86
Bulgaria	945	30	62
Cyprus	147	5	27
Czech Rep.	1726	155	285
Denmark	1248	74	139
Estonia	356	34	70
Finland	1036	19	105
France	10939	383	682
Germany	14441	444	1708
Greece	2074	-24	156
Hungary	1109	-6	43
Ireland	841	15	85
Italy	9308	19	382
Latvia	368	-1	19
Lithuania	387	22	53
Luxembourg	247	0	5
Malta	97	-3	2
Netherlands	3430	-4	141
Poland	6309	348	676
Portugal	1500	28	84
Romania	2383	53	168
Slovakia	594	44	70
Slovenia	314	22	33
Spain	7916	270	648
Sweden	1624	-145	-40
UK	6622	327	723
EU27	79,783	2132	6467

Figure 2.4 shows the relative change in costs across the different Member States.

Figure 2.4 % Change in costs relative to the NEC baseline



The costs of abatement can also be split by pollutant; details are presented below for SO₂ (Table 2.2), NO_x (Table 2.3) and PM_{2.5} (Table 2.4). Across the EU27, the highest costs are associated with NO_x abatement; Member States with the highest costs include Spain, UK, France and Germany. For SO₂ abatement, the highest costs are borne by Poland, France and Germany. Costs associated with additional PM_{2.5} abatement are small.

Table 2.2 Additional costs (Eur Million/yr) of SO₂ abatement resulting from implementation of IPPC BAT AELs at the lower and upper end of the range

Member State	NEC baseline costs	Annual increase in overall costs	
		Upper BAT AEL range	Lower BAT AEL range
Austria	447	-4	12
Belgium	592	-3	2
Bulgaria	164	12	22
Cyprus	53	0	17
Czech Rep.	510	69	127
Denmark	240	-14	39
Estonia	88	24	44
Finland	341	-9	25
France	1916	234	355
Germany	3215	191	995
Greece	489	-11	73
Hungary	192	3	8
Ireland	253	7	19
Italy	2238	4	187
Latvia	69	-2	9
Lithuania	63	3	3
Luxembourg	53	0	0
Malta	25	-4	0
Netherlands	690	-27	32
Poland	1236	318	505
Portugal	345	-1	9
Romania	469	9	25
Slovakia	159	8	9
Slovenia	111	9	14
Spain	1778	65	82
Sweden	464	-140	-81
UK	732	35	56
EU27	16931	774	2590

Table 2.3 Additional costs (Eur Million/yr) of NO_x abatement resulting from implementation of IPPC BAT AELs at the lower and upper end of the range

Member State	NEC baseline costs	Annual increase in overall costs	
		Upper BAT AEL range	Lower BAT AEL range
Austria	953	13	42
Belgium	992	20	84
Bulgaria	598	16	37
Cyprus	82	4	7
Czech Rep.	707	83	152
Denmark	420	88	97
Estonia	121	10	25
Finland	467	22	66
France	5936	154	298
Germany	7166	253	686
Greece	1303	-16	77
Hungary	667	-10	33
Ireland	428	8	61
Italy	6236	21	192
Latvia	221	1	9
Lithuania	276	18	48
Luxembourg	183	0	5
Malta	71	1	2
Netherlands	1490	30	111
Poland	4008	26	160
Portugal	1000	27	67
Romania	1247	37	135
Slovakia	319	33	58
Slovenia	145	13	18
Spain	5330	204	543
Sweden	834	8	39
UK	4634	286	648
EU27	45834	1349	3699

Table 2.4 Additional costs (Eur Million/yr) of PM abatement resulting from implementation of IPPC BAT AELs at the lower and upper end of the range

Member State	NEC baseline costs	Annual increase in overall costs	
		Upper BAT AEL range	Lower BAT AEL range
Austria	233	0	2
Belgium	194	-2	0
Bulgaria	177	2	2
Cyprus	6	1	3
Czech Rep.	389	3	6
Denmark	120	0	4
Estonia	148	0	1
Finland	227	5	14
France	1730	-4	29
Germany	1936	0	27
Greece	336	3	6
Hungary	171	1	2
Ireland	66	0	5
Italy	945	-6	2
Latvia	100	0	1
Lithuania	78	0	1
Luxembourg	8	0	0
Malta	3	0	0
Netherlands	315	-6	-2
Poland	1050	3	11
Portugal	157	2	8
Romania	665	7	8
Slovakia	143	3	4
Slovenia	38	0	1
Spain	534	1	23
Sweden	247	-13	3
UK	584	7	19
EU27	10600	9	178

3 Assessment of benefits

3.1 Methodology

This section of the report describes in summary the methodology used for the assessment of benefits, as developed under the CAFE programme and applied in this analysis. The methods used here are also the same as those used to derive marginal damage costs for the BREF on Economics and Cross Media Effects⁴.

The CAFE CBA methodology was described in three volumes (Holland et al, 2005a, b; Hurley et al, 2005) available from <http://cafe-cba.aeat.com/html/reports.htm>. The development of the CAFE CBA methodology can be traced back to the beginning of the EC DG Research ExternE Programme that started in 1991 and continues to the present day. Further to this, the methodology used here was the subject of intense consultation in 2003 and 2004 with stakeholders from the European Union Member States, academic institutes, environment agencies, industry and non-governmental organisations. It was also subject to formal peer review by senior experts in the USA and Europe (the peer review report is available at the above website).

It is important to differentiate the roles of the GAINS and CBA models. The GAINS model identifies a cost-effective set of measures for meeting pre-defined health and environmental quality targets. The CBA model adds to this analysis by assessing the magnitude of benefits and assesses whether overall benefits are higher or lower than the estimated costs; in other words, whether it is worth carrying out the measures identified in the GAINS model.

This approach for quantifying the benefits of reducing air pollution follows a logical progression through the following stages:

1. Quantification of emissions (here, using results from the GAINS model);
2. Description of pollutant dispersion and chemistry across Europe (again, here based on outputs from the GAINS model);
3. Quantification of exposure of people, environment and buildings that are affected by air pollution (linking the pollution concentrations with the 'stock at risk' e.g. population data);
4. Quantification of the impacts of air pollution, using relationships linking pollution concentrations with physical impacts;
5. Valuation of the impacts where possible; and
6. Assessment of the potential importance of uncertainty with regard to the balance of the costs of pollution control quantified by the GAINS model and their associated benefits.

Data sources are shown in Table 3.1.

Table 3.1. Sources of data for the benefits assessment

	Stock at risk	Response functions	Valuation
Health	UN population data, with additional factors for sensitivity of the population from Eurostat	Working group convened by WHO	Surveys undertaken in NewExt and other projects and debate under CAFE.
Materials	EC ExternE Project	ICP Materials working under LRTAP Convention	Repair cost data from architectural sources
Crops	Stockholm Environment Institute	ICP Vegetation working under LRTAP Convention	World market prices from FAO
Ecosystems	Coordinating Center for Effects	Coordinating Center for Effects via GAINS, providing outputs in terms of exceedance areas	None

In this report only health impacts are quantified. These are by far the most significant part of the benefits numbers to the extent that they are monetisable. Other impacts (on crops, buildings) have not been quantified due to a lack of pollutant concentration data.

⁴ http://ec.europa.eu/environment/ipcc/brefs/ecm_bref_0706.pdf

Following the valuation of impacts at stage 5 in the above list, the core estimates of the benefits of the different scenarios considered in the report are compared with the costs. At this stage only limited account is taken of uncertainty, specifically with respect to the use of different options for valuation of chronic effects on mortality as this impact dominates the benefit estimates. Accounting for the views of different stakeholders and the peer review chronic mortality impacts are quantified both in terms of the change in longevity (valued using the value of a life year or 'VOLY' concept) and in terms of deaths brought forward (valued using the value of statistical life or 'VSL' concept). Clearly the results of these two approaches should be seen as alternatives and are not to be added together.

For valuation, the analysis has been able to take advantage of recent research under the EC DG Research NewExt Project. There has been some debate as to whether it is appropriate to take the mean or median values from the NewExt analysis of VSL and VOLY. The most relevant measure of society's willingness to pay (WTP) is the mean, though this can be affected significantly by a few extreme values. In contrast, the median, though less relevant as an indicator of the average societal WTP, is more robust statistically. Being pragmatic, we use both. Altogether this gives four alternatives on valuation as shown in Table 3.2.

Table 3.2. Values for use in CAFE CBA: Effects of chronic exposure on mortality.

	VSL	VOLY	Derived from:
Median (NewExt)	€980,000	€52,000	Median value
Mean (NewExt)	€2,000,000	€120,000	Mean value

The actual difference in mortality damage quantified using VOLY and VSL-based methods is not as great as the above table might suggest. Much of the difference between VSL and VOLY is cancelled out by the difference between the number of premature deaths quantified compared to the number of life years lost, and there is extensive overlap in the ranges. This issue is addressed in greater depth in Volume 3 of the CAFE-CBA Methodology Report⁵. These uncertainties are considered sufficiently important to be addressed throughout, not just in the detailed appraisal of uncertainties towards the end of the report.

For acute mortality from ozone, the analysis quantifies the number of 'premature deaths' (deaths brought forward)⁶. These cases are valued using a VOLY approach, assuming that on average, each premature death leads to the loss of 12 months of life. The range for the VOLY is therefore applied to these impacts.

Following the initial comparison of core estimates of cost and monetised benefit for each scenario the analysis continues with a detailed uncertainty analysis that addresses the question of the probability of benefits exceeding costs for each scenario. This takes account of statistical variation in inputs, sensitivities to model assumptions and unquantified biases in the analysis. The latter includes biases linked to the EMEP model (e.g. omission of secondary organic aerosols, use of a single year's meteorological data) and to the GAINS model (e.g. potential for error in cost estimation) as well as biases in the benefits assessment such as the omission of ecosystem benefits from monetised estimates.

3.2 Results – Health Impacts

The associated health impacts of the base case and the two IPPC scenarios being assessed were estimated based on pollutant concentration values (O₃ and PM_{2.5}) supplied by IIASA from the GAINS analysis undertaken.⁷

The first set of tables shows the totals for each of the 'core' health impacts for the EU27. A number of other impacts were identified in the CAFE Methodology report for application in sensitivity analysis only as it was felt that their quantification was less robust. Those impacts are not listed here.

⁵ http://cafe-cba.aeat.com/files/cba_method_vol3.pdf

⁶ This is to signify that people whose deaths are brought forward by higher air pollution almost certainly have serious pre-existing cardio-respiratory disease and so in at least some of these cases, the actual loss of life is likely to be small – the death might have occurred within the same year and, for some, may only be brought forward by a few days.

⁷ Pollutant concentration data supplied by IIASA (C. Heyes) on 30th May 2007

As detailed in the previous section, the impacts are split into mortality (i.e. loss of longevity or numbers of premature deaths) and morbidity (i.e. illness) by pollutant (PM and ozone). The quantification of health impacts addresses both long-term (chronic) and short-term (acute) exposures. The analysis includes impacts on PM_{2.5} (anthropogenic – excluding PM from natural sources and for secondary organic aerosols) and ozone (using the metric SOMO35 – the sum of the daily maximum 8-hour mean ozone concentration with a cut-off at 35 ppb⁸). These data are provided as outputs from the GAINS model.

The results show the number of events that happen in each year (i.e. the annual number of impacts or new cases⁹), or the change in the number of impacts and cases over time. The chronic mortality impacts from PM_{2.5} shown here are not directly comparable with the figures provided by IIASA. Both methods are based on an underlying analysis using life tables, applying the same hazard rates. However, for the purposes of optimisation GAINS quantifies total impacts over the lifetime of the cohort exposed in 2020, assuming no change in future emissions. In other words, this value represents the impacts on a given population now over its entire lifetime. For the purpose of the CBA it is necessary to quantify the annual equivalent of this figure in order that annual benefits can be compared with annual costs.

In summary, the CBA reports the effects of an 'annualised 1 year pulse' to provide an annualised value for comparing against annualised costs. The GAINS value looks at the total value of life years saved from sustained pollution changes, as a metric for input in the cost-optimisation.

As outlined in the previous section, two alternative approaches are used for chronic mortality, to estimate years of life lost and premature deaths. These two estimates should not be added.

For EU27, health impacts are reduced under both IPPC implementation scenarios relative to the NEC baseline, as shown in Table 3.3. Table 3.4. Under the *Lower BAT AEL range* implementation case, the reduction in impacts is greater.

Specifically, the reductions in pollution have the following impacts on health outcomes (with ranges representing the different assumptions on the implementation of IPPC BAT AELs):

- A reduction in the total impacts from ozone on mortality by around 450-960 avoided deaths brought forward. A broadly similar level of benefits is predicted for respiratory hospital admissions.
- Other morbidity endpoints associated with exposure to ozone affect a much greater number of people, for example through an estimated 460-920 thousand cases of respiratory medication use, and between 0.9-1.96 million minor restricted activity days.
- A reduction in the mortality impacts from PM of between 125,000 and 270,000 years of life saved each year.
- There are also significant reductions estimated for various morbidity effects of PM_{2.5}.

⁸ This means that for days with ozone concentration above 35 ppb as maximum 8-hour mean, only the increment exceeding 35 ppb is used to calculate effects. No effects of ozone on health are calculated on days below 35 ppb as maximum 8-hour mean. It is likely that the overall effects of ozone on mortality are underestimated by this approach.

⁹ For chronic mortality, this involves a different metric to the output from the GAINS model, which works with the change in years of life lost from sustained pollution levels over 80 years, i.e. it works with a total 'stock' concept, rather than an annualised metrics.

Table 3.3. Estimated annual health impacts in 2020 under national NEC baseline, and based on implementation of IPPC BAT AELs at the lower and upper end of the range

End point	Population at risk	Impact	Poll	NEC Baseline	IPPC implementation cases	
				2020 (CLE)*	Upper BAT AEL range	Lower BAT AEL range
Acute Mortality	All	Premature deaths	O ₃	22,081	21,633	21,121
Respiratory Hospital Admissions (RHAs)	Elderly	Cases	O ₃	20,871	20,440	19,958
Minor Restricted Activity Days (MRADs)	Adults	Days	O ₃	45,044,968	44,116,083	43,089,034
Respiratory medication use	Children	Days	O ₃	13,205,718	12,926,702	12,660,582
Respiratory medication use	Adults	Days	O ₃	8,638,098	8,460,038	8,261,669
Cough and LRS	Children	Days	O ₃	68,871,667	67,408,565	65,891,205
Chronic Mortality - YOLL (Years of life lost)	All	Life years lost	PM	2,519,380	2,394,134	2,246,397
Chronic Mortality - deaths	All	Premature deaths	PM	271,702	258,424	242,455
Infant Mortality	Infants	Premature deaths	PM	404	381	359
Chronic Bronchitis	Adults	Cases	PM	127,636	121,205	113,750
Respiratory Hospital Admissions	All	Cases	PM	41,878	39,796	37,341
Cardiac Hospital Admissions	All	Cases	PM	25,828	24,544	23,029
Restricted Activity Days (RADs)	Adults	Days	PM	221,341,114	210,184,886	197,313,898
Respiratory medication use	Children	Days	PM	1,899,240	1,810,808	1,698,567
Respiratory medication use	Adults	Days	PM	20,734,109	19,696,643	18,480,641
LRS symptom days	Children	Days	PM	87,275,776	82,928,996	77,880,432
LRS among adults with chronic symptoms	Adults	Days	PM	205,779,451	195,551,030	183,474,331

Note two alternative metrics are used for the presentation of chronic mortality from PM. Firstly in terms of years of life lost and secondly in terms of numbers of premature deaths. These are not additive.

Table 3.4. Estimated annual health benefits (i.e. the difference from NEC baseline) from implementation of IPPC BAT AELs at the lower and upper end of the range

End point	Population at risk	Impact	Poll	Upper BAT AEL range	Lower BAT AEL range
Acute Mortality	All	Premature deaths	O ₃	448	960
Respiratory Hospital Admissions	Elderly	Cases	O ₃	431	913
Minor Restricted Activity Days (MRADs 15-64yr)	Adults	Days	O ₃	928,885	1,955,934
Respiratory medication use	Children	Days	O ₃	279,016	545,136
Respiratory medication use	Adults	Days	O ₃	178,060	376,429
Cough and LRS	Children	Days	O ₃	1,463,102	2,980,462
Chronic Mortality - YOLL (Years of life lost)	All	Life years lost	PM	125,246	272,983
Chronic Mortality - deaths	All	Premature deaths	PM	13,278	29,247
Infant Mortality	Infants	Premature deaths	PM	23	45
Chronic Bronchitis	Adults	Cases	PM	6,431	13,886
Respiratory Hospital Admissions	All	Cases	PM	2,082	4,537
Cardiac Hospital Admissions	All	Cases	PM	1,284	2,799
Restricted Activity Days (RADs)	Adults	Days	PM	11,156,228	24,027,216
Respiratory medication use	Children	Days	PM	88,432	200,673
Respiratory medication use	Adults	Days	PM	1,037,466	2,253,468
LRS symptom days	Children	Days	PM	4,346,780	9,395,344
LRS among adults with chronic symptoms	Adults	Days	PM	10,228,421	22,305,120

Note two alternative metrics are used for the presentation of chronic mortality from PM. Firstly in terms of years of life lost and secondly in terms of numbers of premature deaths. These are not additive.

3.3 Results – Health Valuation

The health impacts and benefits outlined above have been expressed in monetary terms, using the approach outlined in the CAFE CBA methodology reports. Strictly speaking, the CAFE CBA methodology is only applicable for assessing the changes between scenarios. However, we have estimated the total monetary damage from health impacts as an illustration of their economic importance, as well as the changes in benefits.

As outlined in the earlier methodology section, there are two methods that can be used for the valuation of mortality impacts – the value of statistical life (VSL, applied to the change in number of deaths) and value of life year (VOLY, applied to changes in life expectancy). For the CAFE CBA methodology, the independent external peer reviewers and several stakeholders suggested that both the VSL and the VOLY approaches be used, to show transparently the variation in results arising from use of these two approaches. It was noted above that despite major differences in the unit valuations, there is significant overlap in the ranges of analysis based around use of the VOLY and VSL approaches. For premature deaths from ozone, two alternative values were used drawing on the median and mean VOLY only.

To avoid an excessive number of tables in this report the intermediate valuation positions (where mortality was valued using the mean VOLY and the median VSL) have been omitted, as they fall within the range based on median VOLY to mean VSL. Total damage for each scenario is shown in Table 3.5. Incremental benefits of are shown in Table 3.6.

Table 3.5 Estimated annual monetised health impacts in 2020 due to air pollution in the EU27 for national NEC baseline and IPPC scenarios (EUR Millions).

End point	Population at risk	Impact	Poll	NEC Baseline	IPPC implementation cases	
				2020 (CLE)*	Upper BAT AEL range	Lower BAT AEL range
Acute Mortality (VOLY median)	All	Premature deaths	O ₃	1,155	1,131	1,104
Acute Mortality (VSL mean)	All	Premature deaths	O ₃	2,591	2,539	2,479
Respiratory Hospital Admissions (RHAs)	Elderly	Cases	O ₃	42	41	40
Minor Restricted Activity Days (MRADs)	Adults	Days	O ₃	1,730	1,695	1,655
Respiratory medication use	Children	Days	O ₃	12	12	12
Respiratory medication use	Adults	Days	O ₃	8	8	8
Cough and LRS	Children	Days	O ₃	2,646	2,590	2,531
Chronic Mortality - YOLL (VOLY median)	All	Life years lost	PM	131,725	125,176	117,452
Chronic Mortality - YOLL (VSL mean)	All	Life years lost	PM	295,673	280,974	263,635
Chronic Mortality – deaths (VOLY median)	All	Premature deaths	PM	266,041	253,040	237,404
Chronic Mortality – deaths (VSL mean)	All	Premature deaths	PM	547,358	520,608	488,439
Infant Mortality (VOLY median)	Infants	Premature deaths	PM	568	536	505
Infant Mortality (VSL mean)	Infants	Premature deaths	PM	1,135	1072	1,011
Chronic Bronchitis	Adults	Cases	PM	23,919	22,714	21,317
Respiratory Hospital Admissions	All	Cases	PM	84	80	75
Cardiac Hospital Admissions	All	Cases	PM	52	49	46
Restricted Activity Days (RADs)	Adults	Days	PM	18,460	17,529	16,456
Respiratory medication use	Children	Days	PM	2	2	2
Respiratory medication use	Adults	Days	PM	19	18	17
LRS symptom days	Children	Days	PM	3,353	3,186	2,992
LRS among adults with chronic symptoms	Adults	Days	PM	7,905	7,512	7,049
Low estimate (VOLY median)				191,680	182,280	171,261
High estimate (VSL mean)				609,317	579,655	544,128

Note two alternative metrics are used for the presentation of chronic mortality from PM. Firstly in terms of years of life lost and secondly in terms of numbers of premature deaths. These are not additive.

Table 3.6 Estimated annual monetised health benefits in 2020 due to air pollution in the EU27 for national NEC baseline and IPPC scenarios (EUR Millions).

End point	Population at risk	Impact	Poll	IPPC implementation cases	
				Upper BAT AEL range	Lower BAT AEL range
Acute Mortality (VOLY median)	All	Premature deaths	O ₃	23	50
Acute Mortality (VSL mean)	All	Premature deaths	O ₃	53	113
Respiratory Hospital Admissions (RHAs)	Elderly	Cases	O ₃	1	2
Minor Restricted Activity Days (MRADs)	Adults	Days	O ₃	36	75
Respiratory medication use	Children	Days	O ₃	0	1
Respiratory medication use	Adults	Days	O ₃	0	0
Cough and LRS	Children	Days	O ₃	56	115
Chronic Mortality - YOLL (VOLY median)	All	Life years lost	PM	6,548	14,273
Chronic Mortality - YOLL (VSL mean)	All	Life years lost	PM	14,699	32,037
Chronic Mortality – deaths (VOLY median)	All	Premature deaths	PM	13,002	28,637
Chronic Mortality – deaths (VSL mean)	All	Premature deaths	PM	26,750	58,919
Infant Mortality (VOLY median)	Infants	Premature deaths	PM	31	62
Infant Mortality (VSL mean)	Infants	Premature deaths	PM	63	125
Chronic Bronchitis	Adults	Cases	PM	1,205	2,602
Respiratory Hospital Admissions	All	Cases	PM	4	9
Cardiac Hospital Admissions	All	Cases	PM	3	6
Restricted Activity Days (RADs)	Adults	Days	PM	930	2,004
Respiratory medication use	Children	Days	PM	0	0
Respiratory medication use	Adults	Days	PM	1	2
LRS symptom days	Children	Days	PM	167	361
LRS among adults with chronic symptoms	Adults	Days	PM	393	857
Low estimate (VOLY median)				9,400	20,419
High estimate (VSL mean)				29,662	65,189

Note two alternative metrics are used for the presentation of chronic mortality from PM. Firstly in terms of years of life lost and secondly in terms of numbers of premature deaths. These are not additive.

Total monetised health impacts under the NEC baseline are estimated to be between EUR billions 192 (low estimate) and 609 (high estimate). Under the *upper BAT AEL range* case, the associated benefits (reduction in monetised impacts) are between EUR billions 9 (low estimate) and 30 (high estimate). Under the *lower BAT AEL range* case, the associated benefits (reduction in monetised impacts) are between EUR billions 20 (low estimate) and 65 (high estimate).

Annual monetised benefits by Member State under each scenario case are shown in Table 3.7.

Table 3.7. Annual health benefits by Member State for 2020 in EUR millions of IPPC implementation relative to NEC baseline. Lower estimate with mortality valued using the median VOLY, and higher estimate with mortality valued using the mean VSL.

Member State	Low estimate		High estimate	
	Upper BAT AEL range	Lower BAT AEL range	Upper BAT AEL range	Lower BAT AEL range
Austria	145	362	444	1114
Belgium	273	673	844	2083
Bulgaria	130	202	491	756
Cyprus	2	6	5	13
Czech Republic	416	754	1352	2450
Denmark	69	169	228	562
Estonia	14	24	52	86
Finland	34	73	109	230
France	1187	2307	3422	6670
Germany	1396	5229	4699	17673
Greece	70	213	254	767
Hungary	378	591	1378	2149
Ireland	41	77	103	193
Italy	296	1231	1067	4468
Latvia	30	50	77	129
Lithuania	59	95	274	444
Luxembourg	11	30	26	70
Malta	3	7	8	20
Netherlands	311	1046	917	3093
Poland	1960	2968	6021	9102
Portugal	112	181	373	600
Romania	710	1025	2410	3467
Slovakia	248	380	742	1132
Slovenia	47	90	157	297
Spain	346	589	1104	1879
Sweden	37	130	115	404
United Kingdom	1075	1918	2992	5338
Total (EU27)	9,400	20,419	29,662	65,189

4 Non-Health Impacts

Impacts on crops and materials are not included in this report due to unavailability of the pollutant metrics necessary to estimate them.

Valuation of ecosystem impacts is not yet possible because of limited research in this area that has specific relevance to reductions in air pollutant emissions. This, in turn, reflects the difficulty of carrying out a meaningful analysis of the economics of biodiversity changes. GAINS data provides information on the state of ecosystems with respect to exceedance of critical loads and levels for acidification, eutrophication and ground level ozone. The GAINS analysis addresses risks from:

- Acid deposition to forest ecosystems (area/percentage of forest area receiving acid deposition above the critical loads);
- Acid deposition to semi-natural ecosystems (area/percentage of semi-natural ecosystems receiving acid deposition above the critical loads);
- Acid deposition to freshwater bodies (catchments) (area/percentage of freshwater ecosystems area receiving acid deposition above the critical loads);
- Excess nitrogen deposition (eutrophication) (area/percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication).

GAINS has used the concept of critical loads as a quantitative indicator for sustainable levels of sulphur and nitrogen deposition. The analysis is based on the critical loads databases compiled by the Coordination Centre on Effects under the UNECE Working Group on Effects. For most ecosystem types (e.g., forests), critical loads are calculated for both acidity and eutrophication. Other receptor types, such as streams and lakes, have only critical loads for acidity, on the assumption that airborne nitrogen does not contribute significantly to eutrophication in these ecosystems. The GAINS analysis groups ecosystems into three classes (forests, semi-natural vegetation such as nature protection areas and freshwater bodies) and performs separate analyses for each class. The GAINS analysis has assessed the deposition to these ecosystems with the critical loads and thus provides an indication to what extent the various types of ecosystems are still at risk of acidification under different baseline conditions. This indicator cannot be directly interpreted as the actual damage occurring at such ecosystems. To derive damage estimates, the historic rate of acid deposition as well as dynamic chemical processes in soils and lakes need to be considered, which can lead to substantial delays in the occurrence of acidification as well as in the recovery from acidification.

4.1 Acid deposition to forest ecosystems

The percentage of forest area in each Member State receiving acid deposition above the critical loads in 2020 is shown in Table 4.1.

Table 4.1 Percentage of forest area receiving acid deposition above the critical loads for NEC baseline emissions and IPPC scenarios in 2020

Member State	Area (km ²)	NEC baseline	Upper BAT AEL range	Lower BAT AEL range
Austria	35745	0.0	0.0	0.0
Belgium	6315	26.1	22.8	18.2
Bulgaria	48330	0.0	0.0	0.0
Cyprus	2320	0.0	0.0	0.0
Czech Republic	11178	42.6	35.9	26.8
Denmark	3149	2.3	1.9	1.3
Estonia	21450	0.0	0.0	0.0
Finland	240403	1.1	1.0	0.9
France	170657	6.5	5.8	4.5
Germany	100954	31.8	31.3	22.4
Greece	9326	2.7	2.7	2.2
Hungary	10448	0.0	0.0	0.0
Ireland	4254	15.1	13.1	11.3
Italy	89560	0.0	0.0	0.0
Latvia	27014	0.0	0.0	0.0
Lithuania	17651	53.6	49.8	48.8
Luxembourg	821	20.8	20.8	20.8
Malta				
Netherlands	5640	88.6	88.5	87.6
Poland	88383	25.9	12.1	7.1
Portugal	21220	4.9	4.9	4.9
Romania	62807	0.3	0.2	0.2
Slovakia	19253	10.1	8.7	8.1
Slovenia	5264	0.0	0.0	0.0
Spain	85225	0.1	0.1	0.1
Sweden	225264	9.0	8.2	6.7
United Kingdom	19748	18.2	15.9	14.8
Total (EU27)	1332379	8.8	7.5	5.9

4.2 Acid deposition to semi-natural ecosystems

A number of countries have provided estimates of critical loads for semi-natural ecosystems. This group typically contains nature and landscape protection areas, many of them designated as Natura2000 areas under the EU Habitats Directive. While this group of ecosystems includes open land and forest areas, GAINS uses a conservative estimate grid-average deposition rate for comparison with critical loads, which systematically underestimates deposition for forested land.

Table 4.2 Percentage of semi-natural areas receiving acid deposition above the critical loads for NEC baseline emissions and IPPC scenarios in 2020

Member State	Area (km ²)	NEC baseline	Upper BAT AEL range	Lower BAT AEL range
Belgium	737	25.3	22.0	20.4
Cyprus	1742	0.0	0.0	0.0
France	9444	26.5	26.5	26.2
Germany	3241	8.1	8.1	4.0
Ireland	4681	0.1	0.0	0.0
Italy	36312	0.0	0.0	0.0
Netherlands	1713	57.3	57.2	55.2
United Kingdom	50133	7.7	6.8	6.2
Total (EU27)	108003	7.2	6.8	6.3

4.3 Acid deposition to freshwater bodies

The GAINS analysis has estimated exceedance of critical loads for the catchments of freshwater bodies (lakes and streams) in Finland, Italy, Sweden, and the UK only.

Table 4.3 Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for NEC baseline emissions and IPPC scenarios in 2020

Member State	Area (km ²)	NEC baseline	Upper BAT AEL range	Lower BAT AEL range
Finland	26426	0.1	0.1	0.1
Italy	6	0.0	0.0	0.0
Sweden	294079	7.1	6.7	6.5
United Kingdom	7788	3.2	2.7	2.7
Total (EU27)	328299	6.4	6.1	5.9

4.4 Excess nitrogen deposition (eutrophication)

Excess nitrogen deposition poses a threat to plant communities in a wide range of ecosystems. The GAINS analysis has estimated exceedance of critical loads across Europe. A change in the method of estimation of the eutrophication exceedances now means estimates of critical loads exceedances are higher than in previous analysis e.g. TSAP CBA baseline report. Previously, estimates were calculated on the basis of the grid-average deposition, whereas now the ecosystem-specific deposition is used.

Table 4.4 Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication for the NEC baseline emissions and IPPC scenarios in 2020

Member State	Area (km²)	NEC baseline	Upper BAT AEL range	Lower BAT AEL range
Austria	35745	83.2	80.5	77.0
Belgium	7052	91.6	91.1	90.7
Bulgaria	48330	84.9	82.8	80.0
Cyprus	4062	75.4	75.1	74.6
Czech Republic	11178	97.7	97.4	97.0
Denmark	3149	79.8	79.2	78.6
Estonia	22411	30.5	29.7	26.5
Finland	240403	32.8	31.3	28.2
France	180102	93.6	93.1	90.6
Germany	104195	92.9	92.2	90.9
Greece	9326	100.0	100.0	100.0
Hungary	10448	79.3	77.0	74.6
Ireland	8936	69.0	68.3	67.6
Italy	125878	56.3	56.0	55.0
Latvia	27014	95.2	95.2	95.2
Lithuania	17651	100.0	100.0	100.0
Luxembourg	821	100.0	100.0	100.0
Malta				
Netherlands	4393	87.5	87.3	87.2
Poland	88383	94.6	94.4	93.7
Portugal	21220	92.7	92.5	92.3
Romania	62807	95.5	95.4	95.4
Slovakia	19253	94.4	93.2	91.1
Slovenia	5264	99.7	99.7	99.7
Spain	85225	78.6	76.9	74.9
Sweden	225264	9.5	9.3	8.7
United Kingdom	74204	19.5	18.7	18.2
Total (EU27)	1442714	60.8	60.0	58.4

5 Comparison of Costs and Benefits

The information in the previous section on health benefits has been compared against the annualised costs of the scenarios, as estimated by the GAINS model. No account is taken of non-health benefits in this report. Annual net benefits with costs subtracted for both IPPC scenarios are shown in Table 5.1, with benefit/cost ratios shown in Table 5.2

Table 5.1. Annual net benefits (EUR millions) of IPPC implementation relative to the NEC baseline. Lower estimate with mortality valued using the median VOLY, and higher estimate with mortality valued using the mean VSL.

Member State	Low estimate		High estimate	
	Upper BAT AEL range	Lower BAT AEL range	Upper BAT AEL range	Lower BAT AEL range
Austria	136	306	435	1058
Belgium	258	587	829	1997
Bulgaria	101	140	461	695
Cyprus	-3	-21	-1	-13
Czech Republic	260	470	1197	2165
Denmark	-5	29	154	422
Estonia	-20	-46	18	16
Finland	16	-32	90	125
France	804	1625	3039	5988
Germany	952	3522	4255	15966
Greece	94	57	278	611
Hungary	384	548	1384	2106
Ireland	26	-8	87	109
Italy	276	849	1047	4086
Latvia	31	31	78	110
Lithuania	37	43	252	392
Luxembourg	11	24	26	64
Malta	6	5	11	18
Netherlands	314	905	921	2952
Poland	1612	2292	5673	8426
Portugal	84	97	345	516
Romania	657	857	2356	3299
Slovakia	205	309	699	1061
Slovenia	26	57	135	264
Spain	76	-60	834	1231
Sweden	183	170	261	444
United Kingdom	748	1195	2665	4615
Total (EU27)	7268	13951	27531	58722

Overall, the benefits are considerably higher than the costs for both IPPC implementation cases under both the low and high valuation estimates. Under the low estimate, the net benefits are between EUR billions 7-14 depending on the implementation case; under the high estimate, they are between EUR billions 28-59.

For a limited number of Member States, costs are higher than benefits where the low valuation estimate is used; these values (net costs) are shaded yellow. Using the high estimate, only Cyprus incurs net costs under the *Lower BAT AEL range* case.

Table 5.2. Benefit-cost (B-C) ratios for IPPC implementation relative to the NEC baseline. Lower estimate with mortality valued using the median VOLY, and higher estimate with mortality valued using the mean VSL.

Member State	Low estimate		High estimate	
	Upper BAT AEL range	Lower BAT AEL range	Upper BAT AEL range	Lower BAT AEL range
Austria	16.3	6.4	50.0	19.8
Belgium	18.4	7.8	56.9	24.1
Bulgaria	4.4	3.3	16.5	12.3
Cyprus	0.4	0.2	0.9	0.5
Czech Republic	2.7	2.7	8.7	8.6
Denmark	0.9	1.2	3.1	4.0
Estonia	0.4	0.3	1.5	1.2
Finland	1.8	0.7	5.8	2.2
France	3.1	3.4	8.9	9.8
Germany	3.1	3.1	10.6	10.4
Greece		1.4		4.9
Hungary		13.8		50.3
Ireland	2.7	0.9	6.8	2.3
Italy	15.2	3.2	54.8	11.7
Latvia		2.7		6.9
Lithuania	2.7	1.8	12.7	8.5
Luxembourg		5.6		13.1
Malta		3.4		9.8
Netherlands		7.4		22.0
Poland	5.6	4.4	17.3	13.5
Portugal	4.0	2.2	13.3	7.1
Romania	13.4	6.1	45.4	20.6
Slovakia	5.7	5.4	17.0	16.1
Slovenia	2.2	2.7	7.3	8.9
Spain	1.3	0.9	4.1	2.9
Sweden				
United Kingdom	3.3	2.7	9.1	7.4
Total (EU27)	4.4	3.2	13.9	10.1

* Yellow shaded cells indicate that costs are higher than benefits.

** Blue shaded cells indicate that B-C ratios have not been presented, as these Member States incur negative abatement costs i.e. they have abatement control beyond what is required under the IPPC cases.

Overall B-C ratios for EU27 are between 3.2 and 4.4 using the low valuation estimate and between 10.1 and 13.9 using the high valuation estimate. B-C ratios are higher for the *Upper BAT AEL range* case. Significant variation occurs between Member States.

The summary table (Table 5.3) below shows the net monetised benefits (only taking account of the core health impacts) of the scenarios (benefits minus costs), and the benefit to cost ratio (benefits divided by costs) for the EU27. The former shows the level of quantifiable benefits achieved; the latter shows the effectiveness of the policies, where the larger the ratio, the more economically efficient the policy is.

Table 5.3. Comparison of Costs and Benefits in EUR billions /year in 2020 for EU27– changes relative to the NEC baseline

	Upper BAT AEL range	Lower BAT AEL range
EU27 Annual monetised benefits (health only)		
Low estimate	9.4	20.4
High estimate	29.7	65.2
EU27 Annual Total Costs		
Total	2.1	6.5
Net benefits (Monetised Benefits minus Total Costs)		
Low estimate	7.3	13.9
High estimate	27.5	58.7
Benefit to Cost Ratio		
Low estimate	4.4	3.2
High estimate	13.9	10.1

The main finding from this analysis is that the benefits are higher than the costs, even if the more conservative (low) valuation estimate is used. The highest B-C ratios are estimated under the *upper BAT AEL range case* of the IPPC Directive scenario (of between 4.4 and 13.9). The lower end case has a B-C ratio range of 3.2 to 10.1.

6 Uncertainty analysis

Uncertainties are present in both the costs and benefits of emission control. Methods for quantification of the uncertainty in benefits were described in Volume 3 of the CAFE-CBA methodology report (Holland et al, 2005b). These methods were further refined for assessments leading up to and including analysis of the Thematic Strategy on Air Pollution (Holland et al, 2005c). Uncertainty is described in terms of probability distributions for inputs to the health analysis covering the incidence rate of any given health effect, response functions and valuations. Monte Carlo analysis is then run over 10,000 iterations to determine the likely spread in final results. This has been done here for net benefits (Figure 6.1) and the benefit-cost ratio (Figure 6.2), in both cases based only on the most conservative benefits estimates (taking median VOLY for mortality valuation). Results are presented for the upper and lower end BAT AEL scenarios, and for the increment between them (as a proxy for a marginal analysis).

The figures show that the probability of net benefits being greater than 0 is more than 99% for all three cases (and similarly of course also the probability that the benefit:cost ratio exceeds 1). The cases where benefits are calculated using larger valuations for mortality are not shown here but of course would demonstrate an even higher probability of benefits exceeding cost.

Some uncertainties on benefits are not addressed here. The most important are likely to be:

- The omission of impacts to crops, ecosystems and buildings.
- The assumption that all types of particle are equally harmful (this analysis follows WHO advice not to differentiate between types of particle on the grounds that there is no empirical basis on which to make adjustments).

Uncertainty is of course not confined to the quantification of health impacts, but is present also in the dispersion modelling and quantification of costs. Of the two it seems likely that the cost assessment is prone to greater uncertainty, drawing on evidence collected in past comparisons of ex-ante and ex-post cost estimates. For scenarios considered in the development of the Thematic Strategy on Air Pollution a range of -50% to +20% of the RAINS estimates of costs was assessed, the downward bias introduced in line with the finding that costs are often overestimated. Given the very low probability calculated above that costs would exceed benefits (<1% in all cases considered) the assumption that costs should be lower would have no effect on conclusions. The assumption that costs should be 20% higher has been tested and also makes very little difference – the biggest change being seen in the probability that there is a net benefit in moving from the *lower BAT AELs* to the *upper*, which falls from >99% to 98%,

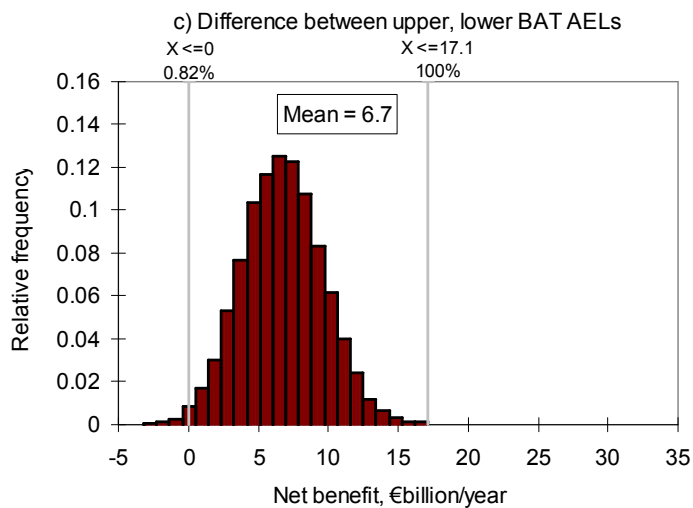
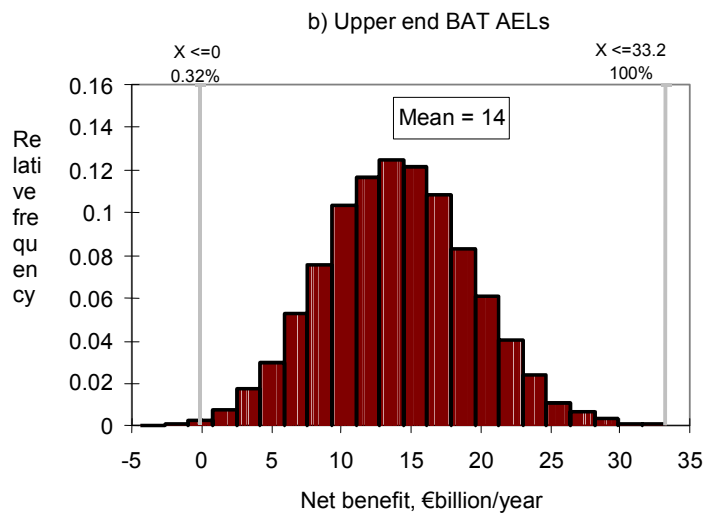
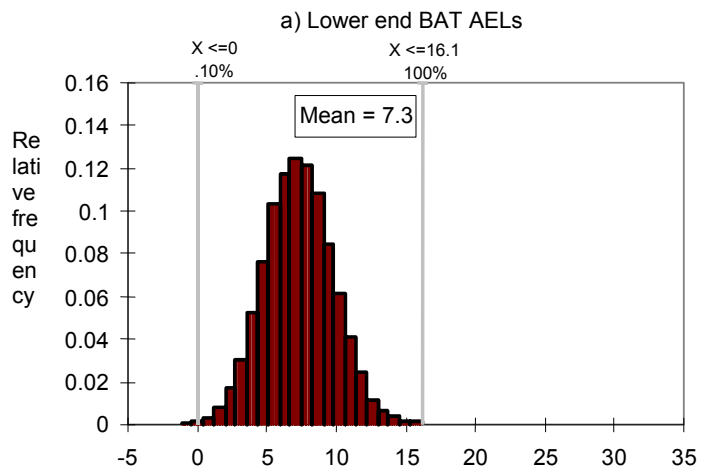


Figure 6.1. Probability distributions showing net benefits for each scenario as means, maximum values and the probability that net benefits > 0.

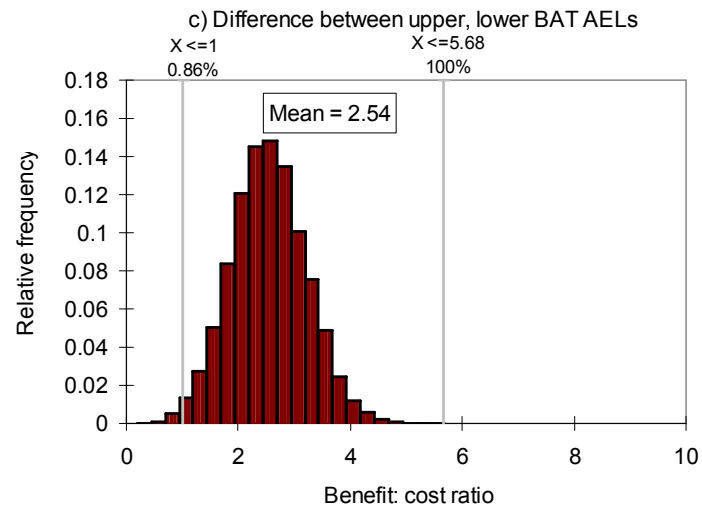
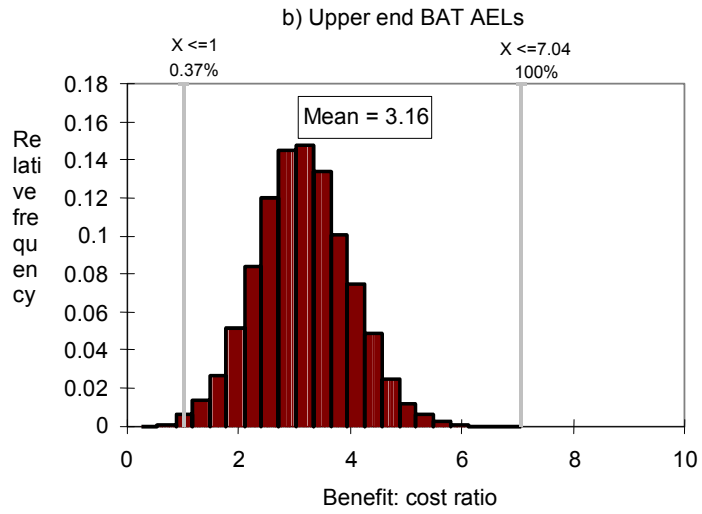
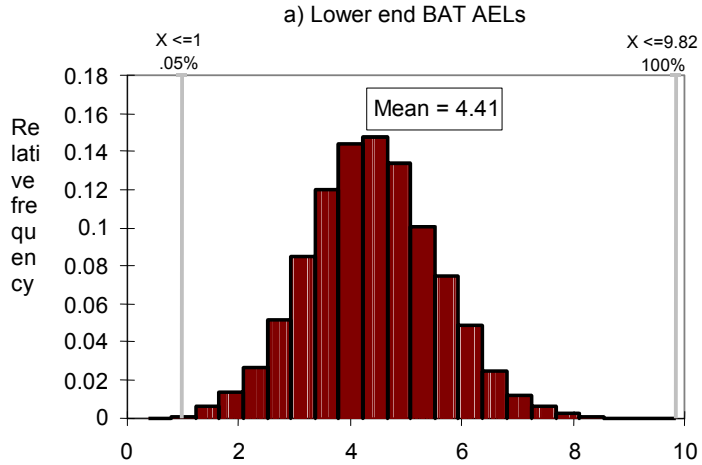


Figure 6.2. Probability distributions for benefit-cost ratios, showing the probability of B/C > 1 and maximum values

7 Conclusions

This report has estimated the benefits (relative to the NEC baseline using Member State projections) of two different scenarios examining different implementation of the IPPC Directive. The estimates of benefits were based only on health impacts; it needs to be recognised that other benefits arise in addition to these monetised benefits e.g. reduction in harmful effects on ecosystems.

These estimates were then compared to abatement costs calculated by IIASA using GAINS, to provide benefit-cost ratios. The main finding from this analysis is that the benefits are higher than the costs, even if the more conservative (low) valuation estimate is used. The highest B-C ratios are estimated under the *upper BAT AEL range* case (of between 4.4 and 13.9). The *lower end case* has a B-C ratio range of 3.2 to 10.1.

There is some variation across Member States concerning relative benefits and costs. Under the low valuation estimate, some Member States realise higher abatement costs than monetised benefits. However, under the high valuation estimate, this applies only to Cyprus.

Uncertainty analysis using ranges, etc. defined during the development of the CBA work for the Thematic Strategy appraisal suggests that there is a very high probability that benefits will exceed costs, adding weight to the conclusions reported above.

8 References

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