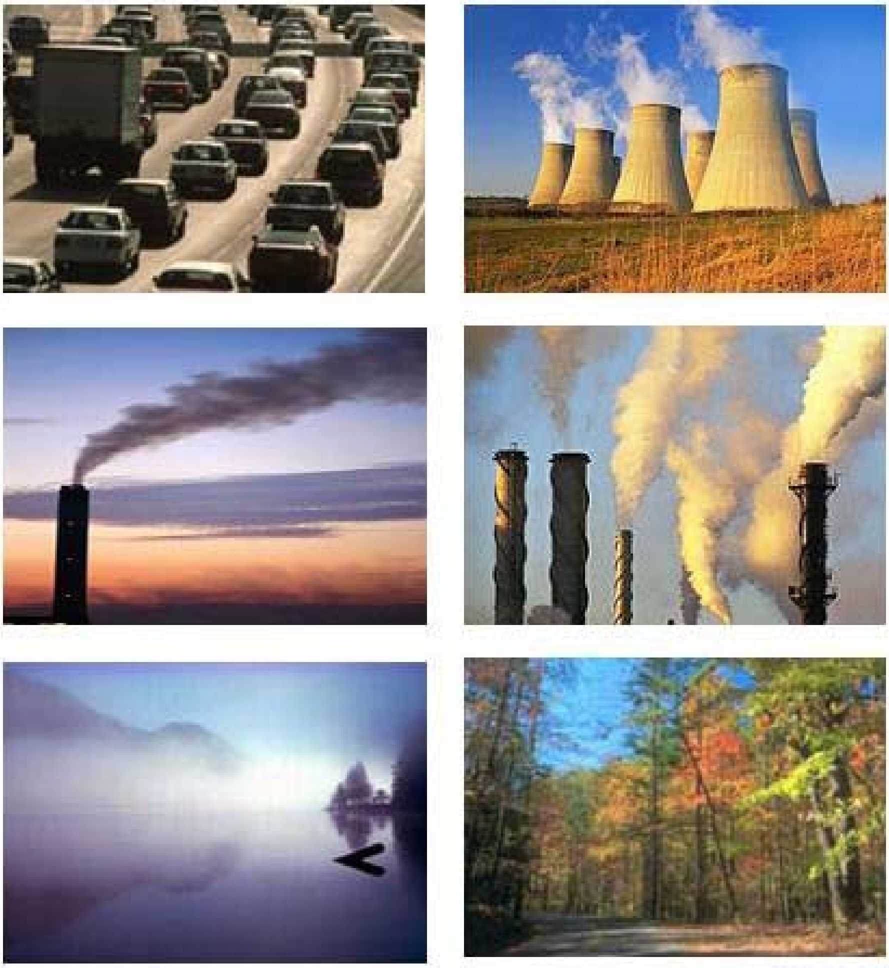
Cost-Benefit Analysis of the Thematic Strategy on Air Pollution



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

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Executive Summary

In May 2001, the European Commission launched the Clean Air for Europe (CAFE) Programme – a knowledge based approach with technical/scientific analyses and policy development that will lead to the adoption of a Thematic Strategy on Air Pollution, fulfilling the requirements of the Sixth Environmental Action Programme. Its aim is to provide long-term, strategic and integrated policy advice for '*achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment';* including '*no exceedance of critical loads and levels for acidification or eutrophication'*.

This report presents the cost-benefit analysis of the Thematic Strategy which was adopted by the European Commission on 21 September 2005. The strategy defines emissions against a series of ambition levels for reducing the impacts of ozone and fine particles on health, and acidification and eutrophication on ecosystems as show in Table i):

Table i) Numerical values of the effect indicators for current legislation, the Thematic Strategy and Maximum Technically Feasible Reduction scenarios in 2020

	Current legislation in 2020	***the Strategy***	***Maximum Technically Feasible Reduction***
Years of life lost due to PM2.5 (EU-wide, million YOLLs)	137 (0%)	106.5 (75%)	96 (100%)
Acidification (country-wise gap closure on cumulative excess deposition)	0%	55%	100%
Eutrophication (country-wise gap closure on cumulative excess deposition)	0%	55%	100%
Ozone (country-wise gap closure on SOMO35)	0%	60%	100%

The % 'gap closure' here relates to the gap between the situation in 2020 if Current Legislation (CLE) was fully implemented and the Maximum Technically Feasible Reduction (MTFR) scenario of the RAINS model. CLE is also referred to as the "CAFE baseline". Damage, even under the MTFR scenario, is projected to be substantial, as can be seen in the years of life years lost due to $PM_{2.5}$.

The cost-benefit analysis (CBA) presented in this report takes as its starting point pollution data generated by the EMEP and RAINS models for the current legislation, the Strategy and MTFR scenarios. Benefits are assessed using the CAFE CBA methodology, developed following extensive consultation with CAFE stakeholders, including WHO and other European expert groups and independent peer review.

Benefits are assessed for the following receptors:

- Health (mortality and morbidity), impacts and monetary equivalent;
- Materials (buildings), impacts and monetised damages;
- Crops, impacts and monetised damages;
- Ecosystems (freshwater and terrestrial, including forests), impacts in terms of critical loads and levels exceedance, but without monetisation.

Health benefits across the EU

Core estimates of health impacts from exposure to ozone and fine particles are shown in Table ii). These results link ozone exposure to 21,000 deaths in the EU25 in 2020, with a reduction to around 19,000 cases per year with the Strategy. For particles, the numbers are larger, with 2.5 million life years lost in 2020 under current legislation, falling to around 1.9 million under the Strategy. The table also shows that air pollution is likely to cause many thousands of hospital admissions each year and many millions of days of ill health across the EU25.

Table ii) Estimated annual health impacts due to air pollution in the EU25 under current legislation, the Strategy and the MTFR in 2020(thousands)

End Point Name	Current legislation in 2020	the Strategy	MTFR
Ozone effects			
Acute Mortality (thousand premature deaths)[1]	21	19	18
Respiratory Hospital Admissions (thousands)	20	19	17
Minor Restricted Activity Days (thousands)	42,000	39,000	36,000
Respiratory medication use (thousand days, children)	13,000	12,000	11,000
Respiratory medication use (thousand days, adults)	8,200	7,500	7,000
Cough and LRS (thousand days children)	65,000	60,000	56,000
PM effects			
Chronic Mortality[2] – thousand years of life lost (YOLLs)	2,500	1,900	1,700
Chronic Mortality[2] – thousand deaths	270	210	190
Infant Mortality (0-1yr) – thousand deaths	0.35	0.27	0.25
Chronic Bronchitis (thousand cases, adults)	128	99	90
Respiratory Hospital Admissions (thousands)	42	33	30
Cardiac Hospital Admissions (thousands)	26	20	18
Restricted Activity Days (thousands)	220,000	170,000	160,000
Respiratory medication use (thousand days, children)	2,000	1,500	1,400
Respiratory medication use (thousand days, adults)	21,000	16,000	15,000
Lower Respiratory Symptom days (thousands, children)	89,000	69,000	62,000
Lower Respiratory Symptom days (thousands, adults)	210,000	161,000	150,000

1) The estimates of acute mortality due to ozone are in this analysis somewhat different from those reported by the RAINS model. This is due to the fact that in the analysis carried out for 2020, we use the age distribution of the population as of 2020. However, the age distribution used in RAINS was based on 2000 data. Thus, the effects of ozone on mortality are more up-to-date in this report. However, the difference of the CBA and RAINS analysis between CLE and the Strategy is small.

2) For chronic mortality (PM), two alternative values are presented, based on quantification using years of life lost and numbers of premature deaths). The two measures are not additive.

These health effects have been converted to a monetary equivalent. Table iii) shows that the total annual health benefits of the Strategy range from €42 to €135 billion for the EU25. The range here arises from the use of alternative methods for mortality valuation.

Table iii) Core estimates of annual health damage and benefits due to air pollution in EU25, with the Thematic Strategy Scenario, and under a MTFR scenario in 2020

	Billion Euro/year		
Total Damage	**Current legislation in 2020**	**the Strategy**	**MTFR**
Low estimate	189	147	133
High estimate	609	474	427
Benefit over CLE baseline		**the Strategy**	**MTFR**
Low estimate		42	56
High estimate		135	181

Non-health impacts
Damage to crops from ozone exposure and to materials from acidic deposition in the year 2020 is estimated here to cause around €2.2 billion of damage a year under the CAFE baseline. The Strategy is estimated to provide annual benefits of €0.3 billion as reduced crop damage thus benefiting the agriculture sector. In addition, the annual benefits of reduced damage to buildings of the Strategy are estimated to be about €0.2 billion. In total, monetised non-health benefits have been estimated to be €0.5 billion every year due to the Strategy.

These figures specifically exclude damage to ecosystems as there is currently no adequate basis to perform monetisation of ecological damage of the types of concern here, and at the European scale. However, information on critical loads exceedance has been generated by the RAINS model (Table iv).

Table iv) Summary statistics on critical loads and levels, showing % area over which there is exceedance across the EU25

		2000	Current legislation in 2020	**the Strategy**	**MTFR**
Eutrophication	Ecosystems	57%	46%	33%	15%
Acidification	Forests	21%	10%	6%	3%
Ozone	Forests	61%	56%	52%	28%

The table demonstrates widespread exceedance of the critical load for eutrophication and the critical level for ozone remaining in 2020. Acidification has been brought under better control, though there are still a significant number of ecosystems at risk. By summarising across the EU25, Table iv) does not pick up some important distributional issues, specifically, that critical levels exceedance for ozone is sharply divided, with little or no exceedance in Northern EU Member States (Estonia, Finland, Latvia, Lithuania and Sweden) but extensive exceedance in all others.

Comparison of costs and benefits
The information given above on monetised benefits of the different policy scenarios has been compared against the costs estimated by the RAINS model. Results in Table v) 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 CLE baseline scenario. At this point, no account is taken of uncertainty other than in mortality valuation (which generates the Low-High ranges shown).

Table v) Comparison of annual costs and benefits for the EU25 under the different scenarios relative to the CLE baseline (€billion/year) in 2020.No account is taken of damage to ecosystems, some health impacts, and cultural heritage.

	the Strategy	MTFR
EU Annual monetised benefits (health, materials and crops)		
Low estimate	42	57
High estimate	136	182
EU-25 Annual Total Costs – change over base line		
Total	7.1	39.7
NET benefits (Monetised Benefits minus Total Costs)		
Low estimate	35	17
High estimate	129	143
Benefit to Cost Ratio		
Low estimate	5.9	1.4
High estimate	19.0	4.6

It is stressed that the analysis above does not include all benefits – notably it excludes benefits to ecosystems, some health impacts, for instance those of secondary organic aerosols (SOAs) and impacts on cultural heritage. It is evident from the scoping analysis carried out as part of the CBA that these impacts are likely to add significant benefits to those already quantified. The scoping study suggested annual benefits between €1.7 to 5.7 billion as a result of the Strategy. The importance of the un-monetised benefits is also evident from estimates of the extent of exceedance of critical levels for ozone and critical loads for acidification and eutrophication shown in Table iv).

Uncertainty analysis

Results of the cost-benefit comparison have been subject to an extensive uncertainty analysis. This has considered the following factors in particular, selected on the basis of our own experience and comments made by other experts:

- Statistical uncertainty in health inputs for incidence rates, response functions and valuation data;
- Sensitivity to the use of alternative approaches to mortality assessment;
- Sensitivity to a reduced risk factor for the dominant impact, mortality from chronic exposure to particles;
- Review of unquantified aspects of the analysis that will bias the results up or down.

Results of the uncertainty analysis demonstrate a robust case for moving from the baseline to the Strategy with a very high probability of benefits exceeding costs (for all plausible sets of assumptions considered in the analysis >99%).

Macroeconomic analysis using GEM-E3

No specific macroeconomic analysis was carried for the Strategy. However, based on macroeconomic analysis on Scenarios A, B and C in the earlier stages using GEM-E3 model (General Equilibrium Model – Energy, Economy, Environment), it was demonstrated that:

- The macroeconomic cost in terms of reduced gross domestic product is about 0.05% in 2020 per annum.
- These costs are very small compared to the health benefits and ecosystem improvements.

- Net effect on employment was zero, implying that some sectors would gain and some lose in terms of employment.
- The benefits of reduced air pollution return mainly to the EU citizens.
- The effect on the competitiveness of the sectors is small because the price effect is limited and all EU member states participate in the abatement effort.

Overall conclusions

This report summarises the benefits of the Strategy for air quality in Europe in 2020. It shows that large benefits are predicted to occur from these scenarios, with monetised annual health, crops and materials benefits in the range between €42 billion and €136 billion for the year 2020, depending on what values are used for reduced mortality due to particulate matter.

The health benefits alone of the Strategy exceed costs, by between six and 19 times.

The annual health benefits for every EU citizen from the Strategy are estimated at €94 to €301 in 2020. This compares to the average annual costs per citizen of €15 in 2020.

The above conclusion excludes benefits from effects excluded from the monetary framework – notably benefits to ecosystems, to health via reduced exposure to secondary organic aerosols, and to cultural heritage. Including these effects would increase the monetised benefits of reduced air pollution.

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Contents

Introduction

Background to this report

In May 2001, the European Commission launched the Clean Air for Europe (CAFE) Programme – a knowledge based approach with technical/scientific analyses and policy analysis designed to lead to the adoption of a Thematic Strategy on Air Pollution, fulfilling the requirements of the Sixth Environmental Action Programme. Its aim is to develop a long-term, strategic and integrated policy advice for '*achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment';* including '*no exceedance of critical loads and levels for acidification or eutrophication'*.

Using results from the CAFE analysis, the European Commission adopted the Thematic Strategy on Air Pollution on 21 September 2005[1], outlining the environmental objectives for future European air quality policy and measures to be taken to achieve these objectives. This report provides the comparison of costs and benefits for the Thematic Strategy scenarios for reducing damage to health from exposure to ozone and fine particles ($PM_{2.5}$) and to ecosystems from acidification and eutrophication.

Scenarios investigated

The starting point for the analysis is a scenario that forecasts emissions in the year 2020 under current legislation (CLE), summarised in Table 1, assuming that countries fulfil their Kyoto obligations and carry on implementing greenhouse gas reduction policies through to 2020.

Table 1. Legislation considered in the Current Legislation (CLE) scenario (source: IIASA/EMEP, 2004).

for SO_2 emissions	for NO_X emissions	for VOC emissions	for NH_3 emissions
Large combustion plant directive	Large combustion plant directive	Stage I directive	No EU-wide legislation
Directive on the sulphur content in liquid fuels	Auto/Oil EURO standards	Directive 91/441 (carbon canisters)	National legislation
Directives on quality of petrol and diesel fuels	Emission standards for motorcycles and mopeds	Auto/Oil EURO standards	Current practice
IPPC legislation on process sources	Legislation on non-road mobile machinery	Fuel directive (RVP of fuels)	
National legislation and national practices (if stricter)	Implementation failure of EURO-II and Euro-III for heavy duty vehicles	Solvents directive	
	IPPC legislation for industrial processes	Directive on reducing VOCs from products (e.g. paints)	
	National legislation and national practices (if stricter)	National legislation, e.g., Stage II	

Source: IIASA/EMEP (2004)

[1] Thematic Strategy on Air Pollution (COM(2005) 446). Directive on Ambient Air Quality and Cleaner Air for Europe (the "CAFE" Directive) (COM(2005) 447) adopted by the European Commission on 21 September 2005, available at e.g. http://europa.eu.int/comm/environment/air/cafe/index.htm

Earlier analysis in CAFE quantified the impacts and associated damage that would occur under the baseline scenario and a series of illustrative scenarios where emissions were varied between current legislation and the maximum technically feasible reduction (MTFR) according to the RAINS model[2]. This allowed identification of different ambition levels for reducing impacts of ozone and fine particles on health and acidification and eutrophication on ecosystems. These were then combined to construct three main scenarios, labelled A, B and C. The analysis of these options is included in a previous CAFE-CBA report (AEA Technology, 2005) and are summarised below, along with the indicators for the scenario adopted by the European Commission on 21 September 2005m called "the Strategy"..

Table 2. Selected numerical values of the effect indicators for the CAFE scenarios

	Current Legislation in 2020 (CLE)	***Scenario A***	***the Strategy***	***Scenario B***	***Scenario C***	***Maximum Technically Feasible Reduction (MTFR)***
Years of life lost due to $PM_{2.5}$ (EU-wide, million YOLLs)	137	110	106.5 (75%)	104	101	96
Acidification (country-wise gap closure on cumulative excess deposition)	0%	55%	55%	75%	85%	100%
Eutrophication (country-wise gap closure on cumulative excess deposition)	0%	55%	55%	75%	85%	100%
Ozone (country-wise gap closure on SOMO35)	0%	60%	60%	80%	90%	100%

The term 'gap closure' here relates to the gap between the Current Legislation (CLE) and the Maximum Technically Feasible Reduction (MTFR) scenarios. It is forecast that substantial damage will remain even under the MTFR scenario, as shown by the years of life lost to fine particle exposure.

Methods

The CAFE CBA methodology used here was described in three volumes (Holland et al, 2005a, b; Hurley et al, 2005) available from http://www.cafe-cba.org and described in a synthesized form in AEA Technology (2005). This latter report also includes a more developed account of the methods used for uncertainty assessment in the CBA, highlighting those factors, such as sensitivity to the function used to quantify chronic mortality impacts of fine particles, that make most difference to the analysis.

The GEM-E3 model has not been used specifically in analysis of the Strategy scenario, as it was possible to interpolate between Scenarios A and B described by AEA Technology (2005).

[2] Note that the MTFR scenario does not provide a true maximum reduction in emissions as the RAINS model is unable to include all possible abatement measures, and does not factor in some potential improvement for efficiency in the measures that are included.

Summary Results – Health Impacts

The first set of tables shows the totals for each of the ‘core’ set of health impacts for the EU25. The analysis presents estimated total health impacts across the EU25 for the year 2020 for the CAFE baseline. All are based on 1997 meteorological data. The analysis has also presented the total health impacts for the Strategy and the MTFR in 2020.

The impacts are split into mortality (i.e. premature deaths) and morbidity (i.e. illness) by pollutant (PM and ozone). The quantification of health impacts addresses the impacts related to both long-term (chronic) and short-term (acute) exposures. The analysis includes impacts of anthropogenic emissions giving rise to $PM_{2.5}$ (excluding PM from natural sources and secondary organic aerosols). Ozone health effects are assessed against the SOMO35 metric – the sum of the daily maximum 8-hour mean ozone concentration with a cut-off at 35 ppb[3].

The results show the number of events that take place in each year (i.e. the annual number of impacts or new cases[4]), or the change in the number of impacts and cases over time.

Two alternative approaches are used for chronic mortality, to derive years of life lost and premature deaths. These two estimates should not be added.

Health impact assessment - results

The results are shown in Table 4. This presents the total numbers of impacts with baseline pollution concentrations in 2020. It also shows the total number of impacts under the Strategy Scenario and the MTFR scenario. Table 5 shows the change in impacts, i.e. the benefits of the Strategy and the MTFR over the 2020 baseline.

Here, the analysis has used the RAINS model for PM concentration data, and the EMEP model for other pollutants (including effects on ecosystems), based on the latest model runs. This modelling is consistent with other information presented on the scenario analysis under the CAFE programme.

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[3] 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.

[4] For chronic mortality, this involves a different metric to the output from the RAINS 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 metric.

Table 3. Analysis of the Strategy: Estimated annual health impacts due to air pollution in 2020 in the EU25, plus the total impacts under the Strategy and the MTFR (2020)

End Point Name	CORE Functions		Current Legislation in 2020	the Strategy	MTFR
Acute Mortality *	Premature deaths	O_3	20,800	19,200	17,759
Respiratory Hospital Admissions (65yr +)	Cases	O_3	20,100	18,500	17,160
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O_3	42,415,500	39,191,000	36,484,733
Respiratory medication use (children 5-14yr)	Days	O_3	12,925,900	11,961,000	11,164,595
Respiratory medication use (adults 20yr +)	Days	O_3	8,171,700	7,548,200	7,025,333
Cough and LRS (children 0-14yr)	Days	O_3	65,278,600	60,350,200	56,204,229
Chronic Mortality – YOLL (Years of Life Lost)**	Life years lost	PM	2,467,300	1,911,800	1,722,700
Chronic Mortality – deaths**	Premature deaths	PM	271,600	210,900	190,200
Infant Mortality (0-1yr)	Premature deaths	PM	350	270	250
Chronic Bronchitis (27yr +)	Cases	PM	128,100	99,400	89,600
Respiratory Hospital Admissions (All ages)	Cases	PM	42,300	32,800	29,500
Cardiac Hospital Admissions (All ages)	Cases	PM	26,100	20,200	18,200
Restricted Activity Days (15-64yr)	Days	PM	221,999,100	171,960,900	154,985,400
Respiratory medication use (children 5-14yr)	Days	PM	1,987,700	1,536,300	1,379,300
Respiratory medication use (adults 20yr +)	Days	PM	20,879,800	16,183,700	14,591,600
Lower Respiratory Symptom days (children 5-14)	Days	PM	88,852,300	68,840,100	61,889,500
LRS among adults (15yr +) with chronic symptoms	Days	PM	207,562,100	160,856,000	144,995,400

*) Results for acute mortality effects of ozone are slightly different to those generated by the RAINS model, as RAINS keeps population constant at 2000 levels and the CBA model factors in population change to 2020. Differences in terms of estimated benefit between current legislation and the Strategy are, however, small.
**) 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 4. Analysis of the Strategy: Estimated annual health benefits (i.e. the difference between the CLE baseline and the Strategy and the MTFR) in 2020 in the EU25.

End Point Name	CORE Functions		the Strategy	MTFR
Acute Mortality (All ages)*	Premature deaths	O_3	1,600	3,041
Respiratory Hospital Admissions (65yr +)	Cases	O_3	1,600	2,940
Minor Restricted Activity Days (MRADs 15-64yr)	Days	O_3	3,224,500	5,930,767
Respiratory medication use (children 5-14yr)	Days	O_3	964,900	1,761,305
Respiratory medication use (adults 20yr +)	Days	O_3	623,500	1,146,367
Cough and LRS (children 0-14yr)	Days	O_3	4,928,400	9,074,371
Chronic Mortality – YOLL (Years of Life Lost)**	Life years lost	PM	555,500	744,600
Chronic Mortality – deaths**	Premature deaths	PM	60,700	81,400
Infant Mortality (0-1yr)	Premature deaths	PM	82	100
Chronic Bronchitis (27yr +)	Cases	PM	28,700	38,500
Respiratory Hospital Admissions (All ages)	Cases	PM	9,500	12,800
Cardiac Hospital Admissions (All ages)	Cases	PM	5,900	7,900
Restricted Activity Days (15-64yr)	Days	PM	50,038,200	67,013,700
Respiratory medication use (children 5-14yr)	Days	PM	451,400	608,400
Respiratory medication use (adults 20yr +)	Days	PM	4,696,100	6,288,200
Lower Respiratory Symptom (LRS) days (child 5-14yr)	Days	PM	20,012,200	26,962,800
LRS among adults (15yr +) with chronic symptoms	Days	PM	46,706,100	62,566,700

*) Results for acute mortality effects of ozone are slightly different to those generated by the RAINS model, as RAINS keeps population constant at 2000 levels and the CBA model factors in population change to 2020. Differences in terms of estimated benefit between current legislation and the Strategy are, however, small.
**) 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.

Health impact assessment - discussion

Ozone concentrations: In the CAFE baseline, annual impacts across the EU 25 are estimated at 21,000 deaths brought forward in the year 2020[5]. However, ozone also leads to much larger numbers of estimated morbidity health impacts, with tens of millions of minor restricted activity days and respiratory medication use days each year. These are clearly less serious effects at the level of the affected individual, but they affect a much greater number of people.

The Strategy is estimated to reduce the total impacts from ozone on health, for example, by 1,600 avoided deaths brought forward. A similar level of benefits is predicted for respiratory hospital admissions. For other morbidity endpoints, the benefits are greater in terms of numbers of cases. For example, the Strategy is estimated to reduce the incidence of respiratory medication use by 1.5 million days and of minor restricted activity by 3 million days.

PM concentrations: Annual impacts across the EU 25 in the CAFE baseline in 2020 are estimated at 2.5 million years of life lost each year. This can also be expressed as 272,000 estimated premature deaths. These results are consistent with the RAINS model, though RAINS calculates the total (not annual) change in life years. Anthropogenic $PM_{2.5}$ exposure also leads to an estimated 350 premature deaths each year amongst infants aged between 1 month and 1 year. The estimated morbidity effects of $PM_{2.5}$ in 2020 range from 68,000 hospital admissions to much larger numbers of less serious effects, for example 20 million respiratory medication use days, and several hundred million restricted activity days.

The Strategy is estimated to reduce the total mortality impacts in the adult population from $PM_{2.5}$ exposure by 556,000 years of life lost each year (61,000 avoided premature deaths). Additional to this, we estimate that 80 deaths amongst infants aged from 1 month to 1 year would be avoided. For morbidity, it is estimated that the Strategy would lead to reductions of 15,000 hospital admissions, 5 million cases of respiratory medication use, and tens of millions of restricted activity days.

[5] The estimates of acute mortality due to ozone are in this analysis somewhat different from those reported by the RAINS model. This is due to the fact that in the analysis carried out for 2020, we use the age distribution of the population as of 2020, whereas RAINS uses 2000 data. Thus, the effects of ozone on mortality are more up-to-date in this report. However, the difference of the CBA and RAINS analysis between CLE and the Strategy is small.

Summary 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 (Holland et al, 2004a; Hurley et al, 2004).

The results are shown in Table 6. All values are for the EU25. This presents the total damage with baseline pollution concentrations in 2020. It also shows the total damage for the Strategy and the MTFR scenario.

Table 7 shows the change in damage, i.e. the benefits, of the Strategy and the MTFR over the 2020 baseline. It is estimated that the annual health benefits of the Strategy will range from €42 billion to €135 billion/year in 2020.

Table 5. Estimated values of annual damage to health in EU25 in 2020 (€ million).

End Point Name		Current Legislation in 2020	the Strategy	MTFR
Acute Mortality (VOLY median)*	O_3	1085	1002	933
Acute Mortality (VOLY mean)*	O_3	2435	2250	2093
Respiratory Hospital Admissions (65yr +)	O_3	40	37	35
Minor Restricted Activity Days (MRADs 15-64yr)	O_3	1629	1506	1402
Respiratory medication use (children 5-14yr)	O_3	12	11	10
Respiratory medication use (adults 20yr +)	O_3	8	7	7
Cough and LRS (children 0-14yr)	O_3	2508	2318	2159
Chronic Mortality – VOLY – low (median)**	PM	129,000	99,959	90,073
Chronic Mortality – VOLY – high (mean)**	PM	289,556	224,370	202,180
Chronic Mortality – VSL – low (median)**	PM	265,965	206,465	186,285
Chronic Mortality – VSL – high (mean)**	PM	547,200	424,784	383,265
Infant Mortality (0-1yr) – low (median)	PM	495	383	345
Infant Mortality (0-1yr) – high (mean)	PM	990	765	689
Chronic Bronchitis (27yr +)	PM	24,011	18,619	16,792
Respiratory Hospital Admissions (All ages)	PM	85	66	59
Cardiac Hospital Admissions (All ages)	PM	52	41	37
Restricted Activity Days (RADs 15-64yr)	PM	18,515	14,342	12,926
Respiratory medication use (children 5-14yr)	PM	2	1	1
Respiratory medication use (adults 20yr +)	PM	20	15	14
LRS symptom days (children 5-14yr)	PM	3,413	2,645	2,378
LRS among adults (15yr +) with chronic symptoms	PM	7,974	6,180	5,570
Total with Mortality – VOLY – low (median)**		**188,849**	**147,131**	**132,741**
Total with Mortality – VOLY – high (mean)**		**351,250**	**273,172**	**246,352**
Total with Mortality – VSL – low (median)**		**325,814**	**253,637**	**228,953**
Total with Mortality – VSL – high (mean)**		**608,894**	**473,586**	**427,437**

*) For acute mortality (O_3), two alternative values are presented, based on a range reflecting the median and mean values for VOLY from the NewExt study.
**) For chronic mortality (PM), four alternative values are presented, based on quantification using years of life lost (using the median and mean YOLL value from NewExt) and numbers of premature deaths (using the median and mean VSL value from NewExt) . These are not additive.

Table 6. Estimated values of annual health benefits over the CAFE baseline (Current Legislation) in the EU25 in 2020 (€ million).

End Point Name		the Strategy	MTFR
Acute Mortality (VOLY median)*	O_3	83	152
Acute Mortality (VOLY mean)*	O_3	186	342
Respiratory Hospital Admissions (65yr +)	O_3	3	6
Minor Restricted Activity Days (MRADs 15-64yr)	O_3	124	228
Respiratory medication use (children 5-14yr)	O_3	1	2
Respiratory medication use (adults 20yr +)	O_3	1	1
Cough and LRS (children 0-14yr)	O_3	189	349
Chronic Mortality – VOLY – low (median)**	PM	29,041	38,927
Chronic Mortality – VOLY – high (mean)**	PM	65,186	87,377
Chronic Mortality – VSL – low (median)**	PM	59,500	79,680
Chronic Mortality – VSL – high (mean)**	PM	122,416	163,935
Infant Mortality (0-1yr) – low (median)	PM	112	150
Infant Mortality (0-1yr) – high *mean)	PM	224	300
Chronic Bronchitis (27yr +)	PM	5,392	7,219
Respiratory Hospital Admissions (All ages)	PM	19	26
Cardiac Hospital Admissions (All ages)	PM	12	16
Restricted Activity Days (RADs 15-64yr)	PM	4,173	5,589
Respiratory medication use (children 5-14yr)	PM	0	1
Respiratory medication use (adults 20yr +)	PM	4	6
LRS symptom days (children 5-14yr)	PM	769	1,036
LRS among adults (15yr +) with chronic symptoms	PM	1,794	2,404
Total with Mortality – VOLY – low (median)**		**41,717**	**56,112**
Total with Mortality – VOLY – high (mean)**		**78,077**	**104,902**
Total with Mortality – VSL – low (median)**		**72,176**	**96,865**
Total with Mortality – VSL – high (mean)**		**135,307**	**181,460**

*) For acute mortality (O_3), two alternative values are presented, based on a range reflecting the median and mean values for VOLY from the NewExt study.
**) For chronic mortality (PM), four alternative values are presented, based on quantification using years of life lost (using the median and mean YOLL value from NewExt) and numbers of premature deaths (using the median and mean VSL value from NewExt) . These are not additive.

Non-Health Impacts

Crops

The approach used for assessing damage to crops was summarised in the methodology section earlier and also in the methodology report, volume 1. Account has been taken of the work of ICP Vegetation, though it is noted that they express concerns about the use (as here) of AOT40 as a metric for crop damage assessment. Analysis will shift to flux based methods as soon as these become available.

Table 7 presents the total crop yield loss from ozone exposure for the EU25 with baseline ozone pollution concentrations in 2020, and with the Strategy and MTFR. The total annual damage in the year 2020 is estimated at just above €1.5 billion/year– with estimated annual benefits of €0.3 billion/year for moving to the emission levels of the Strategy.

Table 7. Estimated annual crop damage due to ozone in the EU25 in 2020 under Current Legislation, the Strategy and the MTFR (€Million)

Total damage per year in the EU25 in 2020		
Current Legislation	**the Strategy**	**MTFR**
1511	1179	997
Annual benefits in 2020		
Current Legislation	**the Strategy**	**MTFR**
0	332	514

Note: Benefits are calculated as the difference between the Strategy and MTFR over baseline.

The analysis of crop damage shows that these effects are small in economic terms in relation to health effects overall (i.e. including $PM_{2.5}$ effects), though effects from ozone on crops are similar in magnitude to ozone related health damage.

Materials

Like the crops analysis, the approach used for assessing damage to materials was summarised in the methodology section earlier and also in the methodology report, volume 1. Account has been taken of the work of ICP Materials.

Table 8 presents the total material damage from acid deposition to utilitarian applications for the EU25 with baseline ozone pollution concentrations in 2020, and with the different ambition levels. The total damage in the year 2020 are estimated at just under €0.74 billion/year– with estimated benefits of the Strategy at €0.19 billion/year above the baseline.

Table 8. Estimated annual damage to materials used in utilitarian applications from acid deposition in 2020 in the EU25 under Current Legislation, the Strategy and the MTFR (€ million).

Total Damage per Year in the EU25 in 2020.		
Current legislation	**the Strategy**	**MTFR**
740	550	460
Benefits in 2020		
Current legislation	**the Strategy**	**MTFR**
0	190	280

Note: Benefits are calculated as the difference between the Strategy and MTFR over baseline.

Ecosystems

The results provided in this section were generated by the RAINS model and are presented also in the report on the Thematic Strategy from IIASA (Amann et al, 2005b). The information is repeated here in the interests of completeness, though some additional notes are provided to assist with interpretation of the data.

Excess nitrogen deposition

There are several mechanisms whereby excess nitrogen deposition to ecosystems can lead to ecological change.

The first of these, acidification, is dealt with below.

The second mechanism is one of nutrient enrichment of nutrient poor habitats leading to eutrophication. Nitrogen (N) is generally the element that is most often limiting to plant growth. As a result, the availability of N has been a significant evolutionary force on plants and is a major determinant of the distribution of different plant species thus influencing plant biodiversity negatively and ultimately also the overall biodiversity. A third mechanism concerns nutrient imbalance (e.g., de Vries et al, 2002), where an excess input of N leads to a deficiency of macronutrients such as K, P and Mg. Nutrient imbalance may lead to an increased sensitivity to frost, drought and parasitic attack.

The extent of exceedance of critical loads for N across the EU25 is summarised in Table 9 and Figure 1. It is immediately clear that exceedance of critical loads for eutrophication is widespread. The total area forecast for exceedance in 2020 (590,000 km^2) is equivalent to the combined area of France and Belgium. Under the Strategy there is significant improvement, though the area subject to exceedance is still large. Improvements over time are gradual, mainly as a result of the small differences in emission of ammonia. The results presented here are supported by field monitoring (see WGE, 2004). Further to this, it should be recognised that these effects will not be equally spread across all types of ecosystem, but will instead be far more serious for some than for others.

Table 9. Percent of ecosystems area with nitrogen deposition above the critical loads for eutrophication. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004. The shading highlights countries where the area subject to exceedance is 50% or more than total ecosystem area (black) or between 25% and 49% of total ecosystem area (grey).

	Ecosystems area (km^2) [1)]	2000	2020 Current legislation	2020 the Strategy	2020 MTFR [2)]
Austria	35563	96%	86%	77%	53%
Belgium	6615	93%	61%	37%	23%
Cyprus	4806	48%	64%	49%	13%
Czech Rep.	18364	95%	77%	39%	12%
Denmark	3031	53%	37%	11%	1%
Estonia	24326	12%	6%	4%	0%
Finland	238698	25%	14%	6%	0%
France	179227	96%	79%	57%	20%
Germany	106908	96%	94%	92%	86%
Greece	13714	76%	73%	52%	2%
Hungary	10763	31%	24%	16%	5%
Ireland	8791	12%	3%	0%	0%
Italy	119679	62%	48%	29%	13%
Latvia	29982	54%	38%	15%	0%
Lithuania	13182	85%	81%	62%	4%
Luxembourg	935	96%	82%	56%	40%
Malta[3)]					
Netherlands	3244	67%	61%	51%	27%
Poland	91265	86%	79%	65%	18%
Portugal	11053	30%	12%	1%	0%
Slovakia	18213	89%	60%	30%	4%
Slovenia	4249	94%	88%	75%	21%
Spain	84278	65%	50%	32%	7%
Sweden	184369	26%	16%	8%	1%
UK	73791	13%	5%	1%	0%
EU25	**1285046**	**57%**	**46%**	**33%**	**15%**

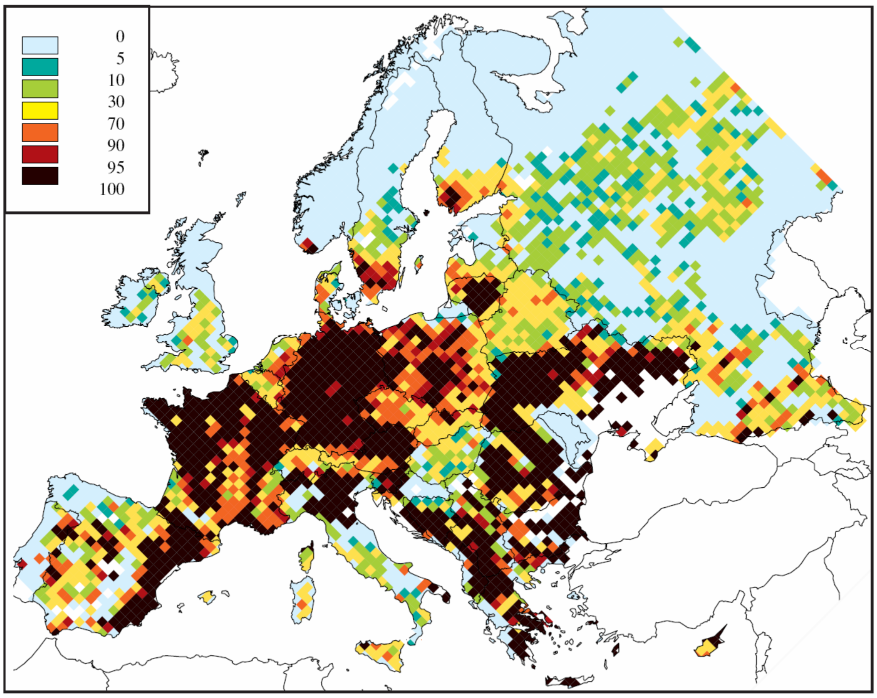
Source: Amann et al (2005)

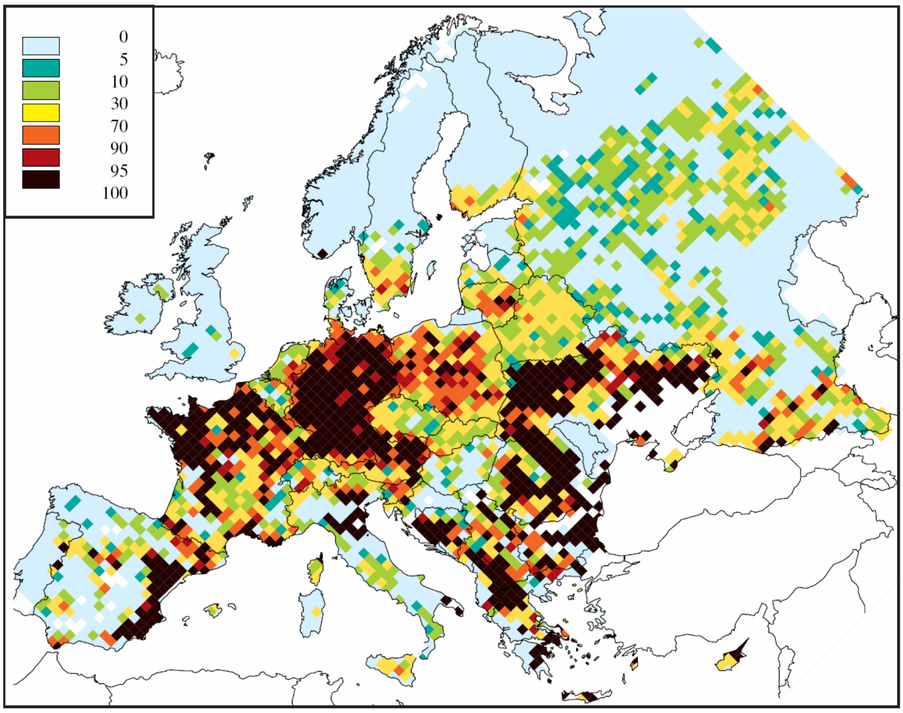
[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

[3]) Data for Malta are not available

Figure 1. Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication for the year 2020; current legislation baseline (top graph) and the Strategy (bottom graph). Calculations are based on meteorological conditions of 1997 using grid-average deposition. The report by Amann et al (2005b), from which these figures were taken, provides further maps.





Acid deposition to forest ecosystems

Table 10 and Figure 2 show results for the Strategy and the MTFR scenario for the exceedance of the critical load for acidity to forests. The RAINS model estimates that in the year 2000 more than 20% of European forests, or almost 250,000 km^2 (an area equivalent to that of the UK) received acid deposition above their critical loads. The emission reductions that are already agreed in the 'current legislation' should reduce this by the year 2020 to approximately 120,000 km^2. With its environmental objectives, the Strategy would bring this area below 67,000 km^2. The worst affected country in terms of % area affected is the Netherlands, by some considerable distance.

Table 10. Percent of forest area with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using ecosystem-specific deposition. Critical loads data base of 2004. The shading highlights countries where the area subject to exceedance is 50% or more than total ecosystem area (black) or between 25% and 49% of total ecosystem area (grey).

	Ecosystems area (km^2) 1)	2000	2020 Current legislation	2020 the Strategy	2020 MTFR 2)
Austria	34573	15.2%	4.7%	2.5%	0.5%
Belgium	6526	55.4%	25.2%	16.3%	13.3%
Cyprus	1854	0.0%	0.0%	0.0%	0.0%
Czech Rep.	18344	80.8%	29.9%	10.2%	1.8%
Denmark	3009	31.8%	5.7%	1.5%	0.3%
Estonia	21252	0.3%	0.0%	0.0%	0.0%
Finland	236139	1.6%	0.9%	0.8%	0.4%
France	168823	12.4%	4.2%	2.6%	0.7%
Germany	103113	72.3%	43.0%	25.3%	12.9%
Greece	13714	0.6%	0.0%	0.0%	0.0%
Hungary	10763	3.9%	1.1%	0.4%	0.0%
Ireland	4166	47.0%	23.0%	17.7%	9.1%
Italy	92577	2.3%	0.7%	0.3%	0.3%
Latvia	28941	0.6%	0.5%	0.0%	0.0%
Lithuania	12438	2.9%	1.0%	0.4%	0.0%
Luxembourg	934	35.1%	13.7%	1.8%	0.0%
Malta 3)					
Netherlands	3778	88.3%	80.6%	71.1%	52.3%
Poland	88281	59.0%	19.7%	1.1%	0.2%
Portugal	11053	2.6%	0.5%	0.2%	0.0%
Slovakia	18211	22.7%	6.9%	3.1%	0.4%
Slovenia	4190	2.8%	0.0%	0.0%	0.0%
Spain	84269	1.0%	0.0%	0.0%	0.0%
Sweden	180911	23.7%	15.3%	12.8%	8.4%
UK	19822	49.0%	23.4%	12.4%	6.0%
EU25	**1167682**	**20.8%**	**10.2%**	**5.7%**	**3.1%**

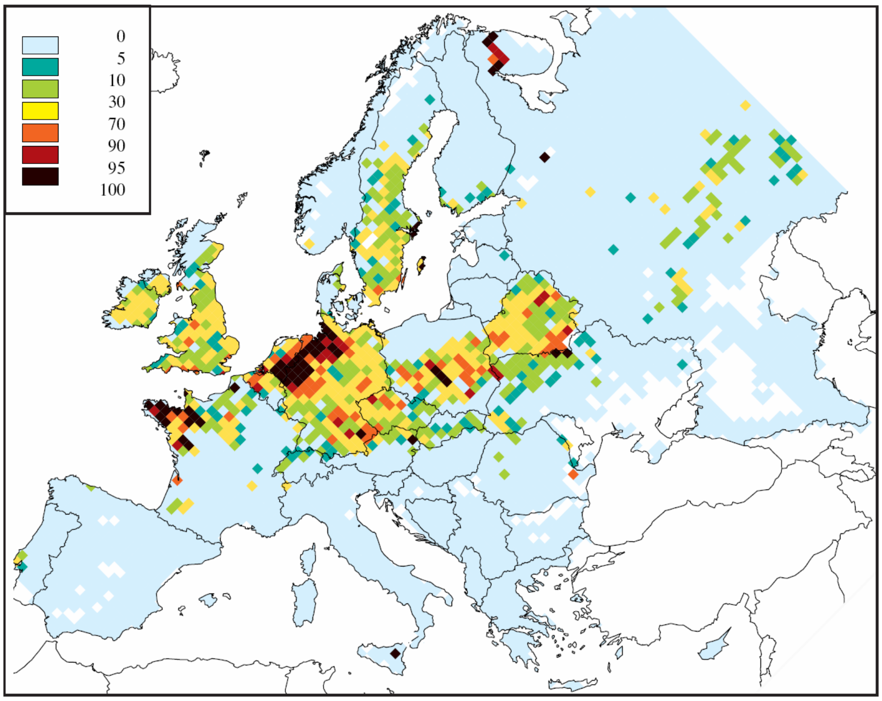
Source: Amann et al (2005b)

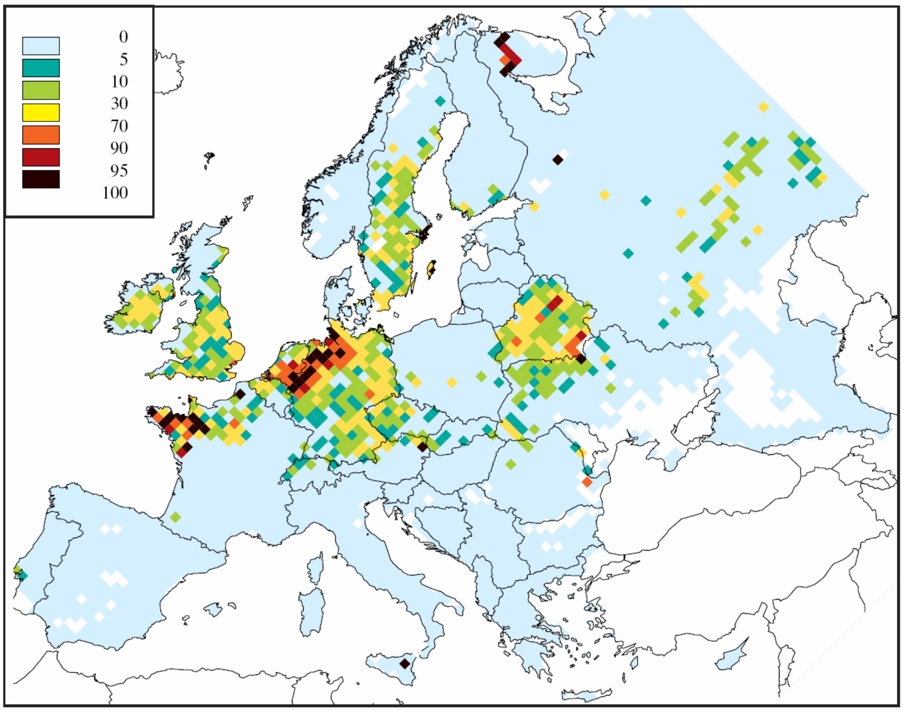
1) Ecosystems area for which critical loads data have been supplied

2) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

3) Data for Malta are not available

Figure 2. Percentage of forest area receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and the Strategy (bottom graph). Calculations are based on meteorological conditions of 1997 using ecosystem specific deposition. Source: Amann et al (2005b).





Acid deposition to semi-natural ecosystems

A number of countries have provided estimates of critical loads for so-called “semi-natural” ecosystems. This group typically contains nature and landscape protection areas, many of them designated as “Natura2000” areas of the EU Habitat directive.

Results in Table 11 and Figure 3 demonstrate the scale of the problem in aggregate terms for each country. As in other parts of this section, however, the aggregate data provide only limited guidance on the scale of the problem, given that different types of ecosystem will be affected to very differing extents. This reflects differences in deposition patterns at finer scales than can be investigated in the current analysis, and variation in the sensitivity of ecosystems. Results are not complete (given the number of countries not represented, and the limited area considered in some countries for which data are available), and for this reason, the information on area exceeded in km^2 is not provided. The most robust guidance provided by the results probably concerns the trends observed. However, exceedance in Germany and the Netherlands remains relatively high in both countries.

Table 11. Percent of the area of semi-natural ecosystems considered by the RAINS model with acid deposition above the critical loads for acidification. 1997 meteorology, ecosystem-specific deposition. The shading highlights countries where the area subject to exceedance is 50% or more than total area of semi-natural ecosystem (black) or between 25% and 49% of total area of semi-natural ecosystem (grey).

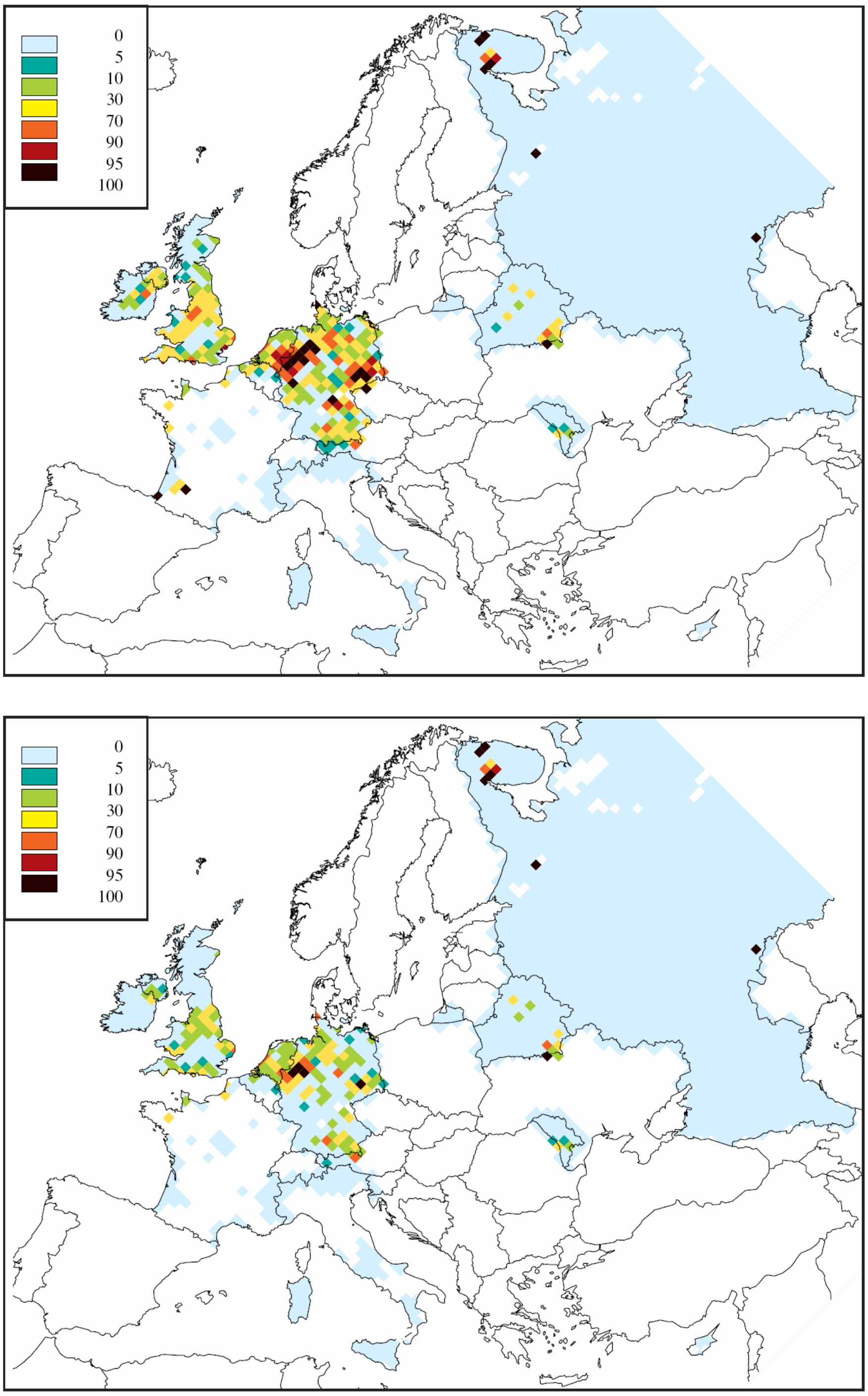
	Ecosystems area (km^2) [1)]	2000	2020 Current legislation	2020 the Strategy	2020 MTFR [2)]
France	10014	37.6%	9.0%	2.5%	0.6%
Germany	3946	68.1%	40.9%	25.1%	11.3%
Ireland	4609	10.3%	2.3%	1.0%	0.4%
Italy	26085	0.0%	0.0%	0.0%	0.0%
Netherlands	1296	63.0%	47.8%	26.7%	17.8%
UK	49700	30.8%	9.3%	4.0%	1.3%

Source: Amann et al (2005b)

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Figure 3. Percentage of the area of semi-natural ecosystems receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and the Strategy (bottom graph). Calculations are based on meteorological conditions of 1997 using ecosystem specific deposition. Source: Amann et al (2005b).



Acid deposition to freshwater bodies

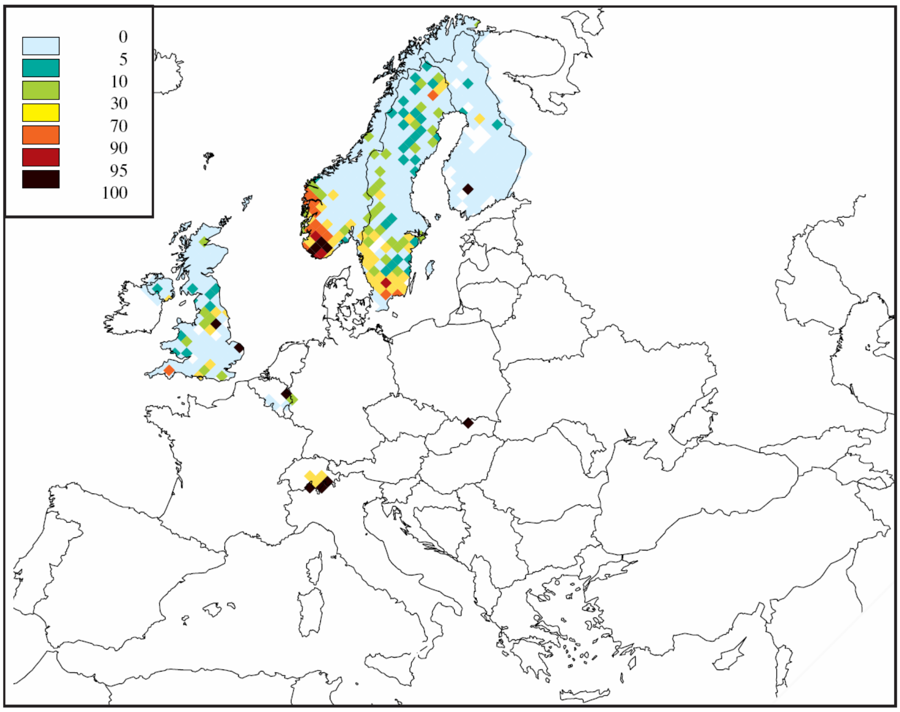
The effects of acidification on freshwater ecosystems are better understood than impacts on terrestrial ecosystems. The impact of greatest public concern has been the loss of game fish (salmon and trout) from rivers and lakes in acid sensitive areas, particularly in northern Europe, though this is linked to other ecological changes also. Reductions in acidifying emissions are starting to show benefits in terms of ecosystem recovery (WGE, 2004). Improvements are not uniform, however, and recovery will take some time, first for water chemistry to stabilise and improve, and then for biological recovery.

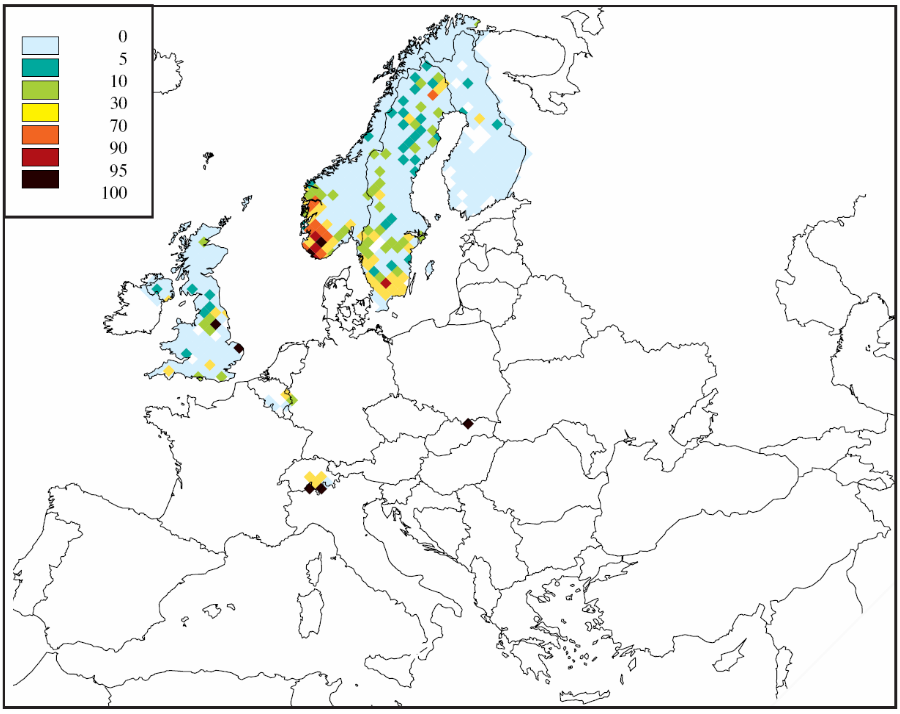
Table 12. Percent of catchments area with acid deposition above the critical loads for acidification. Results calculated for 1997 meteorology, using grid-average deposition. Critical loads data base of 2004.

		2000	2020	2020	2020
	Ecosystems area (km^2) [1)]		Current legislation	the Strategy	MTFR [2)]
Finland	30886	0.7%	0.7%	0.6%	0.2%
Sweden	204069	14.9%	10.5%	9.0%	5.2%
UK	7757	8.1%	3.7%	2.3%	1.3%

Source: Amann et al (2005b)
[1]) Ecosystems area for which critical loads data have been supplied
[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Figure 4. Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and the Strategy (bottom graph). Calculations are based on meteorological conditions of 1997 using grid-average deposition. Source: Amann et al (2005b).





Impacts on forests from ground-level ozone

For the CAFE baseline projection, the forest area where critical levels are exceeded is estimated to decline from 61% of the European forests in 2000 to 56% in the year 2020 (Table 13). The table also demonstrates a sharp division between countries with respect to the extent of critical levels exceedance.

Table 13. Percent of forest area where the critical levels for ozone are exceeded. Results calculated for 1997 meteorology. The shading highlights countries where the area subject to exceedance is 50% or more than total ecosystem area (black) or between 25% and 49% of total ecosystem area (grey).

	Ecosystems area (km^2) [1)]	2000	2020 Current legislation	2020 the Strategy	2020 MTFR [2)]
Austria	37211	100%	100%	100%	41%
Belgium	5964	100%	100%	100%	100%
Cyprus	1116	100%	100%	100%	11%
Czech Rep.	25255	100%	100%	100%	14%
Denmark	2807	99%	89%	89%	18%
Estonia	18420	0%	0%	0%	0%
Finland	207003	0%	0%	0%	0%
France	137329	100%	100%	93%	61%
Germany	104559	100%	100%	100%	80%
Greece	21854	100%	100%	99%	23%
Hungary	16451	100%	100%	100%	0%
Ireland	2464	99%	19%	6%	0%
Italy	79743	100%	100%	100%	99%
Latvia	25101	6%	0%	0%	0%
Lithuania	18901	38%	3%	2%	0%
Luxembourg	1054	100%	100%	100%	100%
Malta	3	100%	100%	100%	100%
Netherlands	2912	100%	100%	99%	98%
Poland	89100	100%	95%	65%	0%
Portugal	27336	100%	100%	93%	32%
Slovakia	20144	100%	100%	69%	0%
Slovenia	10724	100%	100%	100%	17%
Spain	104595	100%	100%	100%	55%
Sweden	273144	18%	4%	1%	0%
UK	14557	85%	50%	43%	25%
EU25	**1247749**	**61%**	**56%**	**52%**	**28%**

Source: Amann et al (2005b)

[1]) Ecosystems area for which critical loads data have been supplied

[2]) Maximum technically feasible emission reductions assumed for all European countries (including non-EU countries)

Aggregating the indicators for forest effects

The analysis carried out in the RAINS model does not permit the total ecosystem area subject to exceedance of one or more critical load/level for acidification, eutrophication and ozone to be calculated. However, given that the ozone results for forests indicate extremely high exceedance in most countries and close to zero exceedance in a few cases, it is possible to use the aggregated national data to estimate the area of forest subject to exceedance of both the critical load for eutrophication *or* acidification and the critical level for ozone. These results are useful as they demonstrate the extent to which forests are subject to more than one pollutant stress (Table 14).

Table 14. Summary statistics for the EU25 showing area of forest subject to exceedance of the critical level for ozone, critical loads for eutrophication and acidification, and combined exceedances of ozone and acidification and ozone and eutrophication. Black and grey shading highlights cases where exceedance covers >50% and 25 to 50% of forest area.

	2000	**Current Legislation in 2020**	**the Strategy**	**MTFR**
Ozone	61%	56%	52%	28%
Acidification	21%	10%	6%	3%
Eutrophication	57%	46%	33%	15%
Ozone + acidification	16%	6%	3%	1%
Ozone + eutrophication	47%	35%	28%	9%

Table 15 repeats the analysis, but excludes Estonia, Finland, Latvia, Lithuania and Sweden as exceedance of the critical level for ozone in these countries is close to zero. It is seen that summary results for the European Union outside of these countries are substantially more severe than when they are included.

Table 15. As Table 14, but excluding the Baltic countries (Estonia, Finland, Latvia, Lithuania and Sweden).

	2000	**Current Legislation in 2020**	**the Strategy**	**MTFR**
Ozone	99.7%	98%	91%	50%
Acidification	28%	13%	6%	3%
Eutrophication	80%	68%	52%	26%
Ozone + acidification	27%	11%	5%	2%
Ozone + eutrophication	80%	68%	48%	15%

Initial Comparison of Costs and Benefits

The information in the previous sections on benefits has been compared against the annualised costs of the scenarios, as estimated by the RAINS model. This is referred to as the 'initial comparison of costs and benefits', as no account is taken at this stage of uncertainty in estimates of either cost or benefit. The annualised costs from RAINS are shown in Table 16 and the annual monetized benefits are shown in Table 17. The monetized health benefits over total costs are shown in Table 18. Data are also presented graphically in Figure 5 to Figure 10.

Table 16. Annualised Costs in Million € in 2020 - change over base line, including road transport measures for the Strategy and the MTFR.

	the Strategy	MTFR
Austria	95	1403
Belgium	298	981
Cyprus	9	80
Czech Rep.	172	614
Denmark	86	800
Estonia	15	158
Finland	63	1088
France	1177	7787
Germany	1401	4340
Greece	74	1000
Hungary	144	567
Ireland	94	707
Italy	692	3412
Latvia	14	137
Lithuania	48	433
Luxembourg	19	51
Malta	3	20
Netherlands	328	979
Poland	633	3787
Portugal	153	1457
Slovakia	68	367
Slovenia	29	187
Spain	688	4449
Sweden	71	1567
UK	776	3349
EU-25	**7149**	**39720**

Source: Amann et al 2005b

Table 17. Health benefits (€million) for the Strategy and MTFR over the Current Legislation baseline in 2020.

	Health benefit for the Strategy		Health benefit for the MTFR	
	LOW (VOLY median)	HIGH (VSL mean)	LOW (VOLY median)	HIGH (VSL mean)
Austria	659	2070	974	3056
Belgium	1417	4495	1935	6127
Cyprus	6	14	10	24
Czech Rep.	1181	3931	1513	5026
Denmark	313	1068	501	1706
Estonia	27	100	49	181
Finland	41	130	127	407
France	5872	17384	8399	24830
Germany	10198	35273	12975	44777
Greece	304	1112	472	1715
Hungary	1426	5307	1754	6516
Ireland	186	478	278	712
Italy	4319	16100	5970	22175
Latvia	96	251	157	413
Lithuania	102	488	165	787
Luxembourg	79	189	105	252
Malta	12	36	18	53
Netherlands	2517	7623	3296	9968
Poland	3911	12243	5031	15723
Portugal	462	1574	706	2396
Slovakia	676	2065	874	2662
Slovenia	180	610	257	867
Spain	1626	5310	2290	7462
Sweden	207	656	482	1532
UK	5902	16800	7772	22089
EU-25	**41717**	**135307**	**56109**	**181457**

Note for acute mortality (O_3), two alternative values are presented, based on a range reflecting the median and mean values for VOLY from the NewExt study. For chronic mortality (PM), four alternative values are presented, based on quantification using years of life lost (using the median and mean YOLL value from NewExt) and numbers of premature deaths (using the median and mean VSL value from NewExt) . These are not additive. The numbers above show the low and high estimates.

The ratio of benefits to costs (combining the above tables) is presented below. A ratio > 1 indicates that benefits are greater than costs (i.e. there are net benefits). Note the numbers are presented for health benefits only.

Table 18. Ratio of health benefits to total costs in 2020 over the Current Legislation baseline for the Strategy and the MTFR.

	Ratio of health benefit to total cost the Strategy		Ratio of health benefit to total cost MTFR	
	LOW (VOLY median)	**HIGH (VSL mean)**	**LOW (VOLY median)**	**HIGH (VSL mean)**
Austria	6.9	21.8	0.7	2.2
Belgium	4.8	15.1	2.0	6.2
Cyprus	0.6	1.5	0.1	0.3
Czech Rep.	6.9	22.9	2.5	8.2
Denmark	3.7	12.5	0.6	2.1
Estonia	1.9	6.8	0.3	1.1
Finland	0.6	2.1	0.1	0.4
France	5.0	14.8	1.1	3.2
Germany	7.3	25.2	3.0	10.3
Greece	4.1	15.0	0.5	1.7
Hungary	9.9	36.8	3.1	11.5
Ireland	2.0	5.1	0.4	1.0
Italy	6.2	23.3	1.7	6.5
Latvia	7.0	18.5	1.1	3.0
Lithuania	2.1	10.2	0.4	1.8
Luxembourg	4.0	9.7	2.1	5.0
Malta	4.1	12.3	0.9	2.7
Netherlands	7.7	23.3	3.4	10.2
Poland	6.2	19.4	1.3	4.2
Portugal	3.0	10.3	0.5	1.6
Slovakia	9.9	30.3	2.4	7.3
Slovenia	6.3	21.4	1.4	4.6
Spain	2.4	7.7	0.5	1.7
Sweden	2.9	9.2	0.3	1.0
UK	7.6	21.7	2.3	6.6
EU-25	**5.8**	**18.9**	**1.4**	**4.6**

Note for acute mortality (O_3), two alternative values are presented, based on a range reflecting the median and mean values for VOLY from the NewExt study. For chronic mortality (PM), four alternative values are presented, based on quantification using years of life lost (using the median and mean YOLL value from NewExt) and numbers of premature deaths (using the median and mean VSL value from NewExt) . These are not additive. The numbers above show the low and high estimates.

The benefits by Member State, the benefit per year per person, and the benefit/cost ratio is shown in the figures below for the low and high estimate of benefits. 23 of 25 Member States are projected to have net benefits from the Strategy[6]. It needs to be emphasized that the ratio is calculated between health benefits alone over total costs. Thus the benefits of

[6] If low health values are used, Finland and Cyprus are projected to have lower benefits than costs.

improved environment are not included. In the impact assessment of the proposal for the directive on Ambient Air Quality and Cleaner Air for Europe (European Commission DG Environment, 2005) the health related benefits of $PM_{2.5}$ reduction are compared against the costs of reducing $PM_{2.5}$ specifically.

Figure 5. Annual monetised health benefits of the Strategy per Member State in 2020 (€ million). Valuation of health benefits is LOW, i.e. based on the median estimate of the Value of a Life Year Lost.

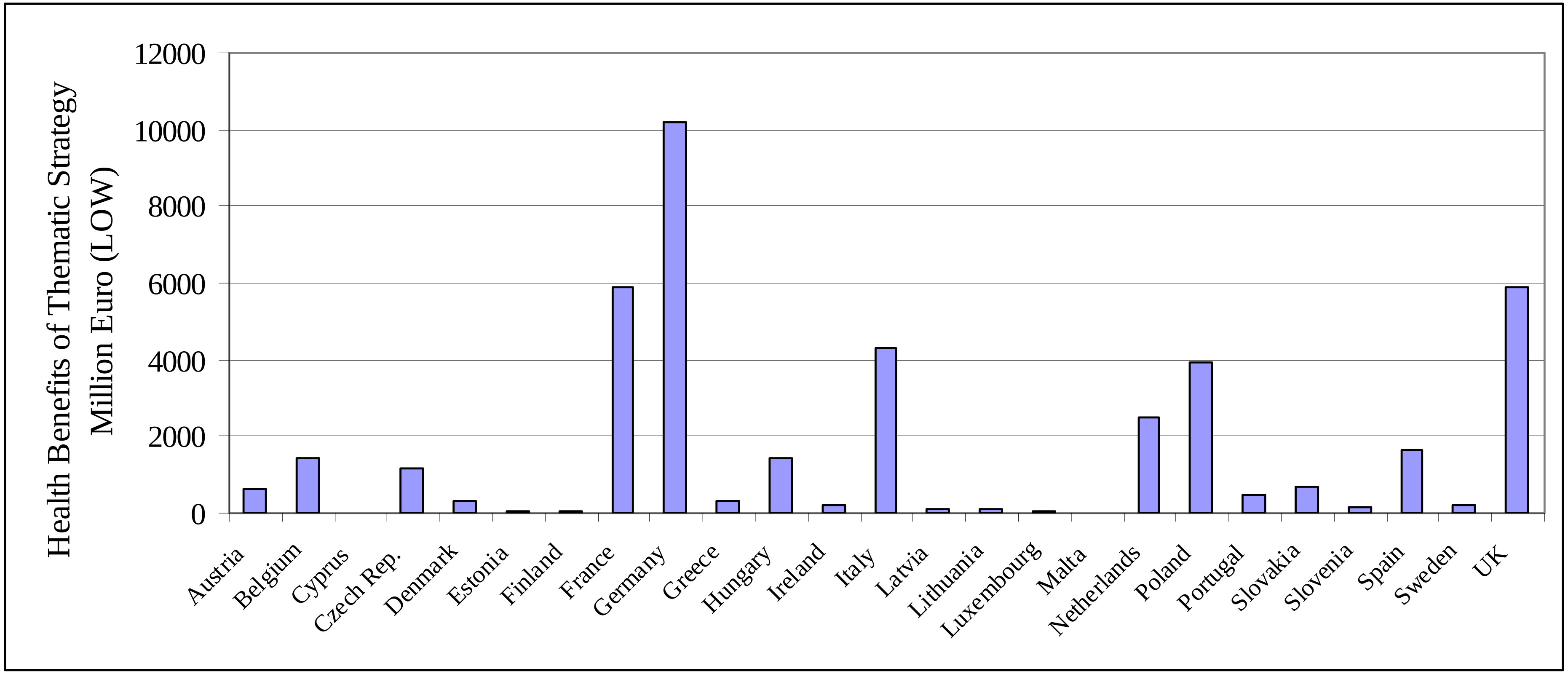


Figure 6. Annual monetised health benefits of the Strategy per Member State in 2020 (€ million). Valuation of health benefits is <u>HIGH,</u> i.e. based on the mean estimate of the Value of a Statistical Life.

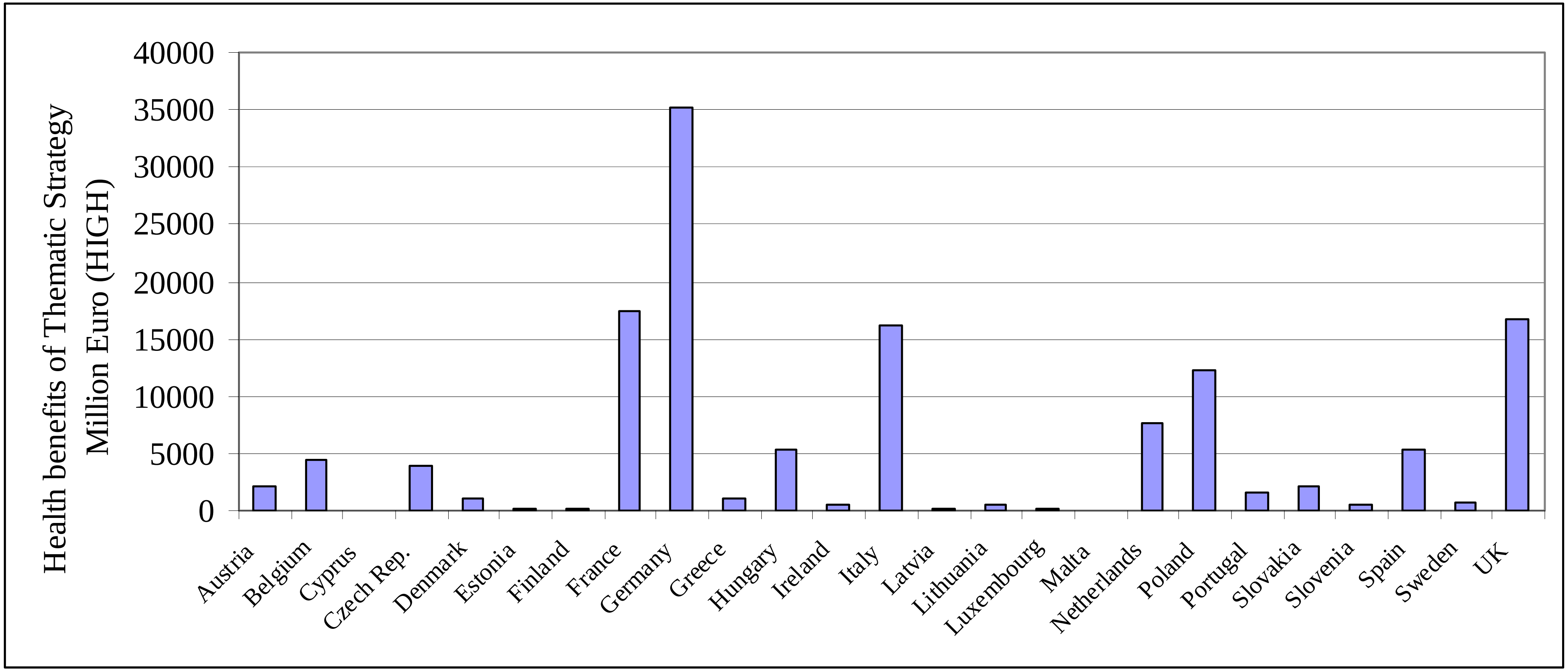


Figure 7. Estimated health benefits (Euro per person of country population) by Member State from the Strategy in 2020. Valuation of health benefits are LOW, i.e. based on the median estimate of the Value of a Life Year.

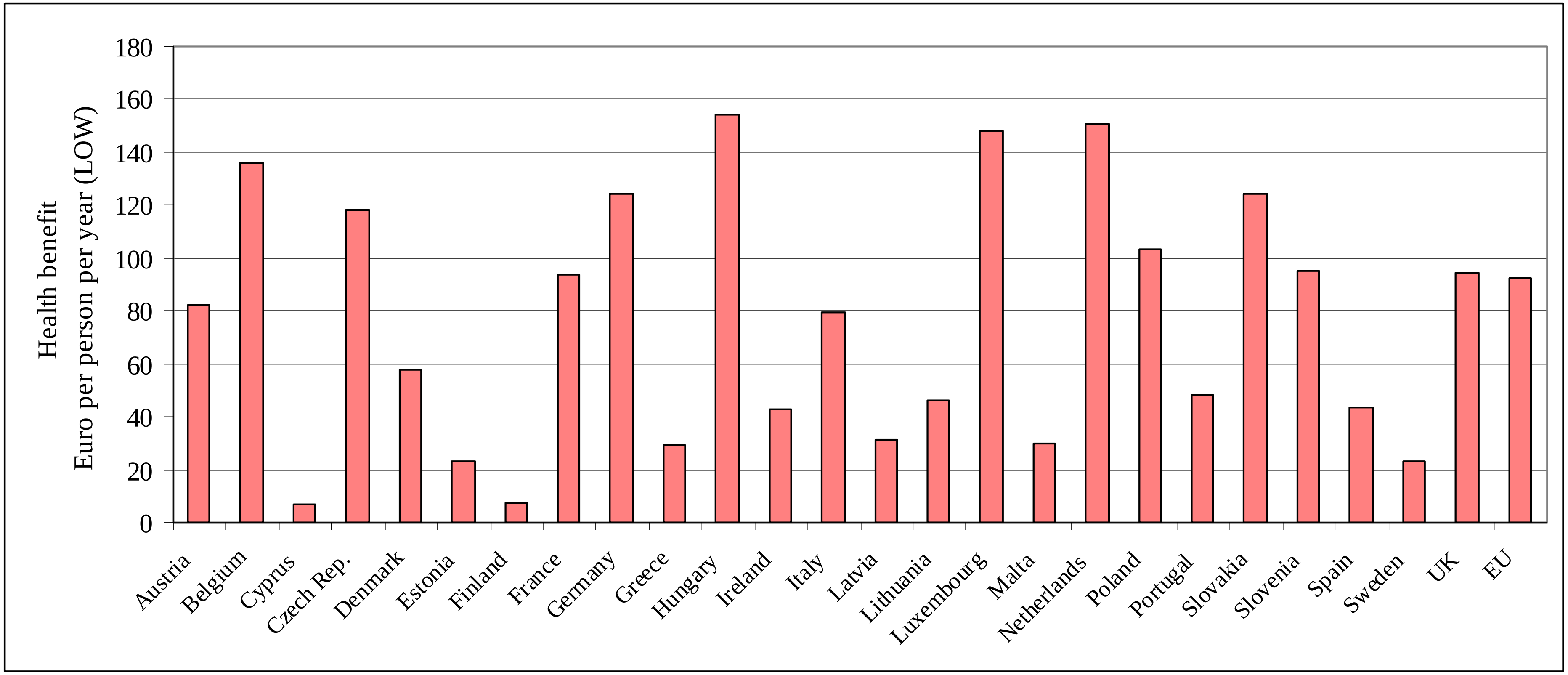


Figure 8. Estimated health benefits (Euro per person of country population) by Member State from the Strategy in 2020. Valuation of health benefits is HIGH, i.e. based on the mean estimate of the Value of Statistical Life.

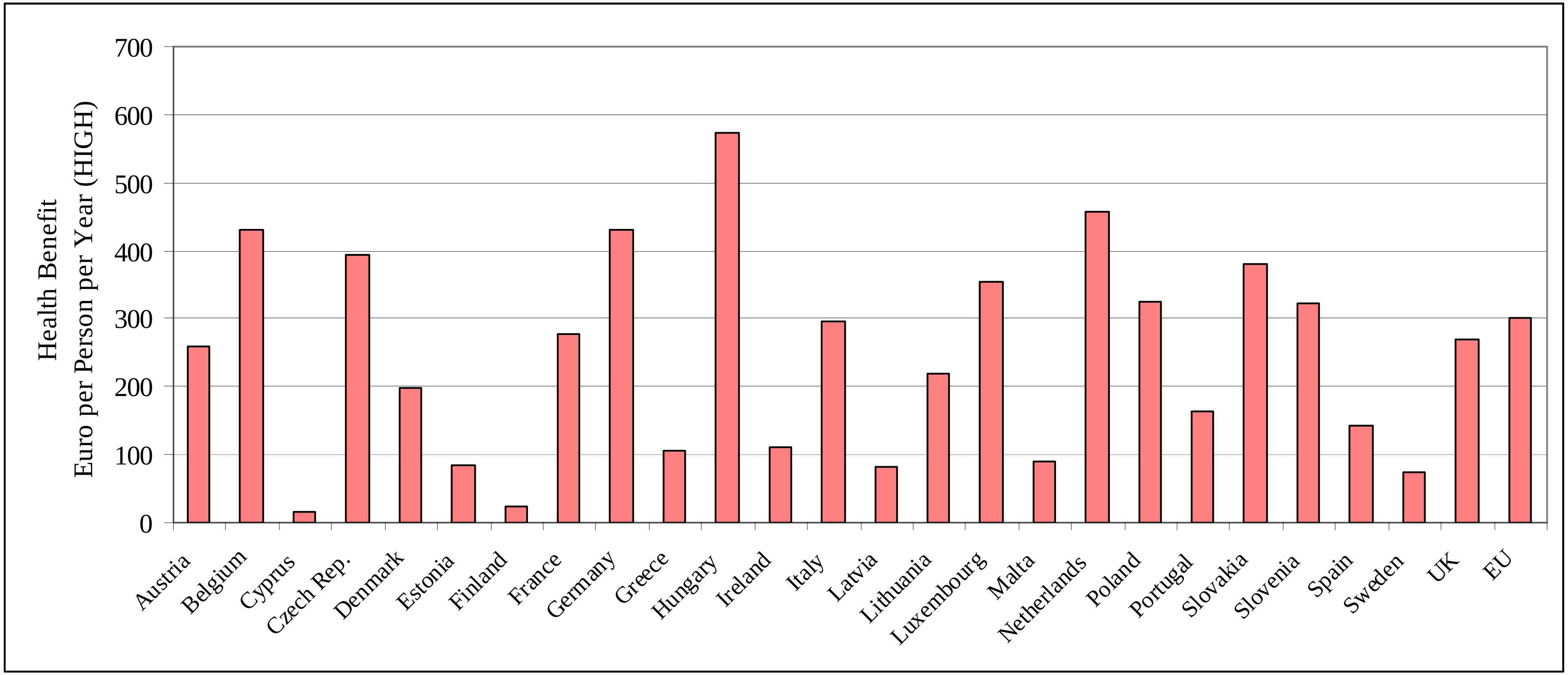


Figure 9. Ratio of health benefits over total costs by Member State of the Strategy in 2020. Valuation of health benefits is LOW, i.e. based on the median estimate of the Value of a Life Year.

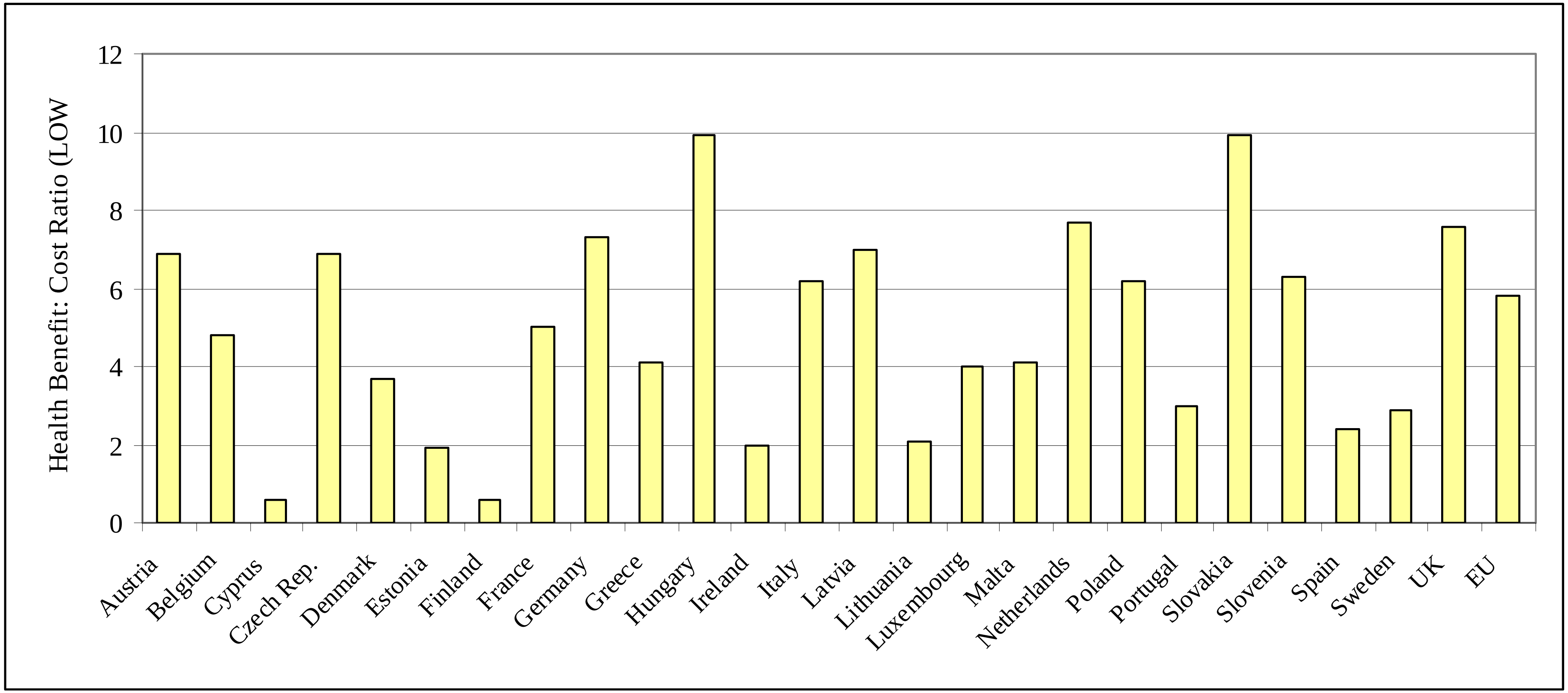


Figure 10. Ratio of health benefits over total costs by Member State of the Strategy in 2020. Valuation of health benefits is HIGH, i.e. based on the mean estimate of the Value of Statistical Life.

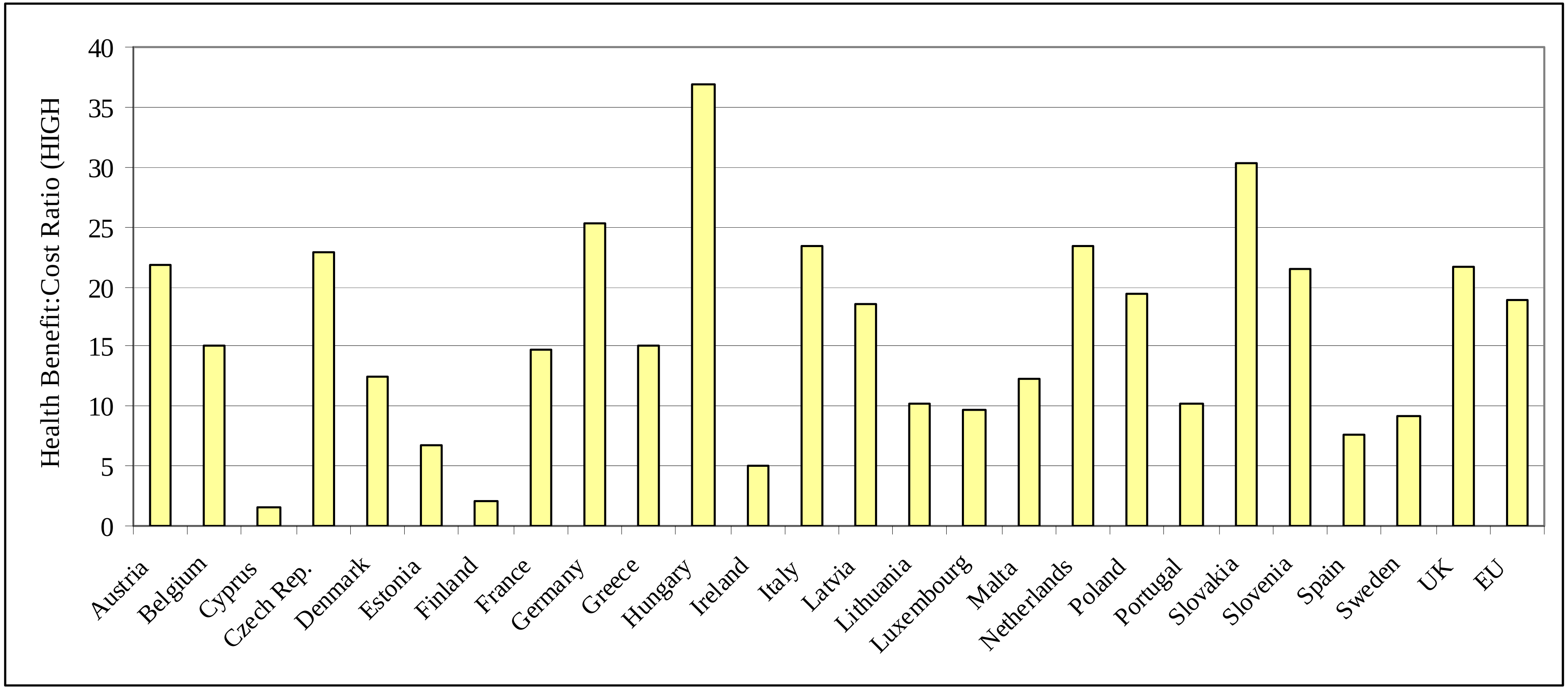


Table 19 shows the net monetised net benefits (excluding, of course, impacts on ecosystems and cultural heritage, effects of secondary organic aerosols on health and so on) of the scenarios (benefits minus costs), and the benefit to cost ratio (benefits divided by costs). The former shows the level of quantifiable benefits achieved; the latter shows the effectiveness of the policies, where the larger the ratio, the more economically efficient the policy is.

The table shows that when compared against the baseline the Strategy and the MTFR lead to net benefits.

The cost-benefit analysis shows that the benefits of the Strategy exceed costs significantly (by a factor of at least six). The ratio of benefits to costs in the MTFR falls, due to the rise in costs of measures relative to the benefits obtained.

The total benefit per person (EU average) from the Strategy is €94 to €301 per year. This compares to costs (EU average) of €15.

Table 19. Summary of annual costs and benefits in 2020.

Monetised Benefits	**Units**	**the Strategy**	**MTFR**
Total with Mortality – VOLY – low (median)	€ million	42,239	56,903
Total with Mortality – VOLY – high (mean)	€ million	78,599	105,692
Total with Mortality – VSL – low (median)	€ million	72,698	97,656
Total with Mortality – VSL – high (mean)	€ million	135,829	182,251
Total costs		7,149	39,720
Net benefits (Monetised Benefits minus Total Costs)			
Total with Mortality – VOLY – low (median)	€ million	42,239	56,903
Total with Mortality – VOLY – high (mean)	€ million	78,599	105,692
Total with Mortality – VSL – low (median)	€ million	72,698	97,656
Total with Mortality – VSL – high (mean)		135,829	182,251
Benefit Cost Ratio (Monetised Benefits divided by Total Costs)			
Total with Mortality – VOLY – low (median)	Ratio	5.9	1.4
Total with Mortality – VOLY – high (mean)	Ratio	11.0	2.7
Total with Mortality – VSL – low (median)	Ratio	10.2	2.5
Total with Mortality – VSL – high (mean)	Ratio	19.0	4.6

*Note**:** Annualised benefits include health, materials and crop damage but exclude damage to the environment as well as damage from natural and secondary particulates*

Uncertainty / Sensitivity Analysis

Methods for describing uncertainties

The focus for the uncertainty assessment of the CBA concerns assessment of the probability of benefits exceeding estimated costs. Volume 3 of the methodology reports describes the uncertainties associated with the CAFE analysis and methods for dealing with them. These were demonstrated extensively in the report on results of the policy option scenarios A, B and C from the CAFE-CBA (AEA Technology, 2005).

A number of uncertainties are not addressed in detail in this report, on the grounds that they will not have a substantial effect on the balance of costs and benefits of the CAFE scenarios. These include account of:

- Additional impacts of both PM and ozone on health which it is felt are quantifiable with a lower level of confidence than those 'core' effects that are quantified above. Inclusion of the sensitivity functions for ozone would greatly increase ozone damages, but these are insignificant in relation to the total PM damage.
- Monetising ozone related mortality using the value of statistical life (VSL) concept as well as the value of a life year (VOLY) concept.
- Different approaches to valuation of ozone related mortality, testing sensitivity to the use of the value of statistical life method as well as the value of a life year approach. [For PM effects, both methods are used whilst for ozone, only the VOLY is applied.]
- Alternative estimates of average loss of life expectancy to ozone related mortality.

Some uncertainties that not accounted for here in detail are clearly more important. Perhaps most notable is the potential effects of different toxicities for the components of the PM mixture, i.e. primary $PM_{2.5}$ from different sources, sulphates and nitrates. In Volume 2 of the CAFE-CBA Methodology Report it was recognised that there was a lack of quantitative evidence for distinguishing between particles at quantification. The Health Effects Task Force of WHO considered this issue in 2003, and again in the CAFE follow-up questions. They noted that:

  - Toxicological studies have highlighted that primary, combustion-derived particles have a high toxic potency; and that
  - Several other components of the PM mix – including sulphates and nitrates – are lower in toxic potency.

Unfortunately there is a lack of established risk estimates for the different components and we agree with the WHO (2004) evaluation that it is currently not possible to precisely quantify the contributions from different sources and different PM components to health effects. This should be considered a research priority for the coming years.

The current methodology assumes that there is a short time between changes in ambient PM and consequent reductions in the risk of mortality (i.e. it assumes there is no lag). If, alternatively, it were judged that there was a significant time-lag between changes in ambient PM and changes in risks of mortality, then the valuation of mortality impacts would differ, because these effects would occur in the future and would be subject to economic discounting.

A scoping analysis has been undertaken for the baseline on various time-lags between changes in pollution and changes in death rates. The only alternative position to the zero lag with a reasonable level of acceptance is that proposed by US EPA in its analysis of the costs and benefits of the US Clean Air Act, where it is assumed that 30% of the effect of reduced pollution on death rates occurs immediately (year 1); 50% of the effect is distributed over years 2-5; and the remaining 20% is distributed over years 6-20. This would have only a modest effect in reducing estimated damage, of around 10%.

Uncertainty analysis: Results

Statistical analysis and sensitivity analysis on mortality valuation

The first part of the uncertainty analysis for the Strategy is to estimate probability distributions for net benefits (total benefit of the core health and crop impacts minus the costs estimated by the RAINS model). The total annual cost of abatement measures across the EU25 estimated by the RAINS model for the Strategy (€7.1 billion per year) is treated as a point estimate with no account taken at this stage of its uncertainty. Probability distributions for the benefits are derived from the assumptions and ranges given in Volume 3 of the Methodology Report for incidence rates for death and illness, exposure-response functions and valuation estimates.

Results are shown in Figure 11, which combines statistical analysis on all core health impacts with sensitivity analysis on the method used for mortality valuation. Extremes are represented by the VOLY-median (lower bound) and VSL-mean (upper bound) combinations. In the centre, the VOLY-mean and VSL-median ranges are virtually indistinguishable.

It is immediately obvious that there is a significant spread in the results, the extremes ranging from a little less than €0 (i.e. a small excess of cost compared to benefit) to a net benefit of €200 billion per year. Overall, the probability that benefits will exceed costs across these results is in excess of 99% (Table 20).

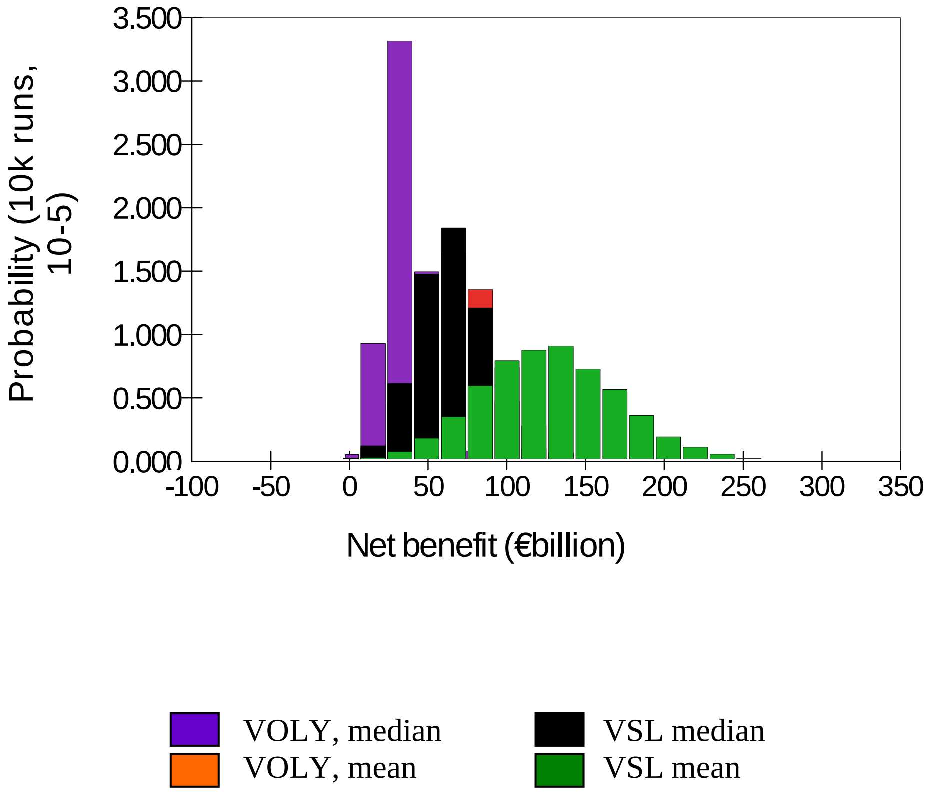


Figure 11. Probability distributions showing net benefit (benefit – cost) for proceeding from the baseline for 2020 to the Strategy, with sensitivity to different approaches to mortality valuation also shown.

Table 20. Annual costs and benefits for the EU25 of proceeding from the baseline for 2020 to the Strategy, and the probability that benefit will exceed cost.

	Cost (core estimate, € billion)	Benefit (core estimate, € billion)	Net benefit (core estimate, € billion)	Probability that benefit > cost
VOLY – median	7.1	42	35	>99%
VOLY – mean	7.1	78	71	>99%
VSL – median	7.1	73	65	>99%
VSL – mean	7.1	136	128	>99%

There is a significant gap in terms of the measures needed to move from the 2020 baseline to the Strategy. From the CBA perspective this is problematic, as it does not ensure that the more expensive measures identified in the RAINS model as necessary to meet Strategy objectives are justified. However, we can approximate a marginal analysis by looking at the costs and benefits of the increment between Scenario A, quantified in our previous report from August 2005, and the Strategy. The results shown in Table 21 demonstrate that for this increment there remains a more than 99% probability of benefits exceeding costs according to the core assumptions made for the benefits analysis.

Table 21. Annual costs and benefits for the EU25 of proceeding from Scenario A to the Strategy, and the probability that benefit will exceed cost.

	Cost (core estimate, € billion)	Benefit (core estimate, € billion)	Net benefit (core estimate, € billion)	Probability that benefit > cost
VOLY – median	1.2	4.7	3.4	>99%
VOLY – mean	1.2	8.8	7.5	>99%
VSL – median	1.2	8.2	6.9	>99%
VSL – mean	1.2	15	14	>99%

Various sensitivity analyses have been run to investigate how robust these estimates are to alternative assumptions relating to mortality assessment (Table 22). If a lower risk factor of 4% per 10µg.m^{-3} was used and if the value of a life year was 75% below the lowest value used in the Cost Benefit Analysis of the Strategy, there would still be a 99% probability that the monetized benefits would be higher than the total costs of the Strategy. In other words, even with these conservative assumptions about risks and value of damage of air pollution to human health, the Strategy is robust. Sensitivity to mortality assessment is low because the costs of meeting the Strategy are more than matched by the benefits of improved morbidity and reduced crop damage.

Table 22. Sensitivity analysis on mortality.

	Probability that monetised benefits are higher than the total costs of the Strategy	
	Baseline to the Strategy	**Scenario A to the Strategy**
1. Use of a 4% per 10µg.m^{-3} risk factor for chronic mortality effects of particles rather than 6%.	99%	97%
2. Reducing the lowest value of a life year adopted (€52,000) by additional 75%. *	99%	96%
3. Combining 1 and 2.	99%	91%

*) This lowering of value of life year lost is not supported by ExternE or NewExt valuation. This low value has been proposed by industry stakeholders (Concawe 2005).

Two other major issues on uncertainty have yet to be addressed. The first is that a number of benefits have not been quantified for the monetised benefits. These include:

1. Health impacts of secondary organic aerosols. A preliminary estimate of additional annual benefits from this effect of between €1.7 and €5.7 billion was made in the earlier report on Scenarios A, B and C (AEA Technology, 2005). A similar additional benefit would be expected under the Strategy.
2. Damage to ecosystems from eutrophication, acidification and ground level ozone.
3. Damage to cultural heritage.

Taken together these impacts would add significantly to the estimated benefits quantified here, further increasing the robustness of the conclusion that benefits are greater than costs for the Strategy.

The second major issue as yet not addressed relates to uncertainty in cost estimates. Several studies (most recently by Watkiss et al, 2005) have demonstrated that forecasts of emission

control costs tend to be significantly overestimated. This may be for a number of reasons, such as:

- Improved abatement efficiency of existing techniques;
- Reduced costs of existing techniques;
- Emergence of new abatement technologies;
- Market trends away from the most polluting options;
- Etc.

The problem of cost overestimation was highlighted by the CAFE report of June 2005 by Amann et al (2005a), which identified a number of factors (CAP reform, implementation of the IPPC Directive in agriculture, use of further emission controls for seagoing ships) that could lead to significant cost savings. This provides further justification for concluding that the result showing that benefits exceed costs is robust.

Assessment of the Macroeconomic Impact of the CAFE Scenarios

Macro-economic analysis was not carried out specifically for the Strategy because results can be extrapolated between Scenarios A and B of the earlier report (AEA Technology, 2005). The costs of the Strategy are about 20% higher than the costs of Scenario A. While the effect of Scenario A on GDP was projected to be 0.04% it can be concluded that the effect of the Strategy on GDP would be about 0.05% in EU25 in 2020[7]. As the effect on employment of Scenarios A and B was very similar, the effect of the Strategy on employment is projected to be in accordance to Scenarios A and B. As the net effect on employment of Scenarios A and B was zero, this is concluded to be the case for the Strategy.

The simulations with GEM-E3 in AEA Technology (2005) allow an assessment of the full economic effects of the scenarios considered. They complement the detailed results from RAINS and the CBA with the impact of air quality policies on the economy. The following conclusions can be drawn of the macroeconomic impact of the Strategy:

- The macroeconomic cost in terms of reduced gross domestic product is about 0.05% in 2020 per annum.
- These costs are very small compared to the health benefits and ecosystem improvements.
- Net effect on employment was zero, implying that some sectors would gain and some lose in terms of employment.
- The benefits of reduced air pollution return mainly to the EU citizens.
- The effect on the competitiveness of the sectors is small because the price effect is limited and all EU member states participate in the abatement effort.

[7] Using Scenario B (which was projected to cost 50% more than the Strategy) as the starting point would yield the same result.

Overall conclusions

This report has estimated the benefits of the Thematic Strategy on Air Pollution in terms of reduced impacts to health, crops, materials and ecosystems across the EU25. In addition, the results of the Maximum Technically Feasible Reduction scenario have been shown for reference.

Ozone concentrations: The Strategy is projected to reduce ozone related mortality in EU25 in 2020 by 1,600 cases, from a baseline of 21,000 cases/year. A similar level of benefits is predicted for respiratory hospital admissions. At the other end of the severity spectrum the Strategy is also estimated to generate 1.5 million less days of respiratory medication use and 3 million fewer minor restricted activity days.

PM concentrations: In 2020 the reduction in PM concentrations arising from the Strategy is estimated to lead to a saving of 556,000 years of life in the EU25. This can also be expressed as 61,000 avoided premature deaths. It is also estimated that the Strategy would avoid 80 infant deaths, 15,000 hospital admissions, 5 million cases of respiratory medication use, and tens of millions of restricted activity days each year.

The monetised equivalent of the health effects is dominated by $PM_{2.5}$ and mortality, though $PM_{2.5}$ related morbidity is also significant.

Annual health benefits of the Strategy range from €42 to €135 billion. The range reflects alternative approaches to mortality valuation.

Non-health impacts across the EU25 – in terms of reduced crop yield and damage to materials – are about €0.5 billion per annum. In monetary terms these impacts are small in relation to health damages overall. However, effects from ozone on crops are similar in magnitude to ozone related health impacts.

Risks to ecosystems in terms of exceedance of critical levels and loads have been analysed by the RAINS model. Extremely high levels of exceedance of the critical level for ozone and forests, and for nitrogen deposition to ecosystems were highlighted. Despite significant improvements with respect to acidification, these ozone and nitrogen deposition continue to pose serious threats to European ecosystems.

Monetised benefits have been compared against the annual costs from the RAINS model, leading to the conclusion that the Strategy will give large net benefits. The health benefits of Strategy are between six (with the low estimate of the value of life year lost) and 19 (with a higher value of human life) times higher than the total costs of the Strategy.

This analysis does not include all benefits. Notably the benefits of improved air pollution to ecosystems and cultural heritage and some health impacts have not been included in the monetised benefits due to lack of data. Investigation of one omitted impact, health effects of secondary organic aerosols, indicates that these omissions are likely to generate significant additional benefits, in excess of €1 billion/year.

Results of the cost-benefit comparison have been subject to an extensive uncertainty analysis. This demonstrates a robust case for moving from the baseline to the Strategy with a very high

probability of benefits exceeding costs (>99% for all plausible sets of assumptions that were tested).

No specific macroeconomic analysis has been carried out for the Strategy. However, based on macroeconomic analysis of Scenarios A, B and C in the earlier stages of analysis it can be concluded that:

- The macroeconomic cost in terms of reduced gross domestic product is about 0.05% in 2020 per annum.
- These costs are very small compared to the health benefits and ecosystem improvements.
- The net effect on employment was zero, implying that some sectors would gain and some lose in terms of employment.
- The benefits of reduced air pollution return mainly to the EU citizens.
- The effect on the competitiveness of the sectors is small because the price effect is limited and all EU Member States participate in the abatement effort.

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