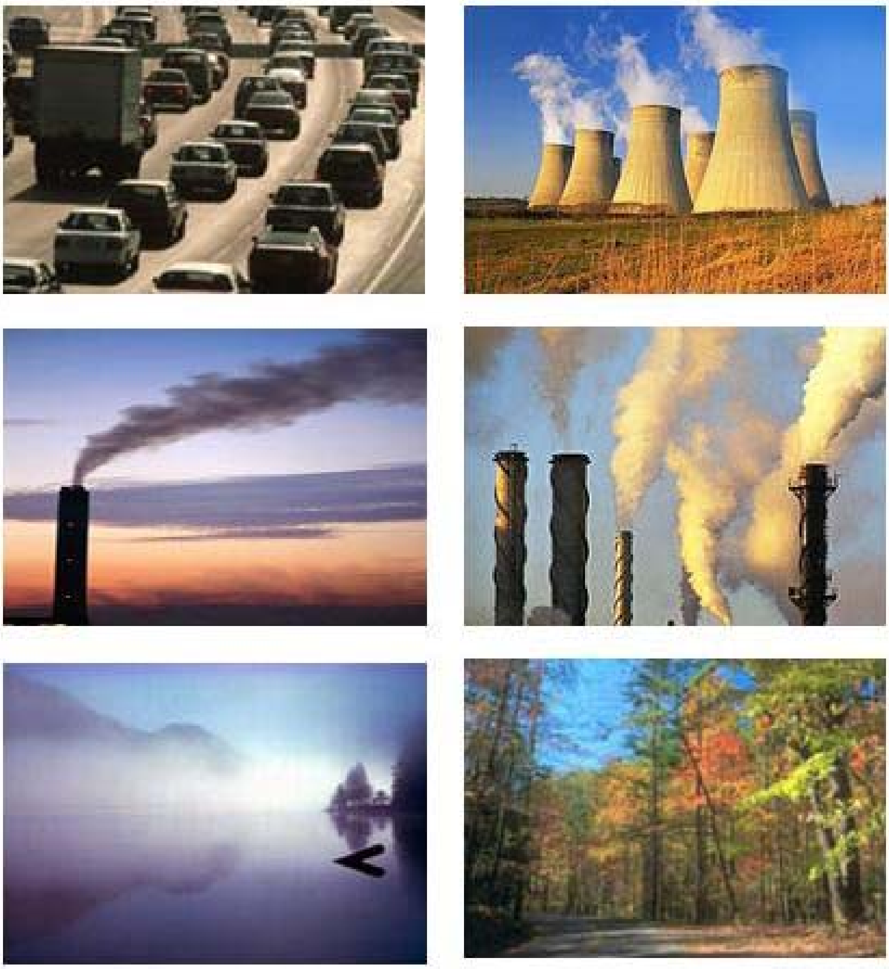
AEAT/ ED48763001/ABC Scenarios. Issue 2

# Cost-Benefit Analysis of Policy Option Scenarios for the Clean Air for Europe programme



## August 2005

**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 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'*.

This report presents the cost-benefit analysis of a series of policy scenarios (labelled A, B and C) proposed for the CAFE programme. These scenarios define low (A), medium (B) and high (C) ambition levels for reducing the impacts of ozone and fine particles on health, and acidification and eutrophication on ecosystems:

**Table i) Selected numerical values of the effect indicators for the CAFE scenarios**

| | ***CLE*** | ***A*** | ***B*** | ***C*** | ***MTFR*** |
|---|---|---|---|---|---|
| Years of life lost due to PM2.5 (EU-wide, million YOLLs) | 137 | 110 | 104 | 101 | 96 |
| Acidification (country-wise gap closure on cumulative excess deposition) | 0% | 55% | 75% | 85% | 100% |
| Eutrophication (country-wise gap closure on cumulative excess deposition) | 0% | 55% | 75% | 85% | 100% |
| **Ozone (country-wise gap closure on SOMO35)** | 0% | 60% | 80% | 90% | 100% |

The term 'gap closure' here relates to the gap between the CLE (baseline) and MTFR (Maximum Technical Feasible Reduction) scenarios. Residual damage, even under the MTFR scenario, can be substantial, as reference to the top row of the table, dealing with years of life lost to fine particle exposure demonstrates.

The analysis takes as its starting point pollution data generated by the EMEP and RAINS models for the current legislation (CLE), A, B, C 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.

A final section deals with macroeconomic impacts, assessed using the GEM-E3 model.

**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 22,000 deaths in the EU25 in 2020, with a reduction to around 18,000 cases per year possible. For particles, the numbers are larger, with 2.5 million life years lost in 2020 under current legislation, falling to around 1.8 million under

Scenario C. 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 2020 in EU25 under current legislation and under Scenarios A, B, C and MTFR. Units: Thousands.**

| End Point Name | CLE 2020 | A | B | C | MTFR |
|---|---|---|---|---|---|
| **Ozone effects** | | | | | |
| Acute Mortality (thousand premature deaths) | 22 | 19 | 19 | 18 | 18 |
| Respiratory Hospital Admissions (thousands) | 20 | 19 | 18 | 18 | 17 |
| Minor Restricted Activity Days (thousands) | 42,000 | 39,000 | 38,000 | 37,000 | 36,000 |
| Respiratory medication use (thousand days, children) | 13,000 | 12,000 | 12,000 | 12,000 | 11,000 |
| Respiratory medication use (thousand days, adults) | 8,200 | 7,500 | 7,300 | 7,200 | 7,000 |
| Cough and LRS (thousand days children) | 65,000 | 60,000 | 59,000 | 58,000 | 56,000 |
| **PM effects** | | | | | |
| Chronic Mortality[1)] – thousand years of life lost (YOLLs) | 2,500 | 2,000 | 1,900 | 1,800 | 1,700 |
| Chronic Mortality[1)] – thousand deaths | 270 | 220 | 210 | 200 | 190 |
| Infant Mortality (0-1yr) – thousand deaths | 0.35 | 0.28 | 0.27 | 0.26 | 0.25 |
| Chronic Bronchitis (thousand cases, adults) | 128 | 103 | 97 | 94 | 90 |
| Respiratory Hospital Admissions (thousands) | 42 | 34 | 32 | 31 | 30 |
| Cardiac Hospital Admissions (thousands) | 26 | 21 | 20 | 19 | 18 |
| Restricted Activity Days (thousands) | 220,000 | 180,000 | 170,000 | 160,000 | 160,000 |
| Respiratory medication use (thousand days, children) | 2,000 | 1,600 | 1,500 | 1,500 | 1,400 |
| Respiratory medication use (thousand days, adults) | 21,000 | 17,000 | 16,000 | 15,000 | 15,000 |
| Lower Respiratory Symptom days (thousands, children) | 89,000 | 71,000 | 67,000 | 65,000 | 62,000 |
| Lower Respiratory Symptom days (thousands, adults) | 210,000 | 170,000 | 160,000 | 150,000 | 150,000 |

Note 1) 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 their monetary equivalent, and added to give a range based on alternative methods for mortality valuation (Table iii).

**Table iii) Core estimates of annual health damage and benefits due to air pollution in 2020 in EU25, with different policy scenario levels, and under a MTFR scenario.**

| | | Billion Euro/year | | | |
|---|---|---|---|---|---|
| **Total Damage** | **CLE** | **A** | **B** | **C** | **MTFR** |
| Low estimate | 189 | 152 | 144 | 140 | 133 |
| High estimate | 609 | 489 | 463 | 449 | 427 |
| **Benefit over CLE baseline** | | **A** | **B** | **C** | **MTFR** |
| Low estimate | | 37 | 45 | 49 | 56 |
| High estimate | | 120 | 146 | 160 | 181 |
| **Incremental Benefits** | | **from CLE to A** | **from A to B** | **from B to C** | **from C to- MTFR** |
| Low estimate | | 37 | 8 | 4 | 7 |
| High estimate | | 120 | 26 | 13 | 22 |

Table iii) shows that the health benefits of the alternative ambition levels range from €37 to 120 billion/year (scenario A) up to €49 to 160 billion/year (scenario C). The additional (incremental) benefits fall with successive scenario, i.e. the incremental benefits of moving from the scenario A to scenario B are greater (at €8 to 26 billion/year) than from scenario B to C (at €4 to 13 billion/year).

**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 CLE baseline. Scenarios A to C yield benefits of between €0.5 to 0.8 billion/year.

Damage to ecosystems has not been monetised as there is currently no adequate basis to perform such analysis. However, information on critical loads exceedance has been generated by the RAINS model, results are summarised in Table iv).

**Table iv) Summary statistics on critical loads and levels, showing % area over which there is exceedance.**

| | | **2000** | **CLE 2020** | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|---|---|---|
| Eutrophication | Ecosystems | 57% | 46% | 33% | 29% | 27% | 15% |
| Acidification | Forests | 21% | 10% | 5.7% | 5.1% | 4.7% | 3.1% |
| Ozone | Forests | 61% | 56% | 52% | 50% | 48% | 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 a few countries (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 their annualised costs, as 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. No account is taken of uncertainty other than in mortality valuation (which generates the Low-High ranges shown). In all cases, even under the MTFR scenario, benefits exceed costs.

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

| | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|
| **EU Annualised benefits (health, materials and crops) change over base** | | | | |
| Low estimate | 38 | 46 | 50 | 57 |
| High estimate | 120 | 147 | 160 | 182 |
| **EU-25 Annualised Costs - change over base line** | | | | |
| Total | 5.9 | 10.7 | 14.9 | 39.7 |
| **NET benefits** | | | | |
| Low estimate | 32 | 35 | 35 | 17 |
| High estimate | 115 | 136 | 145 | 142 |
| **Benefit to Cost Ratio** | | | | |
| Low estimate | 6.3 | 4.3 | 3.4 | 1.4 |
| High estimate | 20 | 14 | 11 | 4.6 |

Results in Table vi) show net benefits and benefit:cost ratios for the increments between adjacent scenarios, again taking no account of uncertainty in the analysis beyond low and high mortality valuations. The Table reveals the following:

- Core estimates of incremental benefits (to the extent that they are quantified and monetised) exceed costs at least as far as Scenario B.
- When going from scenario B to scenario C, the costs are broadly equal to the low estimate of benefits – though they are lower than the high estimate. This is, naturally, reflected in the benefit to cost ratio, which ranges from 0.98 to 3 for the low and high estimate of benefits.
- When going from scenario C to the MTFR, the costs of the additional measures outweigh the monetised benefits that have been quantified in monetary terms– this applies to the full range of estimates accounting for both low and high estimates. This is also reflected in the low benefit:cost ratios, which are all under 1 (i.e. it is not possible on these benefits alone to justify the policy intervention).

**Table vi) Comparison of annualised costs and benefits for the EU25 for the increments between successive policy scenarios. No account is taken of damage to ecosystems, some health impacts, and cultural heritage.**

| | from CLE to A | from A to B | from B to C | from C to MTFR |
|---|---|---|---|---|
| **EU incremental annualised benefits (health and crops)** | | | | |
| Total with Mortality – VOLY – low (median) | 38 | 8.3 | 4.1 | 6.9 |
| Total with Mortality – VSL – high (mean) | 120 | 27 | 13 | 22 |
| **EU-25 annualised costs in Billion€/year - incremental changes to each scenario** | | | | |
| Total | 5.9 | 4.8 | 4.2 | 25 |
| **NET incremental benefits** | | | | |
| Total with Mortality – VOLY – low (median) | 32 | 3.5 | -0.03 | -18 |
| Total with Mortality – VSL – high (mean) | 115 | 22 | 9.1 | -3.0 |
| **Benefit to cost ratio** | | | | |
| Total with Mortality – VOLY – low (median) | 6.3 | 1.7 | 0.98 | 0.3 |
| Total with Mortality – VSL – high (mean) | 20 | 5.6 | 3.2 | 0.9 |

It is stressed that the analysis above does not include all benefits – notably it excludes benefits to ecosystems, some health impacts (e.g. those of secondary organic aerosols, SOAs) and impacts on cultural heritage. That these impacts are likely to add significant benefits to those already quantified is evident from a scoping analysis on SOAs, indicating benefits between €1.7 and 5.7 billion/year as a result of moving from Baseline to Scenario A, and €2.9 to 9.5 billion/year for moving from Baseline to Scenario C. Addition of SOA related benefits would be sufficient to transform the net cost for the low estimate of benefits when moving from scenario B to scenario C to a net benefit. 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 core cost-benefit comparison shown in Tables v) and vi) have been subject to an extensive uncertainty analysis. This has considered the following factors in particular:

- Statistical uncertainty in health benefit inputs for incidence rates, response functions and valuation data;

- Sensitivity to the use of alternative approaches to mortality assessment;
- Sensitivity to uncertainty in cost estimates (taking a range from 50% of the RAINS estimated costs for each scenario to 120%, bearing in mind a tendency observed elsewhere for abatement cost data *ex-ante* (before implementation) to be higher than *ex-post* (actual));
- 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 demonstrate that there is a robust case for moving to Scenario A and Scenario B with a very high probability of benefits exceeding costs (in most cases >90%). A case is also made for proceeding to Scenario C, though this is not quite as robust, and is dependent on the views of decision makers regarding 2 issues:

1. The magnitude of benefits that are not quantified under the core analysis;
2. What constitutes an acceptable probability of deriving a net benefit to justify action being initiated.

The case for moving to Scenario C becomes much firmer, however, if it is believed that the core RAINS estimates of costs are likely to be too high, in line with evidence of the relationship between ex-ante and ex-post cost estimates and also some of the sensitivity analysis provided in the RAINS report on the A, B, C scenarios. Based on the assumption that the policy option should be based on marginal costs being smaller than the marginal benefits there is no case made for moving to the MTFR scenario: costs would need to be vastly overestimated and benefits substantially underestimated.

**Macroeconomic analysis using GEM-E3**

The final part of the report deals with the macroeconomic effects of the policies under each scenario, based on use of the GEM-E3 model (General Equilibrium Model – Energy, Economy, Environment). The following conclusions are drawn:

- The macroeconomic cost of air pollution reduction is limited compared to the benefits obtained in terms of air quality, health and ecosystem improvement, though at the margin (moving from Scenario B to Scenario C) the additional benefits do not compensate for the additional cost in terms of GDP. Note, however, that the GEM-E3 assessment was performed only for the low benefit estimate using the median value of life year (VOLY) which is the lowest in the range.
- The benefits of reduced air pollution return mainly to the EU citizens.
- The effect on the competitiveness of the sectors remains small because the price effect is limited and all EU member states participate in the abatement effort.
- Depending on the policy instrument used the allocation of the burden is different: with a quantity instrument (allowance or performance standard) the cost burden falls mostly on the domestic consumers and therefore on the consumer goods industry, while with the tax instruments (which is analytically the same as an auctioned allowance system) the burden is more evenly spread through the recycling of the revenues.

There are a few important caveats. First these results hold as long as the allocation of effort over the sectors and countries is cost-effective. Second no implementation and monitoring costs have been taken into account because these are likely to be very small compared to the abatement costs. Third all results are based on the low benefit estimate based on use of the median VOLY (value of a life year) for mortality valuation.

It is concluded that the macroeconomic analysis confirms the conclusions drawn from the core analysis and sensitivity analysis. It is appropriate to choose an ambition level of at least Scenario B and possibly Scenario C.

**Overall conclusions**

This report summarises the benefits of the multi-effect policy option scenarios for three ambition levels for air quality in Europe in 2020. It shows that large benefits are predicted to occur from these scenarios, with monetised air pollution benefits in the range between €37 billion and €160 billion for the year 2020, depending on the level of ambition and the estimate (low – high) for mortality.

The cost-benefit analysis shows that the benefits of the three policy scenario levels exceed costs, significantly so for the high estimate of benefits. These conclusions are confirmed in the macroeconomic analysis: it is appropriate to choose an ambition level of at least Scenario B and possibly Scenario C.

It should be emphasized that the above conclusion excludes benefits from effects not included in the monetary framework – notably benefits because of reduced damage to ecosystems and cultural heritage. Including these effects would increase the monetised benefits of reduced air pollution.

## Acknowledgements

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The RAINS team under the leadership of Markus Amann at the International Institute for Applied Systems Analysis.

The EMEP/MSC-W team providing atmospheric dispersion calculations under the leadership of Leonor Tarrason at the Norwegian Meteorological Institute

# 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 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 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 will present its Thematic Strategy on Air Pollution during 2005, 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 a series of scenarios that investigate options 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), assuming that countries fulfil their Kyoto obligations and carry on implementing greenhouse gas reduction policies through to 2020. The legislation considered in the CLE scenario is summarised in Table 1.

**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 | Product directive (paints) | |
| | National legislation and national practices (if stricter) | National legislation, e.g., Stage II | |

Earlier analysis 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[1]. This allowed identification of a series of low, medium and high policy scenario (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 scenarios, A, B and C.

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

| | ***CLE*** | ***A*** | ***B*** | ***C*** | ***MTFR*** |
|---|---|---|---|---|---|
| Years of life lost due to PM2.5 (EU-wide, million YOLLs) | 137 | 110 | 104 | 101 | 96 |
| Acidification (country-wise gap closure on cumulative excess deposition) | 0% | 55% | 75% | 85% | 100% |
| Eutrophication (country-wise gap closure on cumulative excess deposition) | 0% | 55% | 75% | 85% | 100% |
| **Ozone (country-wise gap closure on SOMO35)** | 0% | 60% | 80% | 90% | 100% |

The term 'gap closure' here relates to the gap between the CLE and MTFR scenarios. Residual damage, even under the MTFR scenario, can be substantial, as reference to the top row of the table, dealing with years of life lost to fine particle exposure demonstrates.

Following from Table 2 it is to be expected that the incremental benefits between scenarios (i.e. comparing the benefit of moving from CLE to A, with that of moving from A to B and so on) are not equal.

## Methods

The CAFE CBA methodology was described in three volumes (Holland et al, 2005a, b; Hurley et al, 2005) available from http://www.cafe-cba.org. The development of the CAFE CBA methodology can be traced back to the start 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 RAINS and CBA models. RAINS identifies a cost-effective set of measures for meeting pre-defined health and environmental quality

[1] 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.

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 RAINS model.

This approach follows a logical progression through the following stages:

1. Quantification of emissions (in CAFE, covered by the RAINS model);
2. Description of pollutant dispersion and chemistry across Europe (in CAFE, covered by the RAINS and EMEP models);
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 RAINS model and their associated benefits.

In this report health impacts are quantified first, both in terms of the change in incidence in mortality and morbidity impacts, and then in terms of monetary equivalent. This is followed by quantification of the economic impacts of damage to materials and crops, and assessment of critical loads exceedance for ecosystems. Ecosystem impacts are not monetised.

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 we quantify chronic mortality 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 new 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. Being pragmatic, we use both. Altogether this gives four alternatives on valuation as shown in Table 3.

**Table 3. 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 CBA Methodology Report. These uncertainties are considered sufficiently important to be considered throughout the report, not just in the detailed appraisal of uncertainties towards the end of the report.

A further factor considered for chronic mortality impacts is variation in the risk factor for impact quantification. Following WHO guidance a risk factor of 6% change in mortality rate per 10µg.m$^{-3}$ PM $_{2.5}$ is used for the core analysis, whilst for sensitivity analysis a factor of 4% is used.

For acute mortality from ozone, the analysis quantifies the number of 'premature deaths' (deaths brought forward)[2]. These cases are valued using a VOLY approach, assuming that on average, each premature deaths 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 RAINS 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.

The final part of the report investigates the macroeconomic consequences of the A, B and C scenarios, based on analysis using the GEM-E3 model.

## Data inputs

Most of the data inputs to the CBA relating to stock at risk, exposure-response functions and valuation are defined in the CBA methodology report. In addition, data on emissions, abatement costs, concentrations of PM, and some impacts (e.g. critical loads exceedance data for ecosystems) are taken from the RAINS model. With respect to PM concentration, RAINS approximates the results of the EMEP model on a grid scale of 50x50 km, supplemented by results of the CITY-DELTA project to factor in higher urban concentrations of PM in densely populated areas. For ozone, the study has used results from the EMEP model directly. Concentration data are estimated using the meteorology of 1997.

[2] 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.

# 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 with the three policy scenario levels (A, B, C) and the MTFR in 2020.

As detailed in the previous section, 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 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 ppb[3]).

The results show the number of events that happen 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.

As outlined in the previous section, 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 for the three policy scenario levels and the MTFR scenario. Table 5 shows the change in impacts, i.e. the benefits, of each scenario over the 2020 baseline.

Table 6 shows the incremental change in impacts, i.e. benefits, between each of the scenarios, i.e. from the baseline to scenario A, from scenario A to scenario B. etc.

For the analysis 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

[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.

model runs (March 2005)[5].  This modelling is consistent with other information presented on the scenario analysis under the CAFE programme.

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[5] A final set of scenarios for the Clean Air for Europe (CAFE) programme.  Report number 6.  IIASA. April 14th, 2005.  Draft Version.

**Table 4. Analysis of Scenarios for the Clean Air for Europe programme: Estimated annual health impacts due to air pollution in 2020 in EU25, plus the total impacts with each of the policy scenario levels and the MTFR (2020)**

| End Point Name | CORE Functions | | CLE 2020 | A | B | C | MTFR |
|---|---|---|---|---|---|---|---|
| Acute Mortality | Premature deaths | $O_3$ | 20,800 | 19,200 | 18,600 | 18,300 | 17,759 |
| Respiratory Hospital Admissions (65yr +) | Cases | $O_3$ | 20,100 | 18,500 | 18,000 | 17,700 | 17,160 |
| Minor Restricted Activity Days (MRADs 15-64yr) | Days | $O_3$ | 42,415,500 | 39,191,000 | 38,119,800 | 37,477,100 | 36,484,733 |
| Respiratory medication use (children 5-14yr) | Days | $O_3$ | 12,925,900 | 11,961,000 | 11,644,900 | 11,452,900 | 11,164,595 |
| Respiratory medication use (adults 20yr +) | Days | $O_3$ | 8,171,700 | 7,548,200 | 7,340,900 | 7,217,000 | 7,025,333 |
| Cough and LRS (children 0-14yr) | Days | $O_3$ | 65,278,600 | 60,350,200 | 58,714,800 | 57,732,500 | 56,204,229 |
| Chronic Mortality – YOLL | Life years lost | PM | 2,467,300 | 1,974,800 | 1,866,500 | 1,812,700 | 1,722,700 |
| Chronic Mortality – deaths | Premature deaths | PM | 271,600 | 217,800 | 205,900 | 200,000 | 190,200 |
| Infant Mortality (0-1yr) | Premature deaths | PM | 350 | 280 | 270 | 260 | 250 |
| Chronic Bronchitis (27yr +) | Cases | PM | 128,100 | 102,600 | 97,000 | 94,200 | 89,600 |
| Respiratory Hospital Admissions (All ages) | Cases | PM | 42,300 | 33,800 | 32,000 | 31,100 | 29,500 |
| Cardiac Hospital Admissions (All ages) | Cases | PM | 26,100 | 20,900 | 19,700 | 19,200 | 18,200 |
| Restricted Activity Days (15-64yr) | Days | PM | 221,999,100 | 177,597,000 | 167,894,700 | 163,064,800 | 154,985,400 |
| Respiratory medication use (children 5-14yr) | Days | PM | 1,987,700 | 1,589,600 | 1,497,200 | 1,453,800 | 1,379,300 |
| Respiratory medication use (adults 20yr +) | Days | PM | 20,879,800 | 16,713,200 | 15,803,300 | 15,348,900 | 14,591,600 |
| Lower Respiratory Symptom days (children 5-14) | Days | PM | 88,852,300 | 71,136,400 | 67,155,300 | 65,221,800 | 61,889,500 |
| LRS among adults (15yr +) with chronic symptoms | Days | PM | 207,562,100 | 166,139,500 | 157,056,600 | 152,532,900 | 144,995,400 |

*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 5. Analysis of the Scenarios for the Clean Air for Europe programme : Estimated annual health benefits (i.e. the difference between the CLE baseline and the policy option scenario) in 2020 in EU25, for each of the policy scenario levels and the MTFR (2020)**

| End Point Name | CORE Functions | | A | B | C | MTFR |
|---|---|---|---|---|---|---|
| Acute Mortality (All ages) | Premature deaths | $O_3$ | 1,600 | 2,200 | 2,500 | 3,041 |
| Respiratory Hospital Admissions (65yr +) | Cases | $O_3$ | 1,600 | 2,100 | 2,400 | 2,940 |
| Minor Restricted Activity Days (MRADs 15-64yr) | Days | $O_3$ | 3,224,500 | 4,295,700 | 4,938,400 | 5,930,767 |
| Respiratory medication use (children 5-14yr) | Days | $O_3$ | 964,900 | 1,281,000 | 1,473,000 | 1,761,305 |
| Respiratory medication use (adults 20yr +) | Days | $O_3$ | 623,500 | 830,800 | 954,700 | 1,146,367 |
| Cough and LRS (children 0-14yr) | Days | $O_3$ | 4,928,400 | 6,563,800 | 7,546,100 | 9,074,371 |
| Chronic Mortality – YOLL | Life years lost | PM | 492,500 | 600,800 | 654,600 | 744,600 |
| Chronic Mortality – deaths | Premature deaths | PM | 53,800 | 65,700 | 71,600 | 81,400 |
| Infant Mortality (0-1yr) | Premature deaths | PM | 70 | 80 | 90 | 100 |
| Chronic Bronchitis (27yr +) | Cases | PM | 25,500 | 31,100 | 33,900 | 38,500 |
| Respiratory Hospital Admissions (All ages) | Cases | PM | 8,500 | 10,300 | 11,200 | 12,800 |
| Cardiac Hospital Admissions (All ages) | Cases | PM | 5,200 | 6,400 | 6,900 | 7,900 |
| Restricted Activity Days (15-64yr) | Days | PM | 44,402,100 | 54,104,400 | 58,934,300 | 67,013,700 |
| Respiratory medication use (children 5-14yr) | Days | PM | 398,100 | 490,500 | 533,900 | 608,400 |
| Respiratory medication use (adults 20yr +) | Days | PM | 4,166,600 | 5,076,500 | 5,530,900 | 6,288,200 |
| Lower Respiratory Symptom (LRS) days (child 5-14yr) | Days | PM | 17,715,900 | 21,697,000 | 23,630,500 | 26,962,800 |
| LRS among adults (15yr +) with chronic symptoms | Days | PM | 41,422,600 | 50,505,500 | 55,029,200 | 62,566,700 |

*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 6. Analysis of the Scenarios for the Clean Air for Europe programme : Estimated incremental annual health benefits due to air pollution in 2020 in EU25for each step of the policy scenario levels and the MTFR (2020).**

| End Point Name | CORE Functions | | Baseline - A | A - B | B - C | C - MTFR |
|---|---|---|---|---|---|---|
| Acute Mortality (All ages) | Premature deaths | $O_3$ | 1,600 | 600 | 300 | 541 |
| Respiratory Hospital Admissions (65yr +) | Cases | $O_3$ | 1,600 | 500 | 300 | 540 |
| Minor Restricted Activity Days (MRADs 15-64yr) | Days | $O_3$ | 3,224,500 | 1,071,200 | 642,700 | 992,367 |
| Respiratory medication use (children 5-14yr) | Days | $O_3$ | 964,900 | 316,100 | 192,000 | 288,305 |
| Respiratory medication use (adults 20yr +) | Days | $O_3$ | 623,500 | 207,300 | 123,900 | 191,667 |
| Cough and LRS (children 0-14yr) | Days | $O_3$ | 4,928,400 | 1,635,400 | 982,300 | 1,528,271 |
| Chronic Mortality – YOLL | Life years lost | PM | 492,500 | 108,300 | 53,800 | 90,000 |
| Chronic Mortality – deaths | Premature deaths | PM | 53,800 | 11,900 | 5,900 | 9,800 |
| Infant Mortality (0-1yr) | Premature deaths | PM | 70 | 10 | 10 | 10 |
| Chronic Bronchitis (27yr +) | Cases | PM | 25,500 | 5,600 | 2,800 | 4,600 |
| Respiratory Hospital Admissions (All ages) | Cases | PM | 8,500 | 1,800 | 900 | 1,600 |
| Cardiac Hospital Admissions (All ages) | Cases | PM | 5,200 | 1,200 | 500 | 1,000 |
| Restricted Activity Days (15-64yr) | Days | PM | 44,402,100 | 9,702,300 | 4,829,900 | 8,079,400 |
| Respiratory medication use (children 5-14yr) | Days | PM | 398,100 | 92,400 | 43,400 | 74,500 |
| Respiratory medication use (adults 20yr +) | Days | PM | 4,166,600 | 909,900 | 454,400 | 757,300 |
| Lower Respiratory Symptom (LRS) days (child. 5-14yr) | Days | PM | 17,715,900 | 3,981,100 | 1,933,500 | 3,332,300 |
| LRS among adults (15yr +) with chronic symptoms | Days | PM | 41,422,600 | 9,082,900 | 4,523,700 | 7,537,500 |

*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.

## Health impact assessment - discussion

***Ozone concentrations:*** Annual impacts across the EU 25 are estimated at some 21 000 deaths brought forward in the year 2020. 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 progressive ambition levels (A, B, C) are estimated to reduce the total impacts from ozone on health, with some 1600 to 2500 avoided deaths brought forward, depending on the ambition level. A similar level of benefits is predicted for respiratory hospital admissions. For other morbidity endpoints, the levels of benefits are greater, for example with the scenarios estimated to have benefits of 1.5 million to 2.5 million cases of respiratory medication use, and 3 million to 5 million minor restricted activity days. The incremental analysis in Table 6 shows that a greater incremental benefit occurs in moving from scenario A to B, than from scenario B to C.[6]

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

The progressive ambition levels (A, B, C) reduce the total impacts from PM on health, with some 500,000 to 650,000 years of life saved each year – this can also be expressed as 54,000 to 72,000 avoided premature deaths. There is also an additional benefit in avoiding 70 to 90 infant mortality deaths. For other morbidity endpoints, the levels of benefits are greater, for example with the scenarios estimated to avoid 14,000 to 18,000 hospital admissions, 4.5 million to 6 million cases of respiratory medication use, and tens of millions of restricted activity days. Again, the incremental analysis in Table 6 shows that a greater incremental benefit occurs in moving from scenario A to B, than from scenario B to C.[6]

[6] Note that the difference between scenarios A and B is slightly different from the difference between scenarios B and C.

# 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.

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 the level of economic importance, as well as the changes in benefits. The methodology is described in full in Volume 2 of the Methodology reports. Values are presented for the EU25.  The analysis has also considered the benefits of the ambition levels (A, B, C) and the MTFR.

As outlined in the earlier methodology section, there are two methods that can be used for the valuation of chronic mortality – 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 are presented.  This reflects the range in valuation for a year of life lost from the NewExt study based on the median and mean reported values.  For chronic mortality, four alternative core scenarios are presented. This reflects the range from the two quantification approaches (years of life lost and VOLYs - and premature deaths and the VSL) and the range of mean and median values from the NewExt study for each of these approaches.

## Valuation - results

The results are shown in Table 7.  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 three ambition levels and the MTFR scenario.

Table 8 shows the change in damage, i.e. the benefits, of each scenario over the 2020 baseline.

Table 9 shows the incremental change in damage, i.e. benefits, between each of the scenarios, i.e. from the baseline to scenario A, from scenario A to scenario B. etc.

The analysis shows that the health benefits of the alternative ambition levels range from 37 to €120 billion/year (scenario A), up to €49 to 160 billion/year (scenario C).  The additional (incremental) benefits fall with successive scenario, i.e. the incremental benefits of moving from the scenario A to scenario B are greater (€8 to 26 billion/year) than from scenario B to C (€4 to 13 billion/year).

**Table 7. Valuation of the annual health damage in EU25 (€Million/year) due to air pollution in 2020 for the baseline, Analysis of the scenarios for the Clean Air for Europe programme , and the MTFR**

| **End Point Name** | | **Baseline 2020** | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|---|---|
| Acute Mortality (VOLY median)* | $O_3$ | 1085 | 1002 | 975 | 958 | 933 |
| Acute Mortality (VOLY mean*) | $O_3$ | 2435 | 2250 | 2188 | 2151 | 2093 |
| Respiratory Hospital Admissions (65yr +) | $O_3$ | 40 | 37 | 36 | 36 | 35 |
| Minor Restricted Activity Days (MRADs 15-64yr) | $O_3$ | 1629 | 1506 | 1464 | 1440 | 1402 |
| Respiratory medication use (children 5-14yr) | $O_3$ | 12 | 11 | 11 | 11 | 10 |
| Respiratory medication use (adults 20yr +) | $O_3$ | 8 | 7 | 7 | 7 | 7 |
| Cough and LRS (children 0-14yr) | $O_3$ | 2508 | 2318 | 2256 | 2218 | 2159 |
| Chronic Mortality – VOLY – low (median) | PM | 129,000 | 103,250 | 97,588 | 94,775 | 90,073 |
| Chronic Mortality – VOLY – high (mean) | PM | 289,556 | 231,758 | 219,048 | 212,734 | 202,180 |
| Chronic Mortality – VSL – low (median) | PM | 265,965 | 213,239 | 201,652 | 195,842 | 186,285 |
| Chronic Mortality – VSL – high (mean) | PM | 547,200 | 438,721 | 414,881 | 402,929 | 383,265 |
| Infant Mortality (0-1yr) – low (median) | PM | 495 | 395 | 374 | 363 | 345 |
| Infant Mortality (0-1yr) – high *mean) | PM | 990 | 790 | 747 | 726 | 689 |
| Chronic Bronchitis (27yr +) | PM | 24,011 | 19,225 | 18,184 | 17,662 | 16,792 |
| Respiratory Hospital Admissions (All ages) | PM | 85 | 68 | 64 | 62 | 59 |
| Cardiac Hospital Admissions (All ages) | PM | 52 | 42 | 40 | 38 | 37 |
| Restricted Activity Days (RADs 15-64yr) | PM | 18,515 | 14,812 | 14,002 | 13,600 | 12,926 |
| Respiratory medication use (children 5-14yr) | PM | 2 | 1 | 1 | 1 | 1 |
| Respiratory medication use (adults 20yr +) | PM | 20 | 16 | 15 | 14 | 14 |
| LRS symptom days (children 5-14yr) | PM | 3,413 | 2,733 | 2,580 | 2,506 | 2,378 |
| LRS among adults (15yr +) with chronic symptoms | PM | 7,974 | 6,383 | 6,034 | 5,860 | 5,570 |
| **Total with Mortality – VOLY – low (median)** | | **188,849** | **151,806** | **143,631** | **139,551** | **132,741** |
| **Total with Mortality – VOLY – high (mean)** | | **351,250** | **281,957** | **266,677** | **259,066** | **246,352** |
| **Total with Mortality – VSL – low (median)** | | **325,814** | **261,795** | **247,695** | **240,618** | **228,953** |
| **Total with Mortality – VSL – high (mean)** | | **608,894** | **488,920** | **462,510** | **449,261** | **427,437** |

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

**Table 8. Valuation of the annual health benefits in EU25 (€Million/year) due to air pollution in 2020 above the baseline, Analysis of the scenarios for the Clean Air for Europe programme , and the MTFR**

| **End Point Name** | | **Baseline** | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|---|---|
| Acute Mortality (VOLY median)* | $O_3$ | | 83 | 110 | 127 | 152 |
| Acute Mortality (VOLY mean*) | $O_3$ | | 186 | 248 | 285 | 342 |
| Respiratory Hospital Admissions (65yr +) | $O_3$ | | 3 | 4 | 5 | 6 |
| Minor Restricted Activity Days (MRADs 15-64yr) | $O_3$ | | 124 | 165 | 190 | 228 |
| Respiratory medication use (children 5-14yr) | $O_3$ | | 1 | 1 | 1 | 2 |
| Respiratory medication use (adults 20yr +) | $O_3$ | | 1 | 1 | 1 | 1 |
| Cough and LRS (children 0-14yr) | $O_3$ | | 189 | 252 | 290 | 349 |
| Chronic Mortality – VOLY – low (median) | PM | | 25,750 | 31,412 | 34,225 | 38,927 |
| Chronic Mortality – VOLY – high (mean) | PM | | 57,798 | 70,508 | 76,822 | 87,377 |
| Chronic Mortality – VSL – low (median) | PM | | 52,726 | 64,313 | 70,122 | 79,680 |
| Chronic Mortality – VSL – high (mean) | PM | | 108,479 | 132,319 | 144,271 | 163,935 |
| Infant Mortality (0-1yr) – low (median) | PM | | 100 | 121 | 132 | 150 |
| Infant Mortality (0-1yr) – high *mean) | PM | | 199 | 242 | 264 | 300 |
| Chronic Bronchitis (27yr +) | PM | | 4,786 | 5,827 | 6,348 | 7,219 |
| Respiratory Hospital Admissions (All ages) | PM | | 17 | 21 | 23 | 26 |
| Cardiac Hospital Admissions (All ages) | PM | | 10 | 13 | 14 | 16 |
| Restricted Activity Days (RADs 15-64yr) | PM | | 3,703 | 4,512 | 4,915 | 5,589 |
| Respiratory medication use (children 5-14yr) | PM | | 0 | 0 | 1 | 1 |
| Respiratory medication use (adults 20yr +) | PM | | 4 | 5 | 5 | 6 |
| LRS symptom days (children 5-14yr) | PM | | 681 | 834 | 908 | 1,036 |
| LRS among adults (15yr +) with chronic symptoms | PM | | 1,591 | 1,940 | 2,114 | 2,404 |
| **Total with Mortality – VOLY – low (median)** | | | **37,043** | **45,218** | **49,299** | **56,112** |
| **Total with Mortality – VOLY – high (mean)** | | | **69,293** | **84,573** | **92,186** | **104,902** |
| **Total with Mortality – VSL – low (median)** | | | **64,019** | **78,119** | **85,196** | **96,865** |
| **Total with Mortality – VSL – high (mean)** | | | **119,974** | **146,384** | **159,635** | **181,460** |

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

**Table 9. Valuation of the incremental annual health benefits in EU25 (€Million/year) for each step of the ambition levels and the MTFR due to air pollution in 2020**

| End Point Name | | Baseline - A | A - B | B - C | C - MTFR |
|---|---|---|---|---|---|
| Acute Mortality (VOLY median)* | $O_3$ | 83 | 28 | 16 | 25 |
| Acute Mortality (VOLY mean*) | $O_3$ | 186 | 62 | 37 | 57 |
| Respiratory Hospital Admissions (65yr +) | $O_3$ | 3 | 1 | 1 | 1 |
| Minor Restricted Activity Days (MRADs 15-64yr) | $O_3$ | 124 | 41 | 25 | 38 |
| Respiratory medication use (children 5-14yr) | $O_3$ | 1 | 0 | 0 | 0 |
| Respiratory medication use (adults 20yr +) | $O_3$ | 1 | 0 | 0 | 0 |
| Cough and LRS (children 0-14yr) | $O_3$ | 189 | 63 | 38 | 59 |
| Chronic Mortality – VOLY – low (median) | PM | 25,750 | 5,663 | 2,813 | 4,702 |
| Chronic Mortality – VOLY – high (mean) | PM | 57,798 | 12,710 | 6,314 | 10,555 |
| Chronic Mortality – VSL – low (median) | PM | 52,726 | 11,587 | 5,809 | 9,558 |
| Chronic Mortality – VSL – high (mean) | PM | 108,479 | 23,840 | 11,952 | 19,665 |
| Infant Mortality (0-1yr) – low (median) | PM | 100 | 22 | 11 | 18 |
| Infant Mortality (0-1yr) – high *mean) | PM | 199 | 43 | 21 | 37 |
| Chronic Bronchitis (27yr +) | PM | 4,786 | 1,041 | 521 | 870 |
| Respiratory Hospital Admissions (All ages) | PM | 17 | 4 | 2 | 3 |
| Cardiac Hospital Admissions (All ages) | PM | 10 | 2 | 1 | 2 |
| Restricted Activity Days (RADs 15-64yr) | PM | 3,703 | 809 | 403 | 674 |
| Respiratory medication use (children 5-14yr) | PM | 0 | 0 | 0 | 0 |
| Respiratory medication use (adults 20yr +) | PM | 4 | 1 | 0 | 1 |
| LRS symptom days (children 5-14yr) | PM | 681 | 153 | 74 | 128 |
| LRS among adults (15yr +) with chronic symptoms | PM | 1,591 | 349 | 174 | 290 |
| **Total with Mortality – VOLY – low (median)** | | **37,043** | **8,177** | **4,079** | **6,811** |
| **Total with Mortality – VOLY – high (mean)** | | **69,293** | **15,279** | **7,611** | **12,715** |
| **Total with Mortality – VSL – low (median)** | | **64,019** | **14,101** | **7,075** | **11,667** |
| **Total with  Mortality – VSL – high (mean)** | | **119,974** | **26,409** | **13,249** | **21,825** |

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.

# 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 10 presents the total crop yield loss from ozone exposure for the EU25 with baseline ozone pollution concentrations in 2020, and with the different ambition levels for policy options scenarios. The total damage in the year 2020 are estimated at just above €1.5 billion/year– with estimated benefits of the scenarios from €0.3 to 0.5 billion/year.

**Table 10. Estimated annual crop damage due to air pollution (ozone) in 2020 in EU25, and benefits of the final set of scenarios for the Clean Air for Europe programme and the MTFR (€Million)**

| **Total Damage per Year, EU25, 2020.** | | | | |
|---|---|---|---|---|
| **Baseline** | **A** | **B** | **C** | **MTFR** |
| 1511 | 1179 | 1096 | 1052 | 997 |
| **Benefits. Change in Valuation over baseline,** | | | | |
| **Baseline** | **A** | **B** | **C** | **MTFR** |
| 0 | 332 | 416 | 460 | 514 |
| **Incremental Benefits, as Change in Valuation from each policy step,** | | | | |
| | **from baseline to A** | **from A to B** | **from B to C** | **from C to MTFR** |
| | 332 | 83 | 44 | 55 |

The analysis of crop damage shows that these effects are small in economic terms in relation to health effects overall (i.e. including PM 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 11 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 scenarios from €0.19 to 0.28 billion/year above the baseline.

**Table 11. Estimated annual damage to materials used in utilitarian applications from acid deposition in 2020 in EU25, and benefits of the final set of scenarios for the Clean Air for Europe programme and the MTFR (€Million)**

| **Total Damage per Year, EU25, 2020.** | | | | |
|---|---|---|---|---|
| **Baseline** | **A** | **B** | **C** | **MTFR** |
| 740 | 550 | 510 | 490 | 460 |
| **Benefits. Change in Valuation over baseline,** | | | | |
| **Baseline** | **A** | **B** | **C** | **MTFR** |
| 0 | 190 | 230 | 250 | 280 |
| **Incremental Benefits, as Change in Valuation from each policy step,** | | | | |
| | **from baseline to A** | **from A to B** | **from B to C** | **from C to MTFR** |
| | 190 | 40 | 20 | 30 |

## Ecosystems

The results provided in this section were generated by the RAINS model and are presented also in the report on the A, B and C scenarios from IIASA (Amann et al, 2005). 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.

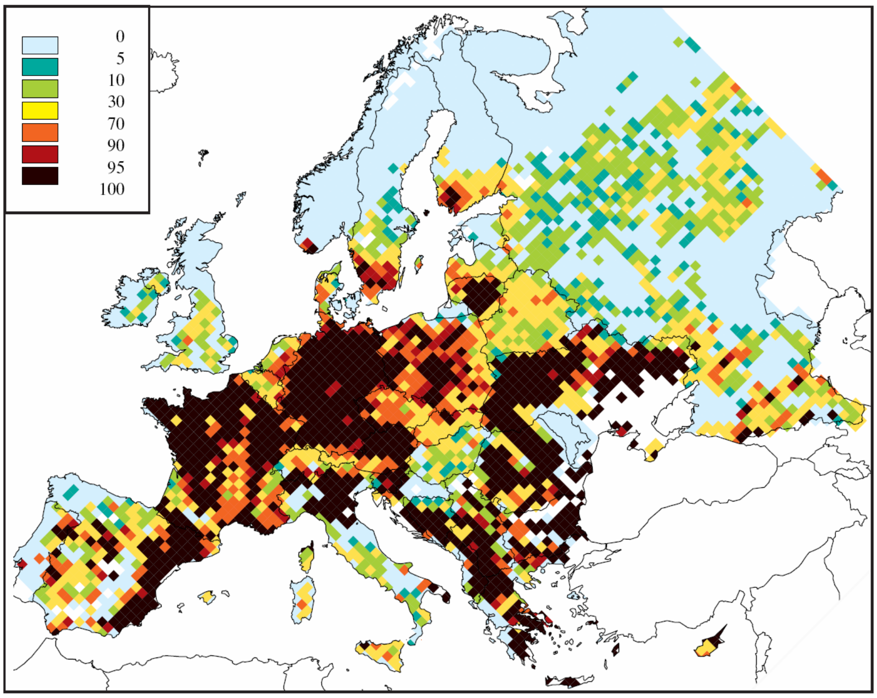
The extent of exceedance of critical loads for N across the EU25 for the scenarios considered here is summarised in Table 12 and Figure 1. It is immediately clear that exceedance of critical loads for eutrophication is widespread. The total area forecast for exceedance in 2020 (590,000 km$^2$) is equivalent to the combined area of France and Belgium. Under Scenarios A, B and C there is significant improvement, though the area subject to exceedance (347,000 km$^2$) is still equivalent to that of Germany. 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 12. 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 Case "A" | 2020 Case "B" | 2020 Case "C" | 2020 MTFR [2)] |
|---|---|---|---|---|---|---|---|
| Austria | 35563 | 96% | 86% | 77% | 71% | 69% | 53% |
| Belgium | 6615 | 93% | 61% | 37% | 32% | 28% | 23% |
| Cyprus | 4806 | 48% | 64% | 49% | 49% | 48% | 13% |
| Czech Rep. | 18364 | 95% | 77% | 39% | 31% | 25% | 12% |
| Denmark | 3031 | 53% | 37% | 11% | 3% | 2% | 1% |
| Estonia | 24326 | 12% | 6% | 4% | 4% | 4% | 0% |
| Finland | 238698 | 25% | 14% | 6% | 5% | 5% | 0% |
| France | 179227 | 96% | 79% | 57% | 44% | 40% | 20% |
| Germany | 106908 | 96% | 94% | 92% | 91% | 90% | 86% |
| Greece | 13714 | 76% | 73% | 52% | 46% | 45% | 2% |
| Hungary | 10763 | 31% | 24% | 16% | 14% | 12% | 5% |
| Ireland | 8791 | 12% | 3% | 0% | 0% | 0% | 0% |
| Italy | 119679 | 62% | 48% | 29% | 25% | 24% | 13% |
| Latvia | 29982 | 54% | 38% | 15% | 13% | 11% | 0% |
| Lithuania | 13182 | 85% | 81% | 62% | 54% | 49% | 4% |
| Luxembourg | 935 | 96% | 82% | 56% | 48% | 43% | 40% |
| Malta[3)] | | | | | | | |
| Netherlands | 3244 | 67% | 61% | 51% | 43% | 41% | 27% |
| Poland | 91265 | 86% | 79% | 65% | 62% | 57% | 18% |
| Portugal | 11053 | 30% | 12% | 1% | 1% | 0% | 0% |
| Slovakia | 18213 | 89% | 60% | 30% | 24% | 18% | 4% |
| Slovenia | 4249 | 94% | 88% | 75% | 73% | 50% | 21% |
| Spain | 84278 | 65% | 50% | 32% | 25% | 21% | 7% |
| Sweden | 184369 | 26% | 16% | 8% | 7% | 5% | 1% |
| UK | 73791 | 13% | 5% | 1% | 0% | 0% | 0% |
| **EU25** | **1285046** | **57%** | **46%** | **33%** | **29%** | **27%** | **15%** |

[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



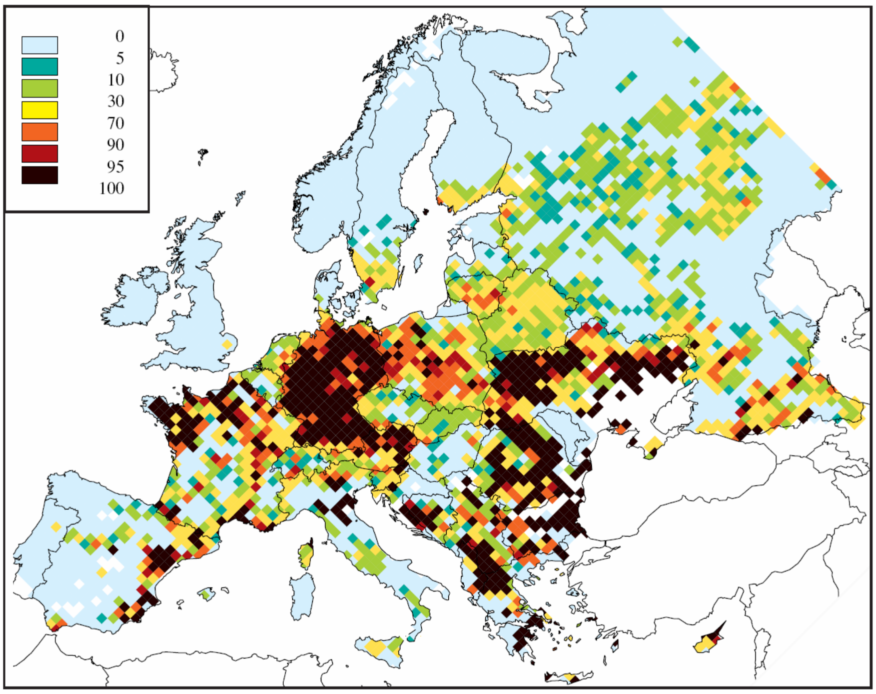




**Figure 1. Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication for the year 2020; current legislation baseline (top graph) and scenario C (bottom graph). Calculations are based on meteorological conditions of 1997 using grid-average deposition.  The IIASA report provides further maps for 2000, and Scenarios A and B.**

## Acid deposition to forest ecosystems

Table 13 and Figure 2 show results for the final set of scenarios for the Clean Air for Europe programme 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 A, B and C policy option scenarios would bring this area below 67,000, 60,000 and 55,000 $km^2$, respectively. The worst affected country in terms of % area affected is the Netherlands, by some considerable distance.

**Table 13. 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 | Case "A" | Case "B" | Case "C" | MTFR 2) |
|---|---|---|---|---|---|---|---|
| Austria | 34573 | 15.2% | 4.7% | 2.5% | 2.0% | 1.6% | 0.5% |
| Belgium | 6526 | 55.4% | 25.2% | 16.3% | 15.1% | 14.5% | 13.3% |
| Cyprus | 1854 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Czech Rep. | 18344 | 80.8% | 29.9% | 10.2% | 6.8% | 5.8% | 1.8% |
| Denmark | 3009 | 31.8% | 5.7% | 1.5% | 1.2% | 1.2% | 0.3% |
| Estonia | 21252 | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Finland | 236139 | 1.6% | 0.9% | 0.8% | 0.7% | 0.7% | 0.4% |
| France | 168823 | 12.4% | 4.2% | 2.6% | 2.0% | 1.8% | 0.7% |
| Germany | 103113 | 72.3% | 43.0% | 25.3% | 21.5% | 19.3% | 12.9% |
| Greece | 13714 | 0.6% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Hungary | 10763 | 3.9% | 1.1% | 0.4% | 0.3% | 0.3% | 0.0% |
| Ireland | 4166 | 47.0% | 23.0% | 17.7% | 16.5% | 15.4% | 9.1% |
| Italy | 92577 | 2.3% | 0.7% | 0.3% | 0.3% | 0.3% | 0.3% |
| Latvia | 28941 | 0.6% | 0.5% | 0.0% | 0.0% | 0.0% | 0.0% |
| Lithuania | 12438 | 2.9% | 1.0% | 0.4% | 0.1% | 0.1% | 0.0% |
| Luxembourg | 934 | 35.1% | 13.7% | 1.8% | 1.0% | 0.3% | 0.0% |
| Malta 3) | | | | | | | |
| Netherlands | 3778 | 88.3% | 80.6% | 71.1% | 68.4% | 66.0% | 52.3% |
| Poland | 88281 | 59.0% | 19.7% | 1.1% | 0.9% | 0.7% | 0.2% |
| Portugal | 11053 | 2.6% | 0.5% | 0.2% | 0.0% | 0.0% | 0.0% |
| Slovakia | 18211 | 22.7% | 6.9% | 3.1% | 2.7% | 2.3% | 0.4% |
| Slovenia | 4190 | 2.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Spain | 84269 | 1.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Sweden | 180911 | 23.7% | 15.3% | 12.8% | 12.2% | 12.0% | 8.4% |
| UK | 19822 | 49.0% | 23.4% | 12.4% | 11.2% | 10.7% | 6.0% |
| **EU25** | **1167682** | **20.8%** | **10.2%** | **5.7%** | **5.1%** | **4.7%** | **3.1%** |

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

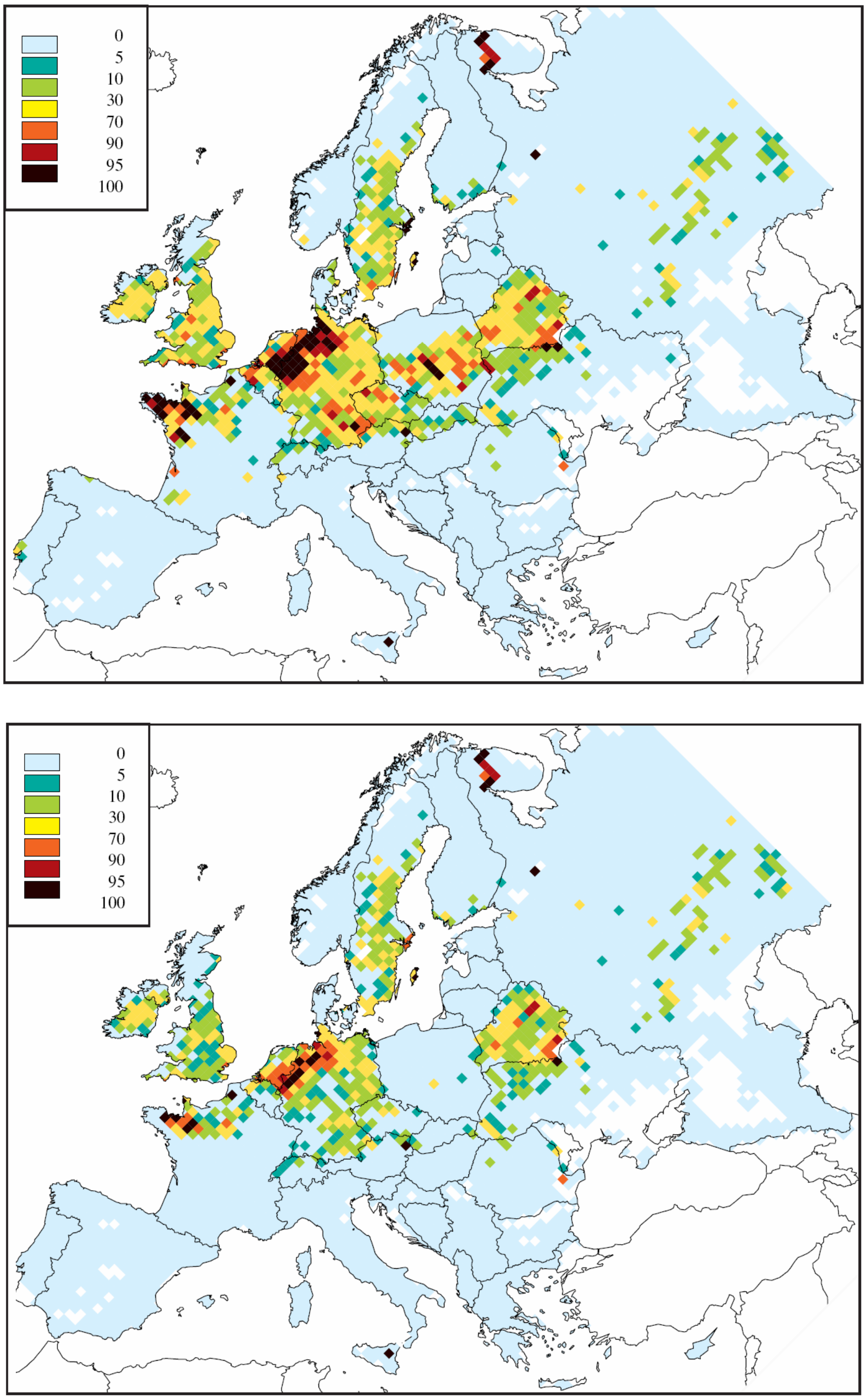



**Figure 2. Percentage of forest area receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and scenario C (bottom graph). Calculations are based on meteorological conditions of 1997 using ecosystem specific deposition. The IIASA report provides further maps for 2000, and Scenarios A and B.**

## 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 14 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. In several of the countries the extent of exceedance looks insignificant under Scenario B. However, exceedance in Germany and the Netherlands remains relatively high in both countries.

**Table 14. 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 | Case “A” | Case “B” | Case “C” | MTFR [2)] |
| France | 10014 | 37.6% | 9.0% | 2.5% | 2.4% | 2.3% | 0.6% |
| Germany | 3946 | 68.1% | 40.9% | 25.1% | 21.0% | 17.6% | 11.3% |
| Ireland | 4609 | 10.3% | 2.3% | 1.0% | 0.9% | 0.8% | 0.4% |
| Italy | 26085 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Netherlands | 1296 | 63.0% | 47.8% | 26.7% | 23.4% | 23.0% | 17.8% |
| UK | 49700 | 30.8% | 9.3% | 4.0% | 3.4% | 3.1% | 1.3% |

[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)

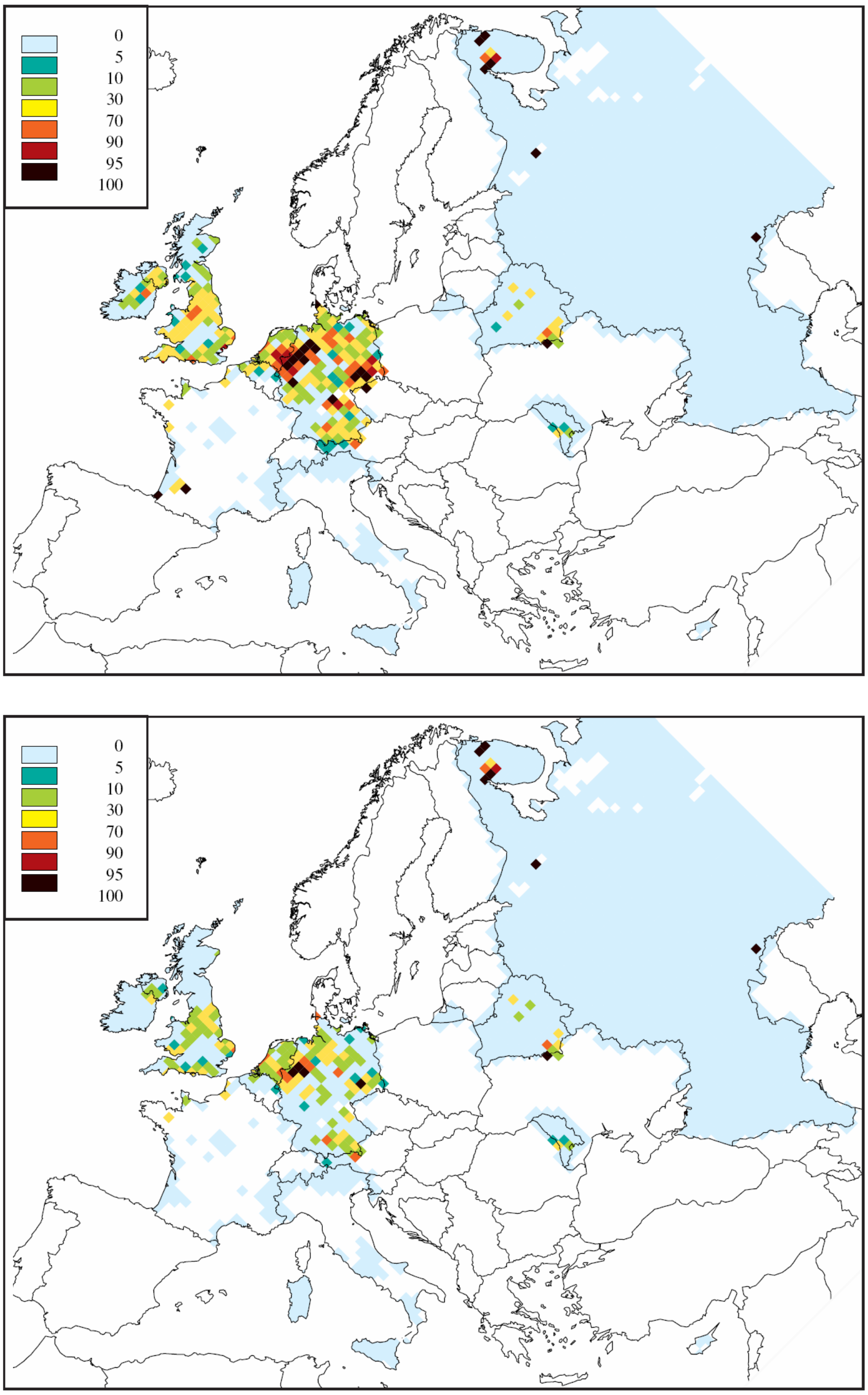



**Figure 3. Percentage of the area of semi-natural ecosystems receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and scenario C (bottom graph). Calculations are based on meteorological conditions of 1997 using ecosystem specific deposition. The IIASA report provides further maps for 2000, and Scenarios A and B.**

## 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 15. 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.**

| | Ecosystems area ($km^2$) [1)] | 2000 | 2020 Current legislation | 2020 Case "A" | 2020 Case "B" | 2020 Case "C" | 2020 MTFR [2)] |
|---|---|---|---|---|---|---|---|
| Finland | 30886 | 0.7% | 0.7% | 0.6% | 0.6% | 0.6% | 0.2% |
| Sweden | 204069 | 14.9% | 10.5% | 9.0% | 8.4% | 8.1% | 5.2% |
| UK | 7757 | 8.1% | 3.7% | 2.3% | 2.0% | 1.8% | 1.3% |

[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)

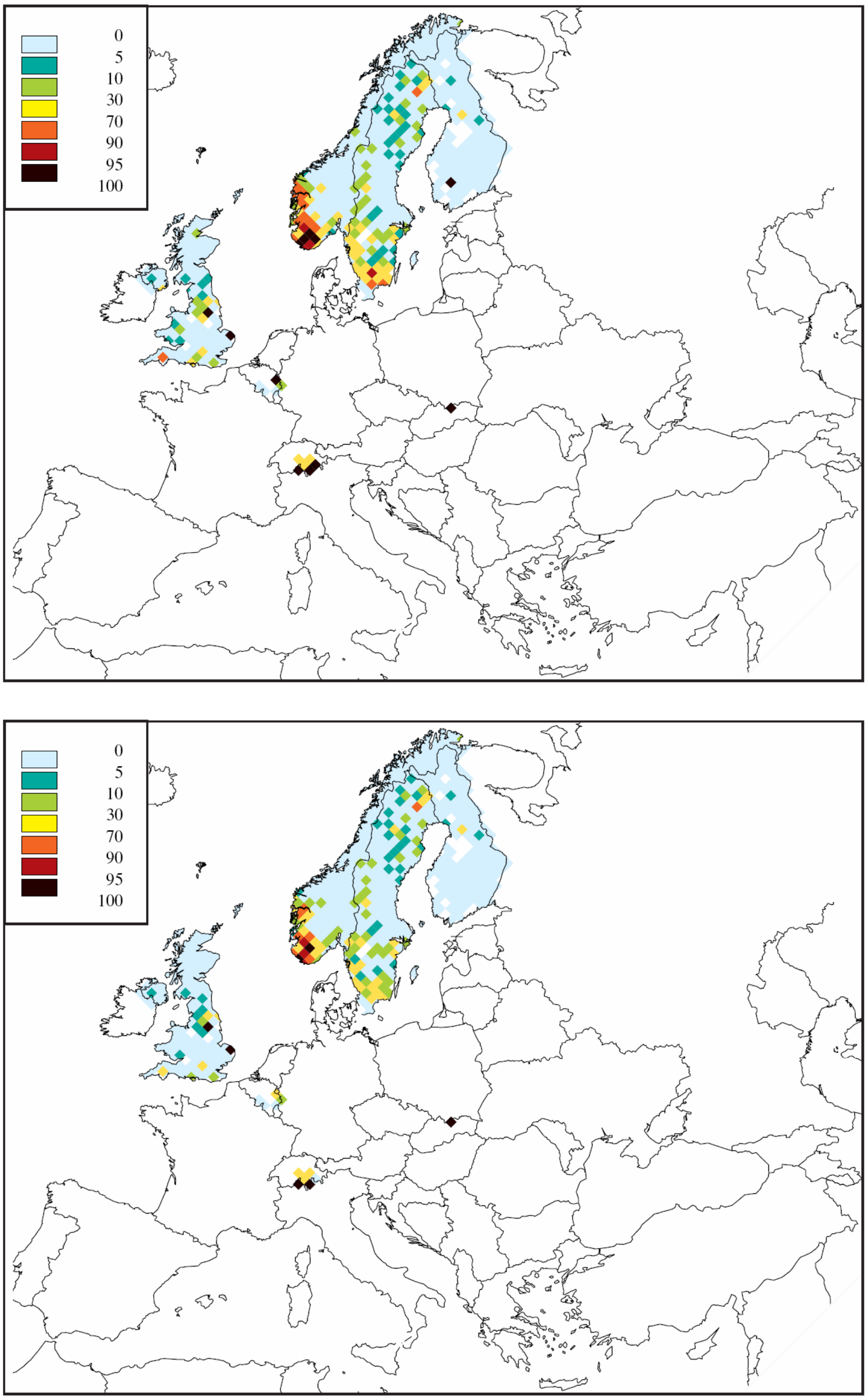



**Figure 4.  Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for the year 2020 current legislation baseline (top graph) and scenario C (bottom graph). Calculations are based on meteorological conditions of 1997 using grid-average deposition.  The IIASA report provides further maps for 2000, and Scenarios A and B.**

## 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 16). The table also demonstrates a sharp division between countries with respect to the extent of critical levels exceedance.

**Table 16. 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 | Case "A" | Case "B" | Case "C" | MTFR 2) |
|---|---|---|---|---|---|---|---|
| Austria | 37211 | 100% | 100% | 100% | 100% | 100% | 41% |
| Belgium | 5964 | 100% | 100% | 100% | 100% | 100% | 100% |
| Cyprus | 1116 | 100% | 100% | 100% | 100% | 100% | 11% |
| Czech Rep. | 25255 | 100% | 100% | 100% | 100% | 100% | 14% |
| Denmark | 2807 | 99% | 89% | 89% | 89% | 86% | 18% |
| Estonia | 18420 | 0% | 0% | 0% | 0% | 0% | 0% |
| Finland | 207003 | 0% | 0% | 0% | 0% | 0% | 0% |
| France | 137329 | 100% | 100% | 93% | 90% | 87% | 61% |
| Germany | 104559 | 100% | 100% | 100% | 100% | 100% | 80% |
| Greece | 21854 | 100% | 100% | 99% | 99% | 99% | 23% |
| Hungary | 16451 | 100% | 100% | 100% | 100% | 100% | 0% |
| Ireland | 2464 | 99% | 19% | 6% | 3% | 3% | 0% |
| Italy | 79743 | 100% | 100% | 100% | 100% | 100% | 99% |
| Latvia | 25101 | 6% | 0% | 0% | 0% | 0% | 0% |
| Lithuania | 18901 | 38% | 3% | 2% | 0% | 0% | 0% |
| Luxembourg | 1054 | 100% | 100% | 100% | 100% | 100% | 100% |
| Malta | 3 | 100% | 100% | 100% | 100% | 100% | 100% |
| Netherlands | 2912 | 100% | 100% | 99% | 99% | 99% | 98% |
| Poland | 89100 | 100% | 95% | 65% | 51% | 45% | 0% |
| Portugal | 27336 | 100% | 100% | 93% | 87% | 76% | 32% |
| Slovakia | 20144 | 100% | 100% | 69% | 59% | 46% | 0% |
| Slovenia | 10724 | 100% | 100% | 100% | 100% | 100% | 17% |
| Spain | 104595 | 100% | 100% | 100% | 96% | 93% | 55% |
| Sweden | 273144 | 18% | 4% | 1% | 1% | 1% | 0% |
| UK | 14557 | 85% | 50% | 43% | 40% | 36% | 25% |
| **EU25** | **1247749** | **61%** | **56%** | **52%** | **50%** | **48%** | **28%** |

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 17).

**Table 17. 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 highlight cases where exceedance covers >50% and 25 to 50% of forest area**

| | **2000** | **2020** | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|---|---|
| Ozone | 61% | 56% | 52% | 50% | 48% | 28% |
| Acidification | 21% | 10% | 6% | 5% | 5% | 3% |
| Eutrophication | 57% | 46% | 33% | 29% | 27% | 15% |
| Ozone + acidification | 16% | 6% | 3% | 2% | 2% | 1% |
| Ozone + eutrophication | 47% | 35% | 28% | 21% | 19% | 9% |

Table 18 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. Even under Scenario C, 85% of the forest area is subject to ozone critical levels exceedance and 43% is subject to exceedance of the critical load for eutrophication. Combining the information for ozone and eutrophication, two thirds of forests in European countries outside of the listed Baltic States will have exceedance of both ozone and eutrophication under the baseline scenario, falling to one third under Scenario C.

**Table 18. As Table 17, excluding the Baltic countries (Estonia, Finland, Latvia, Lithuania and Sweden).**

| | **2000** | **2020** | **A** | **B** | **C** | **MTFR** |
|---|---|---|---|---|---|---|
| Ozone | 99.7% | 98% | 91% | 88% | 85% | 50% |
| Acidification | 28% | 13% | 6% | 5% | 5% | 3% |
| Eutrophication | 80% | 68% | 52% | 46% | 43% | 26% |
| Ozone + acidification | 27% | 11% | 5% | 4% | 4% | 2% |
| Ozone + eutrophication | 80% | 68% | 48% | 37% | 34% | 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[7]. 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. Estimated costs of reaching each scenario from the baseline, and incremental costs of going from one scenario to the next, are shown in Table 19 and Table 20 respectively.

**Table 19. Annualised Costs in Million € in 2020 - change over base line, including road transport measures for the policy option scenarios A, B and C.**

| | A | B | C | MTFR |
|---|---|---|---|---|
| Austria | 114 | 220 | 316 | 1403 |
| Belgium | 218 | 344 | 727 | 981 |
| Cyprus | 9 | 17 | 24 | 80 |
| Czech Rep. | 123 | 211 | 239 | 614 |
| Denmark | 97 | 204 | 290 | 800 |
| Estonia | 12 | 19 | 26 | 158 |
| Finland | 65 | 138 | 208 | 1088 |
| France | 998 | 1963 | 2354 | 7787 |
| Germany | 901 | 1637 | 2320 | 4340 |
| Greece | 66 | 128 | 219 | 1000 |
| Hungary | 101 | 179 | 280 | 567 |
| Ireland | 103 | 198 | 260 | 707 |
| Italy | 589 | 1053 | 1449 | 3412 |
| Latvia | 12 | 21 | 33 | 137 |
| Lithuania | 52 | 98 | 144 | 433 |
| Luxembourg | 20 | 28 | 29 | 51 |
| Malta | 3 | 4 | 5 | 20 |
| Netherlands | 188 | 427 | 458 | 979 |
| Poland | 639 | 799 | 1106 | 3787 |
| Portugal | 96 | 208 | 307 | 1457 |
| Slovakia | 62 | 90 | 150 | 367 |
| Slovenia | 23 | 48 | 67 | 187 |
| Spain | 620 | 1057 | 1583 | 4449 |
| Sweden | 86 | 198 | 338 | 1567 |
| UK | 728 | 1391 | 1920 | 3349 |
| **EU-25** | **5923** | **10679** | **14852** | **39720** |

[7] A final set of scenarios for the Clean Air for Europe (CAFE) programme. Report number 6. IIASA. April 14th, 2005. Draft Version.

**Table 20. Annualised Costs in Million € in 2020 – incremental change between scenarios, including road transport measures between the main policy option scenarios A,B and C..**

| | from Baseline to A | from A to B | from B to C | from C to MTFR |
|---|---|---|---|---|
| Austria | 114 | 106 | 96 | 1087 |
| Belgium | 218 | 127 | 383 | 254 |
| Cyprus | 9 | 8 | 6 | 56 |
| Czech Rep. | 123 | 88 | 28 | 375 |
| Denmark | 97 | 107 | 86 | 510 |
| Estonia | 12 | 6 | 8 | 132 |
| Finland | 65 | 73 | 70 | 881 |
| France | 998 | 965 | 391 | 5433 |
| Germany | 901 | 737 | 683 | 2021 |
| Greece | 66 | 62 | 91 | 781 |
| Hungary | 101 | 79 | 101 | 287 |
| Ireland | 103 | 95 | 63 | 447 |
| Italy | 589 | 463 | 397 | 1962 |
| Latvia | 12 | 9 | 11 | 105 |
| Lithuania | 52 | 46 | 47 | 288 |
| Luxembourg | 20 | 8 | 1 | 22 |
| Malta | 3 | 1 | 2 | 14 |
| Netherlands | 188 | 239 | 31 | 521 |
| Poland | 639 | 160 | 308 | 2681 |
| Portugal | 96 | 111 | 99 | 1150 |
| Slovakia | 62 | 28 | 59 | 217 |
| Slovenia | 23 | 25 | 18 | 120 |
| Spain | 620 | 437 | 527 | 2866 |
| Sweden | 86 | 112 | 140 | 1229 |
| UK | 728 | 664 | 528 | 1430 |
| **EU-25** | **5923** | **4756** | **4173** | **24868** |

The tables below show the net monetised 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.

Table 21 shows that when compared against the baseline all of the scenarios A, B, C and MTFR) lead to net benefits.

**Table 21. Comparison of Annualised Costs and Benefits in Million €/year – changes above the 2020 baseline. Note annualised costs include road transport measures. Annualised benefits include health, materials and crop damage.**

| | A | B | C | MTFR |
|---|---|---|---|---|
| **EU Annualised benefits (health, materials and crops) change over base** | | | | |
| Total with Mortality – VOLY – low (median) | 37,565 | 45,864 | 50,009 | 56,906 |
| Total with Mortality – VOLY – high (mean) | 69,815 | 85,219 | 92,896 | 105,696 |
| Total with Mortality – VSL – low (median) | 64,541 | 78,765 | 85,906 | 97,659 |
| Total with Mortality – VSL – high (mean) | 120,496 | 147,030 | 160,345 | 182,254 |
| **EU-25 Annualised Costs in M€/year - change over base line** | | | | |
| Total | 5,923 | 10,679 | 14,852 | 39,720 |
| **NET benefits** | | | | |
| Total with Mortality – VOLY – low (median) | 31,642 | 35,185 | 35,157 | 17,186 |
| Total with Mortality – VOLY – high (mean) | 63,892 | 74,540 | 78,044 | 65,976 |
| Total with Mortality – VSL – low (median) | 58,618 | 68,086 | 71,054 | 57,939 |
| Total with Mortality – VSL – high (mean) | 114,573 | 136,351 | 145,493 | 142,534 |
| **Benefit to Cost Ratio** | | | | |
| Total with Mortality – VOLY – low (median) | 6.3 | 4.3 | 3.4 | 1.4 |
| Total with Mortality – VOLY – high (mean) | 12 | 8.0 | 6.3 | 2.7 |
| Total with Mortality – VSL – low (median) | 11 | 7.4 | 5.8 | 2.5 |
| Total with Mortality – VSL – high (mean) | 20 | 14 | 11 | 4.6 |

The ratio of benefits to costs naturally[8] falls with higher ambition levels, due to the rise in costs of measures relative to the benefits obtained. However, it is also important to look at the incremental results, the additional costs and benefits for progressively more ambitious targets.

Table 22 shows that, when going from scenario C to the MTFR scenario, the additional costs of measures do not lead to net benefits, i.e. for this policy step, the costs outweigh the benefits – this applies to the full range of benefits (both low and high estimates).

Secondly, when going from scenario B to scenario C, the costs are broadly equal to the low estimate of benefits – though they are lower than the high estimate. This is also reflected in the benefit to cost ratio, which ranges from a little less than 1 to 3 for the low and high estimate of benefits respectively.

[8] Naturally, given the use of cost-curves as the basis for optimisation in the RAINS model.

**Table 22. Comparison of Annualised Costs and Benefits in Million €/year – incremental changes between scenarios in 2020. Note annualised costs include road transport measures. Annualised benefits include health and crop damage.**

| | from Baseline to A | from A to B | from B to C | from C to MTFR |
|---|---|---|---|---|
| **EU incremental annualised benefits (health and crops)** | | | | |
| Total with Mortality – VOLY – low (median) | 37,565 | 8,299 | 4,145 | 6,897 |
| Total with Mortality – VOLY – high (mean) | 69,815 | 15,404 | 7,677 | 12,800 |
| Total with Mortality – VSL – low (median) | 64,541 | 14,224 | 7,141 | 11,753 |
| Total with Mortality – VSL – high (mean) | 120,496 | 26,534 | 13,315 | 21,909 |
| **EU-25 annualised costs in M€/year - incremental changes to each scenario** | | | | |
| Total | 5,923 | 4,756 | 4,173 | 24,868 |
| **NET incremental benefits** | | | | |
| Total with Mortality – VOLY – low (median) | 31,642 | 3,543 | -28 | -17,971 |
| Total with Mortality – VOLY – high (mean) | 63,892 | 10,648 | 3,504 | -12,068 |
| Total with Mortality – VSL – low (median) | 58,618 | 9,468 | 2,968 | -13,115 |
| Total with Mortality – VSL – high (mean) | 114,573 | 21,778 | 9,142 | -2,959 |
| **Benefit to cost ratio** | | | | |
| Total with Mortality – VOLY – low (median) | 6.3 | 1.7 | 1.0 | 0.3 |
| Total with Mortality – VOLY – high (mean) | 12 | 3.2 | 1.8 | 0.5 |
| Total with Mortality – VSL – low (median) | 11 | 3.0 | 1.7 | 0.5 |
| Total with Mortality – VSL – high (mean) | 20 | 5.6 | 3.9 | 0.9 |

So far, no account has been taken of uncertainty, beyond use of four estimates of benefits, based on the median and mean values of the VOLY and VSL. A detailed investigation of uncertainty is performed below.

# Bias in the CBA

The first part of the assessment of uncertainty in the CBA presented here deals with biases in the analysis.  Bias assessment is used for dealing with unquantified uncertainties that are likely to drive the balance of benefits and costs in a particular direction.  Whilst it is not possible to quantify these biases, it is often possible to define their direction (e.g., the omission of impacts will lead to underestimation of damage, whilst the omission of abatement measures will direct towards overestimation of costs) and to give a general indication of the likely magnitude of bias, sorting what is likely to be important from what is not.  This is shown in the tables that follow.  A negative sign indicates that the ratio of benefit to cost would be underestimated as a result of the bias in question, a positive sign indicates that the ratio would be overestimated.  A single sign indicates that the CAFE-CBA team believe that effects are likely to be negligible, a triple sign ('---' or '+++') that the bias in question is likely to be significant.  A double sign indicates that effects may or may not be significant.

The following assessment proceeds through consideration of biases in the EMEP model, the RAINS model and then, finally, the benefits assessment, following from the work reported in Volume 3 of the CBA methodology report and the peer reviews of the EMEP and RAINS models.  Some revision of the scoring given to the estimated effect of each bias on benefit:cost ratio has been made to reflect the scenarios under consideration.

**Biases in the EMEP model**
With respect to the two main CAFE pollutants, $PM_{2.5}$ and ozone, the 2004 review of EMEP concluded that:

- *The model, in the form presented, underestimated observed $PM_{10}$ and $PM_{2.5}$ due to an incomplete description of relevant processes and emissions.  It was, however, able to calculate the regional component of the main anthropogenic PM fractions (sulphate, nitrate, ammonium, some primary components) with enough accuracy to assess the outcome of different control measures.*
- *The model shows an excellent level of performance for daily maximum ozone concentrations.*

These and other issues are considered in Table 23.

**Table 23. Biases in the EMEP modelling. Ratings given in brackets are biases that are unlikely to have a significant effect on the outcome of the CAFE modelling.**

| Source of bias | Likely effect on benefit:cost ratio | Comment |
|---|---|---|
| Variability in meteorology from year to year | (+++/---) | The CAFE analysis has been based on use of meteorological data from 1997 only. Figure 5 and Figure 6 should enable readers to assess the effect of variability in meteorology on results that are based on this year. |
| Underestimation of suspended particle concentrations, particularly through not accounting for secondary organic aerosols. | --- | Overall, secondary organic aerosols contribute around 10% to total aerosol concentrations in the atmosphere over Europe (D. Simpson, personal communication). Part of this will be linked to anthropogenic emissions of VOCs and part to natural emissions. Analysis below seeks to make some estimate of the importance of this effect (see Table 27). |
| Lack of specific account of urban concentrations of:<br>• $PM_{2.5}$<br>• Ozone | <br>0 (assuming CITYDELTA adjustment is correct)<br>++ | Urban concentrations of PM are factored into the RAINS model using the results of the CITYDELTA Project. Ozone concentrations are generally depressed in urban areas as a result of high local NOx emissions. |

As noted in the table, all of the analysis in this report has been carried out using 1997 meteorology. The effect of the use of this single year on exposure to anthropogenic $PM_{2.5}$ excluding secondary organic aerosols in each country is shown in Figure 5. For the EU25 as a whole, 1997 provides results reasonably close to the average, but results are quite variable for individual countries. Reference to Figure 5 provides guidance for each country on the likely difference between results presented for the Scenarios considered here and results based on meteorology from other years.

Like $PM_{2.5}$, ozone is significantly influenced by inter-annual meteorological variability. Results show that 1997 was not a typical year for ozone in all EU Member States. Figure 6 shows variability in exposure across four different meteorological years, with 1997 highlighted. This has little impact on quantified health effects, given that our estimates of ozone impacts are relatively small compared to the effects of fine particles. At the European level the use of 1997 should give results close to the average for particles. However, for some countries, Ireland and Finland in particular, effects may be up to 20% higher or lower than the average across the four years considered.

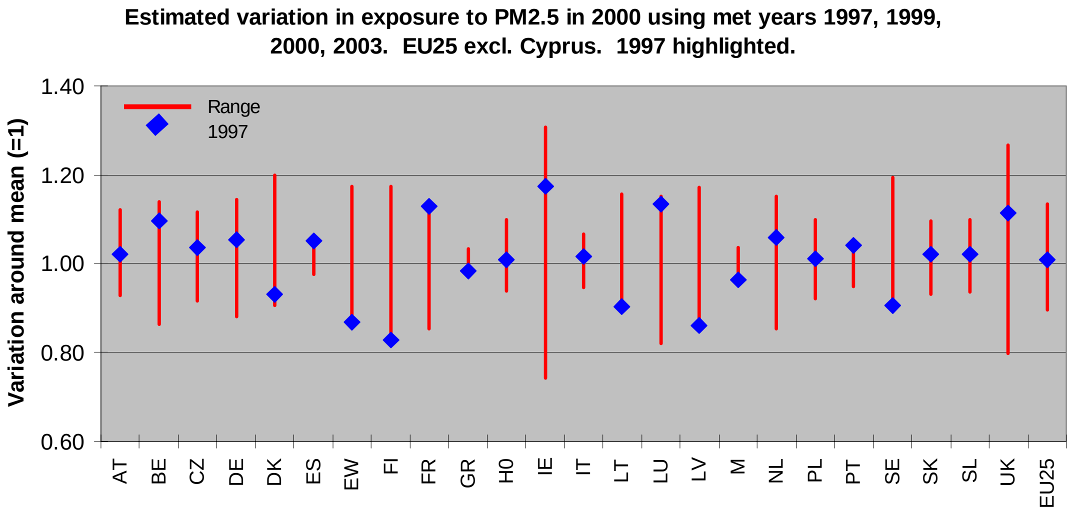



**Figure 5.  Variation in population weighted exposure to $PM_{2.5}$ from variation in assumed meteorological year (1997, 1999, 2000 and 2003).  1997, the year used for the analysis in this report, is highlighted.**

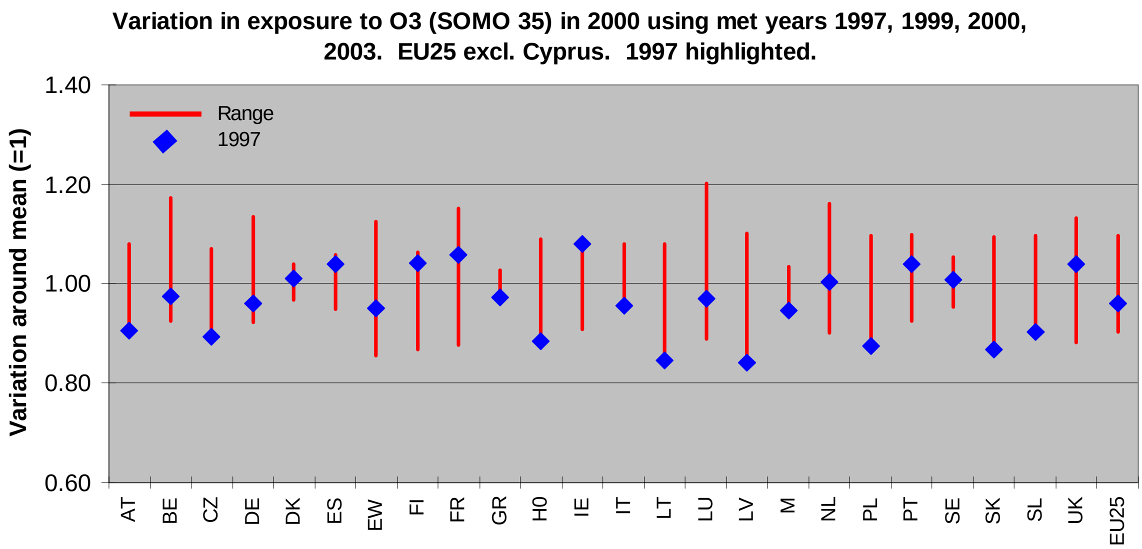



**Figure 6.  Variation in population weighted exposure to ozone expressed as SOMO35 from variation in assumed meteorological year (1997, 1999, 2000 and 2003).  1997, the year used for the analysis in this report, is highlighted.**

The omission of secondary organic aerosols from the analysis is dealt with below under the section on the ‘Extended CBA’.

## Biases in the RAINS modelling

The peer review of the RAINS model carried out as part of the CAFE Process provides detailed consideration of both statistical uncertainties and biases (Swedish Environmental Research Institute, 2004).  This has been used as the basis for the information presented in

Table 24. Some of the biases identified in the review are not discussed in the table as they are not considered relevant to the CAFE process. For example, the omission of impacts of particles and ozone on morbidity is addressed through the wider quantification of benefits in the CAFE-CBA[9]. Nonetheless, the modelling is clearly subject to a significant number of possible biases.

As in any case where a large number of uncertainties are identified, there are likely to be some areas where biases cancel each other out to some degree. An obvious example from Table 24 concerns the effects of N deposition to ecosystems, where the peer review concluded that impacts of N on acidification and eutrophication were likely to be (respectively) overstated and understated.

**Table 24. Biases in the RAINS modelling. Ratings given in brackets are biases that are unlikely to have a significant effect on the outcome of the CAFE modelling.**

| Source of bias | Likely effect on benefit:cost ratio | Comment |
|---|---|---|
| Emission starting point bias for $NH_3$, NOx, $PM_{2.5}$, $SO_2$ and VOCs | ---/+++ | Negative bias arises because of uncertainty in emission inventories and the potential for switching to cleaner fuels or production systems by the baseline year for reasons unrelated to air quality regulation. Positive bias arises through uncertainty in emission inventories and possible legislative change in other areas that could cause emissions to increase. |
| Omission of some existing and future technical abatement measures from the RAINS model:<br>• Omission of low cost measures<br>• Omission of mid cost measures<br>• Omission of high cost measures | <br><br><br>---<br>---<br>-- | Biases to overestimation of costs and underestimation of the maximum feasible reduction. |
| Lack of account of future technical developments for existing measures: | --- | Leads to an assumption of lower cost-effectiveness of existing technologies than will be achieved through further development |
| Omission of non-technical measures that would lead to behavioural change | --- | Non-technical measures provide additional scope for emission reduction |
| Lack of differentiation of particles by species for health impact assessment | ---/+++ | Likely tendency would be to reduce the cost-effectiveness of abatement packages by inadequate focus on the most harmful particles. |

[9] It is, in any case, not necessary to include morbidity impacts in RAINS. Environmental impacts are used by RAINS as indicators to permit optimisation against pre-defined targets. So long as the impacts selected for this process reflect changes in related effects, the use of a single impact to act as indicator is sufficient.

| Source of bias | Likely effect on benefit:cost ratio | Comment |
| --- | --- | --- |
| Modelling urban exposure:<br>• Urban background $PM_{2.5}$<br>• Hot spot $PM_{2.5}$<br>• Urban background ozone<br>• Hot spot ozone | Accounted for<br>(---)<br>++<br>(++) | Application of the results of the CITYDELTA study enables RAINS to account for elevated background concentrations of $PM_{2.5}$ in urban areas. However, the model does not include adjustment of data for urban background ozone, or assessment of hot-spot $PM_{2.5}$ or hot-spot ozone. The lack of account of hot-spot conditions is considered not so important for health effect quantification as models are calibrated against background concentrations. Failure to correct for urban background ozone is of limited importance to this analysis because of the small proportion of benefits attributed to ozone and health. |
| Restriction of analysis to the EU25 | --- | Leads to underestimation of benefits of reduction of emissions from the EU25. Also increases estimated costs of reaching targets by failure to account for low cost options in non-EU countries. |
| Inter-annual variability in meteorology | | Discussed in Table 23. |
| Underestimation of deposition of S and N to sensitive ecosystems<br><br>Overestimation of the role of N in critical loads for acidification<br><br>Underestimation of ecosystem sensitivity to eutrophication | --<br><br>++<br><br>-- | Given that there is no economic quantification of impacts to ecosystems these impacts do not affect the reported cost-benefit relationship directly, but may influence concern over unquantified ecological impacts where stakeholders use the extended CBA to consider how unquantified effects would alter their attitude to reported cost-benefit relationships. |
| Omission of health impacts on people aged under 30 years | -- | When carried through to the CBA of possibly limited importance given the quantification of morbidity effects for all age groups and limited mortality amongst the under 30s in Europe. |
| Use of year 2000 population data and death rates for quantification of ozone effects on mortality | - | Reduces quantified impacts for future years given demographic changes that lead to an aging population in the EU25. Impact limited in CAFE because of the relatively low impact of ozone compared to $PM_{2.5}$. |
| Use of 'cut-point' for quantification of ozone impacts | - | The use of the cut-point does not reflect a threshold for ozone effects. Impact of the use of the cut-point is, however, limited in the analysis presented here given the small size of quantified ozone effects.. |

There is a clear dominance in Table 24 of factors that bias costs up and benefits down. Overall this seems likely to lead to a bias to non-action on air pollution generally. Three questions need to be answered:

1. How large is the bias?
2. Does it apply equally to all pollutants?
3. Does it apply equally to all regions?

Quantification of the bias is clearly very difficult – if it were easy it could be incorporated into the modelling. Unfortunately there have been very few attempts to compare ex-ante

estimates of control costs with actual costs. Those analyses that have done this have shown a strong tendency for ex-ante estimates to exaggerate costs. However, such studies are purely retrospective and cannot be used as a reliable guide to the quality of future results without further consideration. Further to this, biases will vary between pollutants, not least because of variability in the quality of emission inventories. $SO_2$ emissions, for example, are known with a far better level of confidence than PM emissions. Biases will also vary between regions, reflecting differences in the availability of alternative fuels, quality of national data and so on.

Direct analysis of the effect of these biases is not possible given that they are unquantified. However, the sensitivity analysis below assesses the probability that benefits would exceed costs factoring in variation in costs in the range [RAINS estimate +20%] to [RAINS estimate - 50%]. The choice of this interval is skewed downwards (implying that RAINS is more likely to exaggerate costs than underestimate them) because of the dominance in Table 24 of factors leading to cost overestimation and the results of analysis comparing ex-ante and ex-post estimates of abatement costs (Watkiss et al, 2005 and others).

## Biases in the benefits analysis

In common with the cost-effectiveness modelling undertaken using the RAINS model, the benefits assessment is prone to a significant number of biases. These are listed in Table 25. Readers who consider that some potential biases have been omitted from this table should consult other sections of the report to see if they are dealt with elsewhere (e.g. alternative positions on mortality valuation and aspects covered in Table 23 and Table 24 dealing with the EMEP and RAINS models respectively). Again, views on the direction and likely significance of biases are the authors' own.

The omission of impacts from the analysis is dealt with below in the section on 'Extended CBA'.

The failure to differentiate particles by species for the health impact assessment seems to be the most important *potential* cause of overestimation of benefits of individual measures, though it could bias results either way depending on which types of particle are targeted under a specific strategy. Other biases that could lead to overestimation seem less important, reflecting more uncertainty in data extrapolation than anything fundamental.

Another area where bias is likely though it is not clear which direction that bias would go in concerns the morbidity assessment in the benefits analysis. Specifically it relates to two issues, the application of health functions from the US and western Europe across the whole of Europe, and the use of uniform incidence data. Both areas are worthy of further research in the near future. Given variability across Europe any biases that are present may tend to cancel each other out as reference to incidence data in Volume 2 of the CAFE-CBA methodology report suggests.

**Table 25.  Biases in the benefits analysis**

| **Source of bias** | **Likely effect on benefit:cost ratio** | **Comment** |
|---|---|---|
| Unquantified impacts:<br>• Ecosystem acidification<br>• Ecosystem eutrophication<br>• Impacts of ozone on ecosystems<br>• Damage to cultural heritage<br>• Chronic health effects of exposure to ozone<br>• Effects of coarse particles (size range $PM_{2.5\ to\ 10}$) on health<br>• Chronic effects of PM exposure on cardio-vascular disease<br>• Health effects of secondary organic aerosols (SOAs) | ---<br>---<br>---<br>--<br>---?<br><br>-<br><br>---?<br><br>--- (see Table 27) | Further information on the likely importance of omissions from the benefits analysis is discussed elsewhere in this report.<br><br>In some cases importance will vary strongly between abatement options, e.g.;<br>• An option that does not control VOCs will have very little effect on exposure to SOAs.<br>• Abatement options controlling coarse particles could have significant additional benefits for situations where they comprise a major fraction of total particle mass. |
| Lack of differentiation of particles by species for health impact assessment | +++/--- | Effect on quantified benefits will depend on the level of control for each type of particle. |
| Use of health functions from the US and western Europe | ++/-- | Further research is needed to test whether there are systematic differences between regions. |
| Quantification of deaths from chronic exposure to PM using techniques not based on life tables (only relevant where VSL is used for mortality valuation). | ++ | Some potential for double counting of deaths, depending on the time horizon used for the analysis. |
| Use of uniform incidence data for the whole of Europe for most morbidity effects | ++/-- | Again, further research is needed to test whether there are systematic differences between regions.  The identification of consistent sets of incidence data is recognised as a problem for transferability of health response functions generally. |
| Use of AOT40 based relationships to quantify impacts of ozone on crops | +? | Likely to cause overestimation of impacts amongst un-irrigated crops in drier parts of Europe.  Overall effect unclear.  Should be resolved in 2005 by a switch to flux-based modelling. |

A final area concerns probable overestimation of crop damage estimates in drier parts of Europe through the use of AOT40 based functions rather than flux based estimates (though in northern Europe the AOT 40 based functions may underestimate the damage due to ozone). It is intended that the analysis will move to the use of flux functions later in 2005 for some important agricultural crops, drawing on ongoing research programmes.  Analysis presented at the February 2004 meeting of ICP Vegetation indicated that this bias may not be as significant as originally thought.  It will also be countered to some extent by some impacts of ozone being left out of the analysis (e.g. visible injury to salad vegetables, or the omission of some crops from available maps of agricultural production).  These factors, together with the overall scale of estimated ozone damage to crops suggest that this bias will not be significant.

## Conclusions on biases in the CBA

It has been demonstrated that there are important biases in the dispersion modelling using the EMEP model, cost modelling using the RAINS model, and the benefits assessment:

**Dispersion and chemistry modelling:** The most important bias seems to be the omission of secondary organic aerosols.  The scoping analysis presented in Table 27 provides a first indication of the potential magnitude of SOA health impacts.

**Cost and emission modelling using RAINS:** The most important biases in the RAINS modelling are overestimation of costs and underestimation of the maximum technically feasible reduction through the omission of some abatement measures from the cost curves that underpin RAINS, and problems in forecasting improvements in emerging and new technologies.  There is some potential for underestimation of costs by RAINS, though available evidence suggests that this is unlikely, particularly once results for different sectors and countries are aggregated.

**Benefits assessment:**  Here, the most important biases appear to relate to the omission of some impact categories from the monetised assessment.  These are dealt with in more detail below.

Overall, this review suggests that costs are likely to be overestimated and costs underestimated by the models used for the CAFE analysis.  These conclusions are carried forward to the detailed uncertainty and sensitivity analysis for each scenario.

# Extended CBA

## Overview

The objective of the 'extended-CBA' is to draw attention to those effects that are not quantified in monetary terms in the main analysis, and would thus, ordinarily, be omitted from the comparison of costs and benefits.  Where possible, the analysis in this section provides estimates of benefit using alternative methods to those used above.  The intention of providing information in this way is to prompt stakeholders to consider whether the impacts that are outside the main analysis are likely to be important enough to change the balance of costs and benefits.  Initial guidance on the importance of these effects is given in Table 26.

**Table 26.  Ratings for the extended CBA.  Effects considered likely to be negligible are omitted from this table.**

| Effect | Rating |
|---|---|
| **Forests** | |
| Effects of $O_3$, acidification and eutrophication | ★★★ |
| **Freshwaters** | |
| Acidification and loss of invertebrates, fish, etc. | ★★★ |
| **Other ecosystems** | |
| Effects of $O_3$, acidification and eutrophication on biodiversity | ★★★ |
| **Materials** | |
| Effects on cultural assets | ★★ |
| **Health** | |
| Ozone: chronic effects on mortality and morbidity | ★★ |
| PM: chronic effects on cardiovascular disease | ★★ |
| PM: effects of coarse particles | ★ |
| $SO_2$: chronic effects on morbidity | ★ |
| Direct effects of VOCs | ★ |
| Social impacts of air pollution on health | ★★ |
| Altruistic effects | ★★ |
| Omission of effects of secondary organic aerosols | ★★★ |
| **Crops** | |
| Indirect air pollution effects on livestock | ★ |
| Visible injury to leaf crops following ozone exposure | ★ |
| Changes in the taste and nutritional quality of crops following ozone exposure | ★★ |
| Interactions between pollutants, with pests and pathogens, climate... | ★★ |
| **Visibility** | |
| Change in amenity | ★ |
| **Groundwater quality and supply of drinking water** | |
| Effects of acidification | ★ |

**Key**

| | |
|---|---|
| ★★★ | Impacts likely to be significant at the European level |
| ★★ | Impacts that may be significant at the European level |
| ★ | Impacts unlikely to be important at the European level, but of local significance |

Based on this table and the information that underpins it, we conclude that:

- Inclusion of impacts on forests, freshwaters and other ecosystems, and of secondary organic aerosols on health, could add significantly to the benefits quantified for emission reductions.  Further information on these impacts is given below.

- Inclusion of the effects of chronic exposure to ozone on health and to PM on cardiovascular disease, social impacts of air pollution on health, altruistic effects such as the value placed by one person on another's ill health, damage to cultural assets and some impacts on crops via interactions with pests and pathogens may be important, but there is inadequate evidence available to make a firm conclusion at this point in time.
- The other effects listed in the table are unlikely to make a substantial difference to quantified benefits at the European scale, but may be significant in some areas.  As an example, visible injury to crop plants (as distinct to reduction in yield, which may or may not be related) is only of importance for a few leaf crops (lettuce, chicory, parsley, spinach, etc.) that make up a small fraction of European crop production.  Whilst impacts may be serious for some farmers on some occasions, they are not likely to be important at the European scale.

The most important of these effects, impacts on ecosystems and effects of secondary organic aerosols, are discussed below.  The ratings provided in Table 26 are simply intended as flags to highlight issues that are, or are not, likely to be important to the economic assessment of pollution impacts under the CAFE programme.  The omission of a number of potentially significant effects from the monetised benefits analysis demonstrates a bias to underestimation of damage.

## Omission of impacts to ecosystems

The failure to quantify a significant number of impacts is an obvious problem for the benefits analysis and quite clearly biases to underestimation of the benefit:cost ratio.  This problem is highlighted further below, in Table 27 which shows that the benefits of reducing exposure to secondary aerosols could well run to several €billion, sufficient to change an estimated net cost to a net benefit in some significant cases.

Although there is no data available to permit quantification of ecosystem damage at a European scale at the present time, it is probable that any such valuation would indicate a substantial figure, on the following grounds:

- Exceedance of critical levels and critical loads remains widespread;
- Past international legislation on transboundary air pollution has been very largely driven by concern over ecological damage.

## Omission of secondary organic aerosols (SOA)

The secondary organic aerosol (SOA) fraction of ambient particles is formed following emission of various (natural and anthropogenic) volatile organic compounds that are chemically changed through atmospheric chemistry and subsequently form or attach to particles.  The overall effects of the omission of SOA from the analysis would be:

1. To underestimate PM-health impacts from anthropogenic sources and associated benefits of VOC control.
2. To limit the estimate of *potential* improvement that may be made through control of anthropogenic sources of fine particles.
3. To increase the apparent costs of reducing exposure to $PM_{2.5}$, once beyond the point where VOC controls would enter the cost-curve.

4. Together, therefore, the omission of secondary organic aerosols would bias analysis against recommending further cuts in VOC emissions.

It is important to ask how big the damage associated with SOA is. Whilst the models are not sufficiently advanced to enable a direct estimate to be made it is at least possible to make a first estimate of its impact in terms of the cost benefit analysis presented here. The fraction of organic material in the aerosol phase varies considerably, on average making up 20 to 60% of the total $PM_{2.5}$ mass (Dusek, 2000; CAFE WG PM, 2004). Of this, the secondary organic fraction accounts for up to about 20% of the total amount of organic substances in some areas (Dusek, 2000). In view of the wide range of estimates of the fraction of secondary organic aerosols we have used a central estimate of 10% of $PM_{2.5}$ is secondary organic aerosol. Further to this, given that natural sources make up about 25% of European VOC emissions it is reasonable to estimate that 75% of the SOA (7.5% of total particle concentrations) is associated with anthropogenic VOC emissions.

Analysis is presented in Table 27. The first line of results gives the total quantified health effects of PM exposure, accounting for sensitivity to the method used to value mortality but excluding any impact of SOA. The second line inflates these results to account for the 7.5% estimated to be attributable to anthropogenic SOA, and the third line shows the difference, in other words, the damage attributable to *anthropogenic* SOA only.

The first block of results below this (shaded grey) estimates the reduction in damage from anthropogenic SOA under each scenario compared to the baseline scenario, based on the assumption that they would fall linearly with reductions in VOC emissions. The second block of results shows the incremental change when moving from scenario to scenario.

**Table 27. Approximation of damage associated with secondary organic aerosols (SOAs) that are not quantified elsewhere in this report.**

| **Reduction vs. baseline (CLE 2020)** | | | VOLY median | VOLY mean | VSL median | VSL mean |
|---|---|---|---|---|---|---|
| **Total PM health damage less SOA (€million) for the baseline (CLE) scenario** | | | **184,000** | **345,000** | **321,000** | **601,000** |
| **PM health damage with 7.5% anthropogenic SOA (€million) for the baseline (CLE) scenario** | | | **199,000** | **374,000** | **348,000** | **651,000** |
| **Estimate of damage from SOA (€million)** | | | **15,000** | **29,000** | **27,000** | **50,000** |
| | | | **Estimated change in SOA health damage by scenario (€million)** | | | |
| **Total reduction in SOA health damage in each scenario compared to the baseline scenario** | | | VOLY median | VOLY mean | VSL median | VSL mean |
| Scenario | VOC emitted (t) | Reduction (t) | | | | |
| CLE | 5,916,000 | - | | | | |
| A | 5,230,000 | 686,000 | 1,700 | 3,300 | 3,000 | 5,700 |
| B | 4,937,000 | 979,000 | 2,500 | 4,600 | 4,300 | 8,100 |
| C | 4,771,000 | 1,145,000 | 2,900 | 5,400 | 5,000 | 9,500 |
| MTFR | 4,303,000 | 1,613,000 | 4,100 | 7,600 | 7,100 | 13,000 |
| **Benefit from reduction in SOA health damage in each scenario compared to the previous scenario** | | | | | | |
| CLE to A | | 686,000 | 1,700 | 3,300 | 3,000 | 5,700 |
| A to B | | 293,000 | 740 | 1,400 | 1,300 | 2,400 |
| B to C | | 166,000 | 420 | 790 | 730 | 1,400 |
| C to MTFR | | 468,000 | 1,200 | 2,200 | 2,100 | 3,900 |

Referring back to Table 22 which compared incremental costs and benefits of moving from the baseline to Scenario A, from A to B, B to C and C to MTFR, these additional benefits would have a very significant effect on the following cases:

- Moving from Scenario B to C, a net benefit would arise for all cases including that where mortality is valued using the median VOLY (the one case for which a net cost is quantified in Table 22 for moving from Scenario B to C).
- Moving from C to MTFR, a net benefit would arise for the case where mortality is valued using the mean VSL.  For the other three cases a net cost would still be present.

It is accepted, of course, that there are differences in reactivity between VOCs, that the assumption of linearity in response to changes in VOC emissions is simplistic, and that the 10% estimate for SOA contribution to ambient $PM_{2.5}$ levels is approximate.  However, this analysis does at least give some quantitative indication of the possible importance of SOA to the CAFE analysis, demonstrating that it is likely that they would add substantially to the damage quantified elsewhere in this report. If included in the benefits analysis a reduction of SOA would probably entail further measures to reduce VOC emissions.

## Conclusions on omitted impacts

Despite the methodological limitations acknowledged above, the results of the analysis of secondary organic aerosols, with additional benefits in the order of several hundred or billion euro for each scenario add weight to the view expressed in Table 26 that the main quantification presented in this report omits several significant benefits that should be considered further by policy makers.

# Uncertainty / Sensitivity Analysis

## Methods for describing uncertainties

Volume 3 of the methodology reports describes the uncertainties associated with the CAFE analysis and methods for dealing with them.  Three methods are identified for dealing with uncertainties:

### Statistical analysis
Statistical analysis is used for dealing quantitatively with uncertainties that are amenable to this type of analysis.  Volume 3 of the CAFE-CBA methodology report quantifies the spread of monetised damage around estimated health impacts of ozone and PM exposure – readers should consult that report for information on the methods used (based around use of the @RISK modelling tool), assumed probability distributions, etc.  It is acknowledged that the description of statistical uncertainties in this work is itself prone to some level of uncertainty.

### Sensitivity analysis
Sensitivity analysis is used for dealing quantitatively with specific parameters for which alternative positions are available (e.g. VSL vs. VOLY) or for which we have little information on statistical spread around best estimates (e.g. cost data).

### Bias assessment
As discussed above.

## Uncertainties not addressed in detail in this report

### 'Sensitivity' health impacts from PM
Volume 2 of the CAFE-CBA Methodology report identifies a number of health impacts which, for various reasons, it is not felt appropriate to include in the core analysis. Sensitivity analysis was undertaken on these effects in Volume 3 of the Methodology report and in the baseline analysis.  In terms of the number of additional health impacts for PM, sensitivity analysis showed these additional impacts are important, being linked with hundreds of millions of additional potential cases or days of illness.  However, the economic importance of these impacts is not large in relation to those quantified in the 'core analysis' (i.e. they do not represent a major additional monetary benefit).

### 'Sensitivity' health impacts from ozone
Similarly, Volume 2 of the Methodology Report identified a number of health impacts for ozone for which quantification under the core analysis was not recommended, but for which it was felt that there was a sufficient body of evidence to warrant quantification in a sensitivity analysis.  In terms of the number of additional health impacts, the sensitivity analysis found them to be important, in the region of hundreds of millions of additional cases or days of illness.  They also added significantly to the quantified monetary benefits of controlling ozone.  However, they were insignificant in relation to the total PM damage. Additional uncertainty analysis on them was thus not considered necessary for this report.

### Valuation of ozone mortality
For the core analysis of acute mortality from ozone, the analysis quantifies the number of 'premature deaths' (deaths brought forward).  These cases are valued using a VOLY

approach, assuming that on average, each premature deaths leads to the loss of 12 months of life.  To further examine sensitivity to the approach used, the CAFE CBA baseline report (Watkiss et al 2005b) has considered the potential effect of using a full Value of Statistical Life (0.98 million Euro) for these premature deaths.  This would significantly add to ozone related damage, though it would still be significantly less important than PM.  Again, this sensitivity analysis is not considered necessary for this report.

Similarly, it would be possible to test the sensitivity of results to the assumption that each premature death on average leads to a loss of 12 months of life.  Again, however, this would make little difference to the overall results of the analysis and so is not considered necessary.

### Sensitivity on PM and chronic mortality

A number of issues were raised in the methodology report with respect to PM and chronic mortality that are outside the scope of the core analysis.

The first and most important 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.  The latter 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 any established risk estimates for the different components.  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.  However, we believe there is value in exploring this as a sensitivity analysis, for example to differentiate between policies that reduce primary rather than secondary particles from combustion.

Some scoping analysis of the baseline scenario has shown that different assumptions about the causality (toxicities) of different components on the $PM_{2.5}$ mixture do lead to very different damage by Member State when compared to the existing baseline – even if the overall causality from $PM_{2.5}$ across the EU is constant.  Interestingly, the % of the ambient PM mixture that is primary $PM_{2.5}$ is remarkable constant across all countries – it is the other components such as sulphates and nitrates that differ dramatically by Member State.  For example if nitrates are assigned a lower causality, and primary $PM_{2.5}$ a higher causality, then the very large damage seen in many central countries (e.g. Germany, France, Netherlands – which have very high nitrate concentrations) would be reduced in relation to other countries.  A different pattern of countries would be affected if the causality of sulphates is reduced (i.e. Greece and Cyprus).

Given the different proportion of components of the PM mixture by Member State, it is also clear that future policies will lead to significantly different damage and benefit numbers, if there are different assumptions made about the causality of the PM mixture.  This is therefore considered an important issue for sensitivity analysis in relation to future scenarios.

The second major aspect raised in the methodology report in relation to chronic mortality concerned lag phases.  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 deaths 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%.

## Structure of the uncertainty analysis

The uncertainty analysis starts with a commentary on the sensitivity of benefits results to the choice of meteorological year.  The following sections then describe uncertainty in scenarios A, B and C and MTFR (Maximum Technically Feasible Reduction in emissions according to the measures and assumptions contained in the RAINS model).

In each case the analysis starts with statistical assessment of uncertainties in the benefits analysis using the procedures, values and estimates of spread defined in Volume 3 of the Methodology report.  This is combined with the two sensitivity analyses on mortality valuation (VOLY vs. VSL, median vs. mean).  This stage of the analysis proceeds as far as describing the probability for each set of assumptions under each scenario that the total quantified benefit of moving from scenario to scenario will exceed the cost estimated by the RAINS model.

Next, we provide a sensitivity analysis of response to uncertainty in the costs estimated in RAINS.  This investigates by how much costs would need to change to have a significant impact on the balance of costs and benefits.  Costs are varied in 10% steps between 120% and 50% of the costs estimated by the RAINS model.  The sensitivity analysis is skewed downwards on the grounds that numerous investigations (see Watkiss et al, 2005) of actual costs of air pollution controls compared to costs estimated prior to legislation coming into force have demonstrated a strong tendency to cost overestimation.  There are several likely reasons for this, including innovation by industry in making controls more effective and cheaper, and step changes away from the more polluting technologies (e.g. fuel switching from coal, lignite or heavy fuel oil to natural gas) for reasons that are not related to air pollution legislation. A further factor is that economic instruments, such as taxes may be used to change behaviour that will encourage alternative and cheaper options to be implemented that cause further abatement.

The third part of the analysis considers how large the unquantified benefits of reducing damage to ecosystems, cultural heritage, etc. and reducing human exposure to secondary

organic aerosols would have to be to have a significant influence on the outcome of the analysis. ‘Significance’ is assessed against various probability levels.

A final section on conclusions includes discussion of the interpretation of probabilised results generated by this analysis.

## Uncertainty analysis for Scenario A

### Statistical analysis and sensitivity analysis on mortality valuation

The first part of the uncertainty analysis for Scenario A 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 (€5.9 billion per year) is treated initially as a point estimate with no account taken of its uncertainty, this being considered below. 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 7, 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 28).

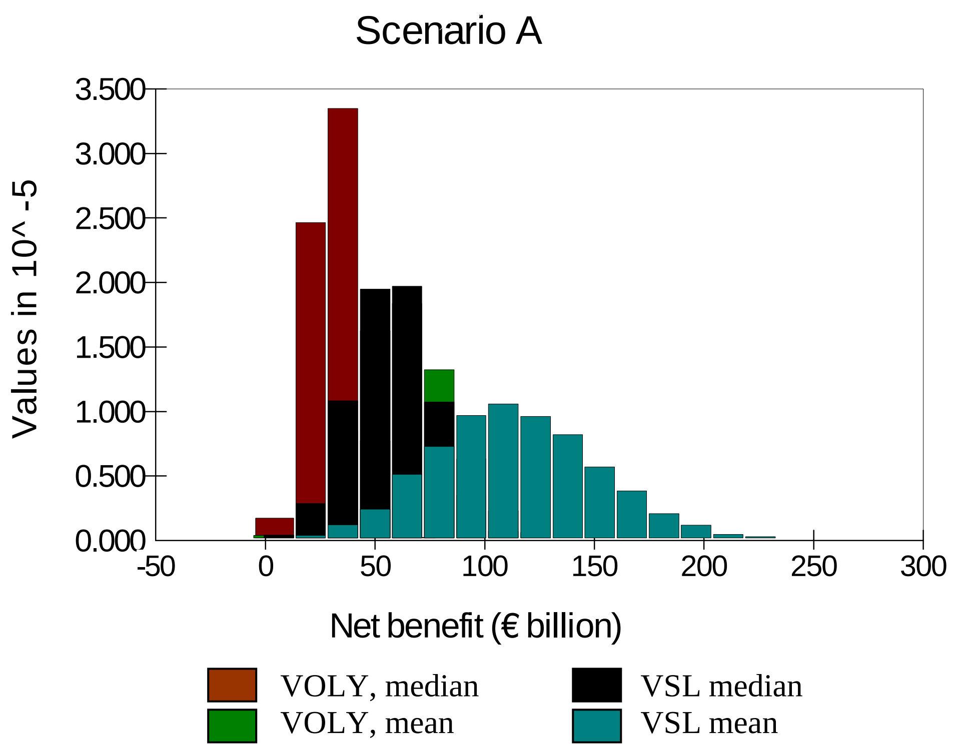



**Figure 7. Probability distributions showing net benefit (benefit – cost) for proceeding from the baseline to Scenario A, with sensitivity to different approaches to mortality valuation also shown.**

**Table 28. Annual costs and benefits for the EU25 of proceeding from the baseline to Scenario A, 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 | 5.9 | 37 | 31 | >99% |
| VOLY – mean | 5.9 | 70 | 64 | >99% |
| VSL – median | 5.9 | 64 | 58 | >99% |
| VSL – mean | 5.9 | 120 | 114 | >99% |

### Sensitivity of results to risk factor for chronic impacts on mortality

The WHO review suggested that sensitivity to the risk factor for chronic impacts on mortality should be explored in the analysis, with a sensitivity run using 4% rather than 6% per 10 $\mu g.m^{-3}$. [10] Whilst there is a significant drop in benefit, the probability that benefit would exceed cost is only slightly reduced.

**Table 29. Annual costs and benefits for the EU25 of proceeding from the baseline to Scenario A, and the probability that benefit will exceed cost, using a risk factor for chronic effects of particles on mortality of 4% per 10 $\mu g.m^{-3}$ instead of 6%.**

| | Cost (core estimate, € billion) | Benefit (core estimate, € billion) | Net benefit (core estimate, € billion) | Probability that benefit > cost |
|---|---|---|---|---|
| VOLY – median | 5.9 | 29 | 23 | >98% |
| VOLY – mean | 5.9 | 50 | 45 | >98% |
| VSL – median | 5.9 | 47 | 41 | >98% |
| VSL – mean | 5.9 | 84 | 78 | >98% |

Note that the analysis that follows is based on the core estimate of 6% per 10 $\mu g.m^{-3}$.

### Sensitivity of results to uncertainty in cost estimates

The total cost of Scenario A has been varied between 50% and 120% of the IIASA estimate in 10% steps. This skewed distribution reflects the results of past investigations of cost estimations (see Watkiss et al, 2005), that show a strong tendency for actual costs to be lower than originally forecast. The probability that benefit exceeds cost remains in excess of 99% in all cases.

### Sensitivity of results to omission of impacts

The exclusion of impacts to ecosystems, etc., biases the results of the benefit assessment to underestimation. The conclusion that benefits would exceed costs with a probability in excess of 99% (or in excess of 98% where the lower risk factor for mortality quantification is applied) would therefore not change significantly through investigation of this sensitivity. The results from Table 27 suggest that additional benefits from inclusion of secondary organic aerosols would add between €1.7 billion/year and €5.7 billion/year to reported benefits. The assessment of ecological damages based on regulator-revealed preference also suggests that there are substantial un-monetised benefits in the core estimates presented in this report.

### Conclusion for Scenario A

It is concluded that the finding that the benefits of moving from the baseline scenario for 2020 to emissions under scenario A exceed the costs (as estimated by the RAINS model) is robust to the factors explored in this uncertainty analysis.

[10] Section 3.2.1 in Volume 2 of the CAFE CBA Methodology report also makes a case for using a higher risk factor, though this sensitivity is not investigated here.

## Uncertainty analysis for Scenario B

### Statistical analysis and sensitivity analysis on mortality valuation

The first part of the uncertainty analysis for Scenario B 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) for the incremental change from Scenario A to Scenario B.  The total annual (incremental) cost of abatement measures across the EU25 estimated by the RAINS model (€4.8 billion per year) is treated initially as a point estimate with no account taken of its uncertainty, this being considered below.  Probability distributions for the benefits are derived from the 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 8, 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 whilst there is a significant spread in the results with the extremes ranging from a little less than €0 (i.e. a small excess of cost compared to benefit) to a net benefit of €40 billion per year, best estimates in all cases show a net benefit.  Overall, based on the ranges, etc. included in this uncertainty analysis, the probability that benefits will exceed costs across these results is in excess of 99% when mortality valuation is based on the VSL or the mean VOLY (Table 30), or 95% when mortality valuation is based on the median VOLY.

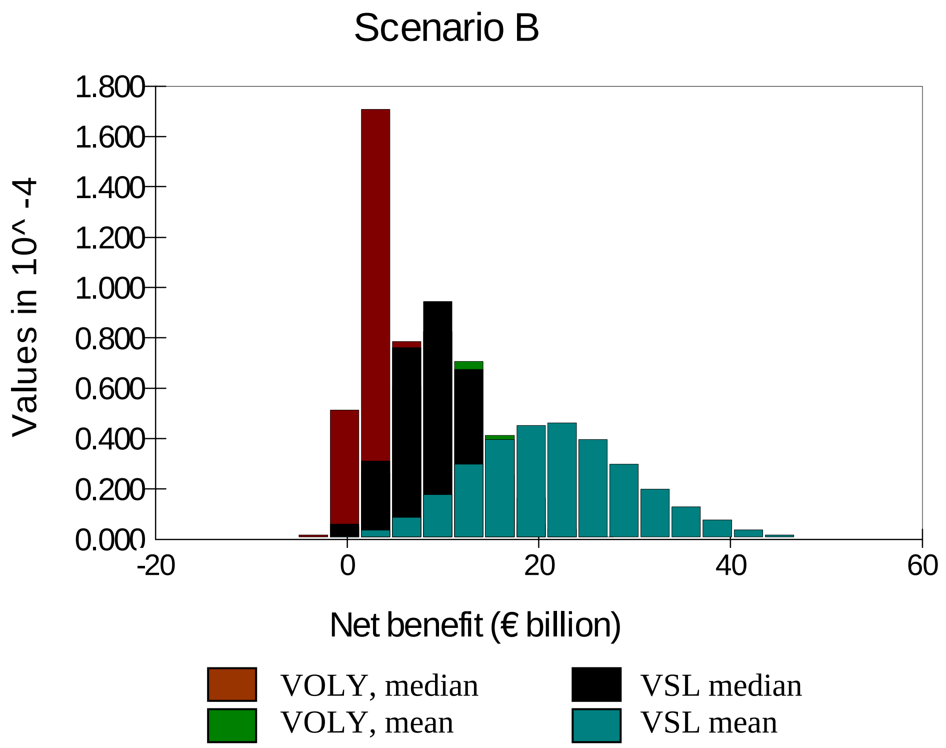



**Figure 8.  Probability distributions showing net benefit (benefit – cost) for proceeding from Scenario A to Scenario B, with sensitivity to different approaches to mortality valuation also shown.**

**Table 30. Annual costs and benefits of proceeding from Scenario A to Scenario B, 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 | 4.8 | 8.2 | 3.5 | 95% |
| VOLY – mean | 4.8 | 15 | 11 | >99% |
| VSL – median | 4.8 | 14 | 9.4 | >99% |
| VSL – mean | 4.8 | 26 | 22 | >99% |

## Sensitivity of results to risk factor for chronic impacts on mortality

The WHO review suggested that sensitivity to the risk factor for chronic impacts on mortality should be explored in the analysis, with a sensitivity run using 4% rather than 6% per 10 $\mu g.m^{-3}$. [11] Whilst there is a significant drop in benefit, the probability that benefit would exceed cost remains above 90% for all cases except where the median VOLY is used, where it falls to 77%.

**Table 31. Annual costs and benefits for the EU25 of proceeding from Scenario A to Scenario B, and the probability that benefit will exceed cost, using a risk factor for chronic effects of particles on mortality of 4% per 10 $\mu g.m^{-3}$ instead of 6%.**

| | Cost (core estimate, € billion) | Benefit (core estimate, € billion) | Net benefit (core estimate, € billion) | Probability that benefit > cost |
|---|---|---|---|---|
| VOLY – median | 4.8 | 6.4 | 1.6 | 77% |
| VOLY – mean | 4.8 | 11 | 6.3 | 92% |
| VSL – median | 4.8 | 10 | 5.5 | 92% |
| VSL – mean | 4.8 | 19 | 14 | 96% |

Note that the analysis that follows is based on the core estimate of 6% per 10 $\mu g.m^{-3}$.

## Sensitivity of results to uncertainty in cost estimates

The analysis presented above did not include assessment of the uncertainty in estimated costs of reducing pollution. The incremental cost of moving from Scenario A to Scenario B as estimated by the RAINS model has been varied between 50% and 120% of the IIASA estimate in 10% steps. Review of past analysis suggests that it is most likely that costs are overestimated, though here we do not rule out altogether some possibility of underestimation.

We have considered separately the conditions where uncertainty affects cost estimates across their full range up to the abatement levels of Scenario B (Figure 9) and only within the increment from Scenario A to Scenario B under investigation in this section (Figure 10). The latter may apply where costs are correct up to the level of Scenario A emissions, but under- or over-estimated thereafter, perhaps through the omission of one or more abatement measures from the cost-curve. The changes in cost are greater for the former (the results shown in Figure 9) than the latter (the results shown in Figure 10) as they deal with total cost above baseline.

[11] As noted above, Section 3.2.1 in Volume 2 of the CAFE CBA Methodology report also makes a case for using a higher risk factor, though this sensitivity is not investigated here.

Figure 9 demonstrates that the probability that benefit exceeds cost remains in excess of 95% in all cases except for the VOLY median based estimates where total cost (i.e. the cost of moving from Baseline to Scenario B) according to the RAINS model is increased to 110% (88% probability of a net benefit) and 120% (73% probability of a net benefit). Similarly, Figure 10 demonstrates that the probability that benefit exceeds cost remains in excess of 95% in all cases except for the VOLY median based estimates where incremental cost of moving from Scenario A to Scenario B according to the RAINS estimate is increased to 110% (93% probability of a net benefit) and 120% (89% probability of a net benefit).

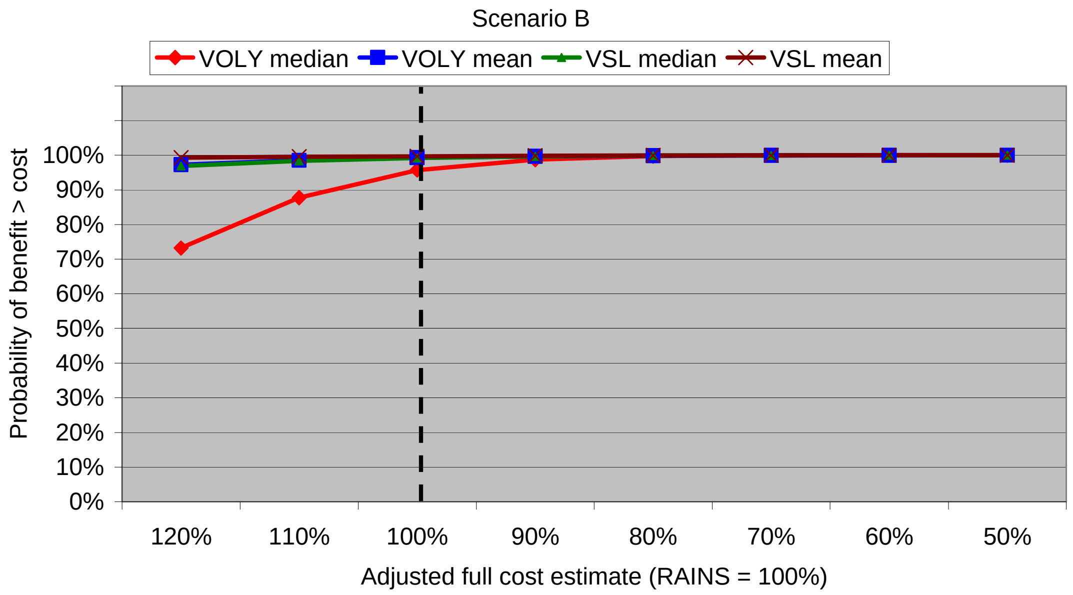



**Figure 9. Sensitivity to uncertainty in total costs of the probability of a net benefit in moving from baseline to Scenario B.**

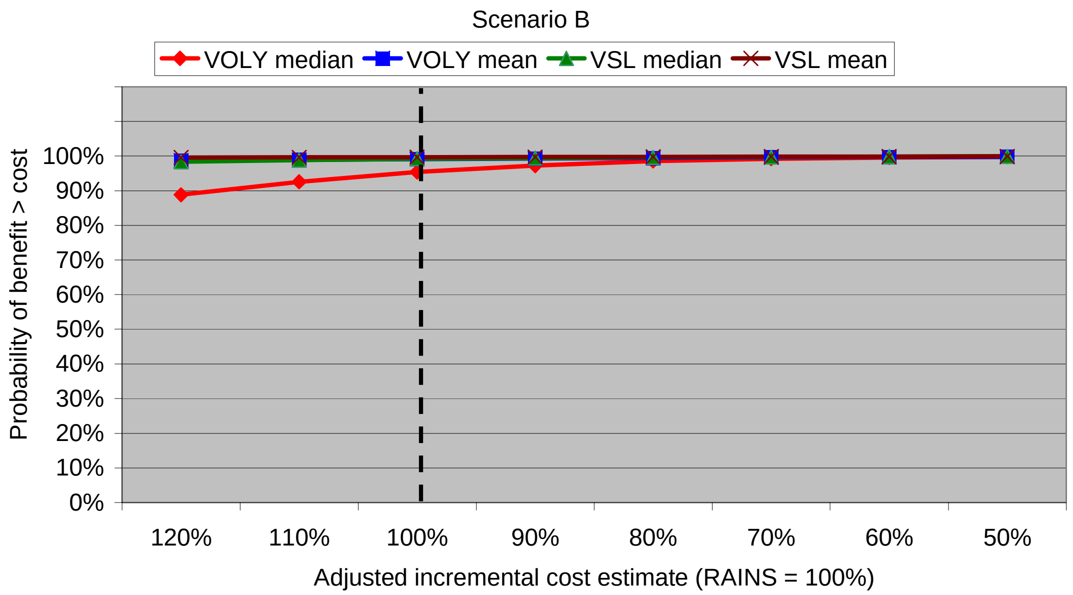



**Figure 10. Sensitivity to uncertainty in incremental costs of pollution abatement of the probability of a net benefit in moving from Scenario A to Scenario B.**

### Sensitivity of results to omission of impacts

The exclusion of impacts to ecosystems, etc., biases the results of the benefit assessment to underestimation. The most important of these impacts (Table 25, Table 26) are considered to be:

- Health impacts of secondary organic aerosols of anthropogenic origin
- Chronic effects of PM exposure on cardio-vascular disease
- Chronic health effects of exposure to ozone
- Impacts on ecosystems through acidification and eutrophication
- Impacts of ozone on ecosystems
- Effects on crop quality (as opposed to yield)
- Damage to cultural heritage

Given the high probabilities demonstrated so far for Scenario B with respect to the likelihood of benefit exceeding cost, the only cases for which consideration of the effect of omitted impacts seems relevant here concern the situation where mortality is valued using the median VOLY and the RAINS estimate of total annual costs for the EU25 is underestimated by 10% or 20%[12].(i.e. true cost = 110% or 120% of the RAINS estimate) Here, we ask how large would the unquantified benefits need to be in order to push the likelihood of benefit exceeding cost for the step from Scenario A to Scenario B beyond probabilities of 50%, 75% and 90%? Results are shown in Table 32, expressed in absolute terms (€billion per year) and as a percentage of the best estimate of quantified benefit in going from Scenario A to Scenario B where mortality is valued using the median VOLY.

**Table 32. Sensitivity analysis showing how large unquantified benefits need to be in order for the probability that benefit exceeds cost to be greater than 50%, 75% and 90% for the median VOLY case, assuming the costs of Scenario B to be underestimated by 10 and 20%.**

| Probability of benefit > cost | 10% cost underestimation by RAINS | | 20% cost underestimation by RAINS | |
|---|---|---|---|---|
| | Additional annual benefit needed | | Additional annual benefit needed | |
| | € billion | as % of quantified benefit | € billion | as % of quantified benefit |
| 50% | 0 | 0% | 0 | 0% |
| 75% | 0 | 0% | 0.09 | 1.1% |
| 90% | 0.25 | 3% | 1.4 | 17% |

Scoping analysis on the health impacts of secondary organic aerosols was reported in Table 27. For the case in question (Scenario B, VOLY-median mortality valuation) this suggested additional benefits in the region of €740 million. Referring to Table 32, and accepting the uncertainty in the estimate of SOA effects, there are strong grounds for concluding that the unquantified benefits are substantial enough to push net benefits through most possible probability-decision thresholds for Scenario B.

There is a question of how large the probability of a net benefit needs to be before action should be considered appropriate. Some stakeholders may consider that anything greater

[12] For all other cases considered, the conclusion that benefits would exceed costs with a probability in excess of 99% would not change through investigation of the effect of the omission of impacts from the benefits analysis. Stakeholders who believe that it is correct to take the mean VOLY or the mean or median VSL, or who believe that costs are very unlikely to be underestimated by RAINS, may disregard this part of the analysis.

than a 50% probability of benefit exceeding cost is sufficient to warrant action being taken, that on balance it shows that there is likely to be a net benefit of action. The higher percentiles are given for those who consider that a higher level of probability is desirable, whether on the grounds of certainty in the outcome of agreed policy or for comparison with other policies where a probabilised CBA has been performed. Some stakeholders may of course come at this from the opposite direction, willing to accept a relatively low probability of a net benefit on grounds of sustainability and the view that there is a greater onus on proving that costs outweigh benefits than vice-versa.

### Conclusion for Scenario B

Overall, it is concluded that the finding that the benefit of moving from Scenario A for 2020 to Scenario B exceeds the cost (as estimated by the RAINS model) is robust to the factors explored in this uncertainty analysis. Even in a conservative case (assumed 20% underestimation of cost by RAINS, combined with mortality valuation based on median VOLY) there is still a 73% probability that benefit exceeds cost (Figure 9). From previous evidence of abatement cost estimation it seems more likely that costs are overestimated by the RAINS model, in which case the probability that benefit exceeds cost is >95% (Table 30).

Sensitivity to the risk factor for mortality from chronic exposure to PM seems limited. For the base case where costs are taken as calculated by the RAINS model there is very little effect on the probability of benefit exceeding cost unless mortality is valued using the median value of the VOLY. In that case, the probability of a net benefit declines from 95% to 77%.

Consideration of impacts that are not monetised in the main analysis suggests additional unaccounted benefits of at least €700 million/year, further reinforcing the case for Scenario B.

## Uncertainty analysis for Scenario C

### Statistical analysis and sensitivity analysis on mortality valuation

The first part of the uncertainty analysis for Scenario C is to estimate probability distributions for <u>net</u> benefits (total benefit of the core health and crop impacts <u>minus</u> the costs estimated by the RAINS model) for the incremental change from Scenario B to Scenario C. The total annual cost for the EU25 estimated by the RAINS model (€4.2 billion per year for this change) is treated initially as a point estimate with no account taken of its uncertainty, this being considered below. Probability distributions for the benefits are derived from the 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 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 whilst there is a significant spread in the results with the extremes ranging from a <u>net cost</u> of €3 billion per year to a <u>net benefit</u> of €40 billion per year. For the ranges associated with the VSL and the mean VOLY best estimates show a net benefit. For the range associated with the median VOLY, however, the best estimate shows a small net cost (€0.1 billion/year).

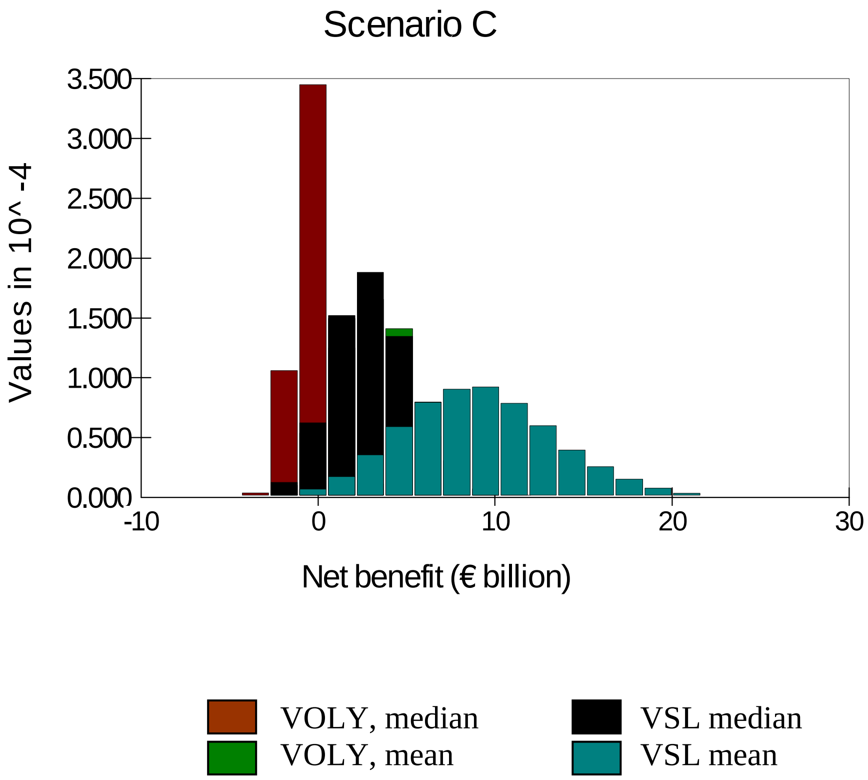



**Figure 11. Probability distributions showing net benefit (benefit – cost) for proceeding from Scenario B to Scenario C, with sensitivity to different approaches to mortality valuation also shown.**

Overall, based on the ranges, etc. included in this uncertainty analysis, the probability that benefits will exceed costs across these results is in excess of 90% when mortality valuation is based on the VSL or the mean VOLY (Table 33), but only 46% when mortality valuation is based on the median VOLY.

**Table 33. Annual costs and benefits of proceeding from Scenario B to Scenario C, 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 | 4.2 | 4.1 | -0.1 | 46% |
| VOLY – mean | 4.2 | 7.7 | 3.5 | 94% |
| VSL – median | 4.2 | 7.1 | 2.9 | 93% |
| VSL – mean | 4.2 | 13 | 8.8 | 99% |

## Sensitivity of results to risk factor for chronic impacts on mortality

The WHO review suggested that sensitivity to the risk factor for chronic impacts on mortality should be explored in the analysis, with a sensitivity run using 4% rather than 6% per 10 $\mu g.m^{-3}$. [13] The effect of this sensitivity is more marked than for Scenarios A and B, with the probability of a net benefit falling from 46% to 17% for the VOLY-median case, and from over 90% to around 70% for the VOLY-mean and VSL-median cases.

[13] As noted above, Section 3.2.1 in Volume 2 of the CAFE CBA Methodology report also makes a case for using a higher risk factor, though this sensitivity is not investigated here.

**Table 34. Annual costs and benefits for the EU25 of proceeding from Scenario B to Scenario C, and the probability that benefit will exceed cost, using a risk factor for chronic effects of particles on mortality of 4% per 10 µg.m$^{-3}$ instead of 6%.**

| | Cost (core estimate, € billion) | Benefit (core estimate, € billion) | Net benefit (core estimate, € billion) | Probability that benefit > cost |
|---|---|---|---|---|
| VOLY – median | 4.2 | 3.2 | -1.0 | 17% |
| VOLY – mean | 4.2 | 5.6 | 1.4 | 72% |
| VSL – median | 4.2 | 5.2 | 0.98 | 69% |
| VSL – mean | 4.2 | 9.3 | 5.1 | 90% |

Note that the analysis that follows is based on the core estimate of 6% per 10 µg.m$^{-3}$.

### Sensitivity of results to uncertainty in cost estimates

The analysis presented above did not include assessment of the uncertainty in estimated costs of reducing pollution. The incremental cost of moving from Scenario B to Scenario C as estimated by the RAINS model has been varied between 50% and 120% of the IIASA estimate in 10% steps. Review of past analysis suggests that it is most likely that costs are overestimated, though here we do not rule out altogether the possibility of some level of underestimation.

We have considered separately the conditions where uncertainty affects cost estimates across their full range up to the abatement levels of Scenario C (Figure 12) and only within the increment from Scenario B to Scenario C under investigation in this section (Figure 13). The latter may apply where costs are considered correct up to the level of Scenario B emissions, but under- or over-estimated thereafter, perhaps through the omission from the cost-curve of one or more abatement measures. The changes in cost are greater for the former (the results shown in Figure 12) than the latter (the results shown in Figure 13) as they deal with total cost above baseline.

Figure 12 demonstrates the following:

- **Benefits with mortality valued using the median VOLY:** Benefit exceeds cost with a probability greater than 90% for all cases where cost equals 90% or less of the RAINS estimate. The probability falls rapidly to 47% at the RAINS estimate, 7.3% at 110% of RAINS and 0.3% at 120% of RAINS.
- **Benefits with mortality valued using the mean VOLY:** The probability of benefit exceeding cost is greater than 90% for all cases equal to or less than the RAINS estimate of cost. With cost equal to 110% of RAINS the probability falls to 80%, and for cost equal to 120% of RAINS, to 57%.
- **Benefits with mortality valued using the median VSL:** The probability of benefit exceeding cost is greater than 90% for all cases equal to or less than the RAINS estimate of cost. With cost equal to 110% of RAINS the probability falls to 75%, and for cost equal to 120% of RAINS, to 48%.
- **Benefits with mortality valued using the mean VSL:** The probability of benefit exceeding cost is greater than 90% throughout the range of costs investigated.

The pattern is not so dramatic in Figure 13, where the probability of benefit exceeding cost is greater than 80% for the full range of costs examined for the sets of results where mortality is valued using mean VOLY, median VSL and mean VSL. Results are also a little less sensitive to increased costs when mortality is valued using the median VOLY, with the

probability of benefit exceeding cost falling from 46% at the RAINS estimate to 31% at 110% of RAINS and 19% at 120% of RAINS.  However, in this case it is necessary to reduce costs to 77% of the RAINS estimate before probability of a net benefit exceeds 80%, and to 67% of RAINS for a probability in excess of 90%.  The lower sensitivity here compared to Figure 12 is to be expected because (as already noted) the cost changes are smaller, given that Figure 13 deals with incremental rather than total costs.

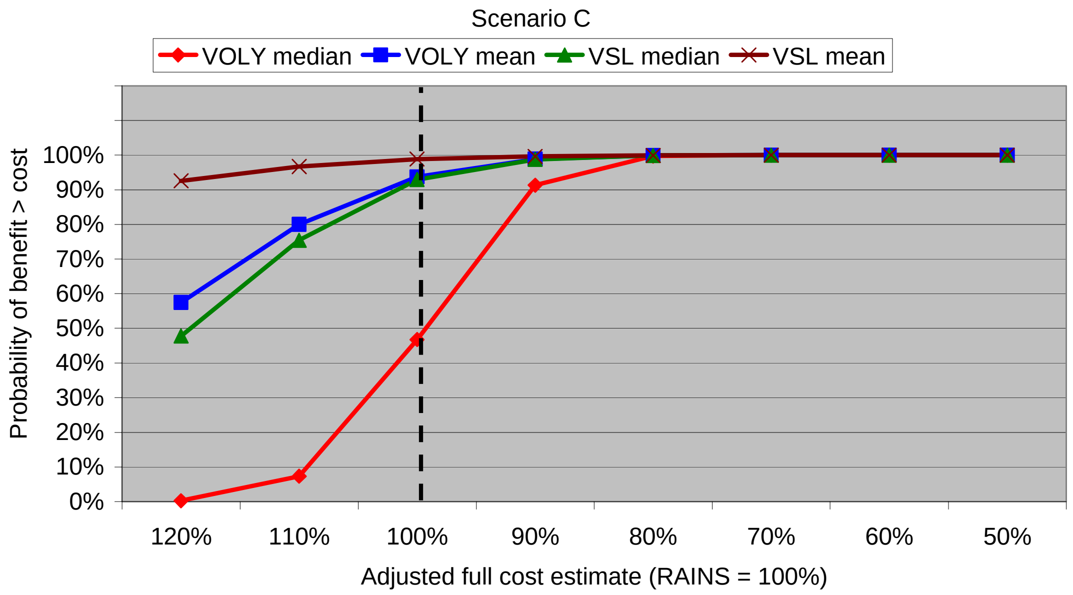



**Figure 12.  Sensitivity to uncertainty in total costs of the probability of a net benefit in moving from baseline to Scenario C.**

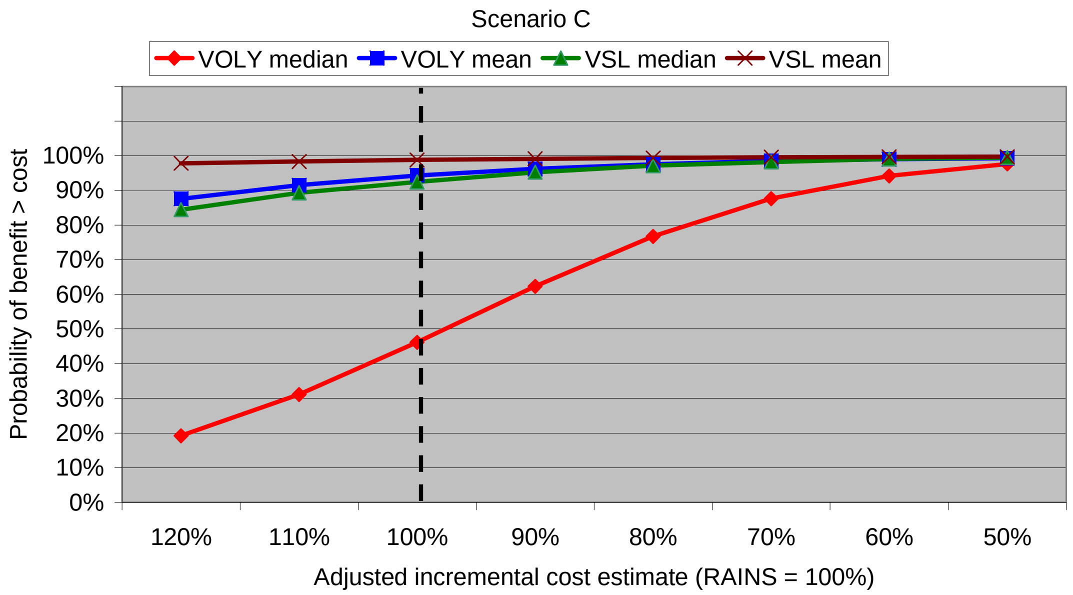



**Figure 13.  Sensitivity to uncertainty in incremental costs of pollution abatement of the probability of a net benefit in moving from Scenario B to Scenario C.**

### Sensitivity of results to omission of impacts

The exclusion of impacts to ecosystems, etc., biases the results of the benefit assessment to underestimation. The most important of these impacts (Table 25 and Table 26) are considered to be:

- Health impacts of secondary organic aerosols of anthropogenic origin
- Chronic effects of PM exposure on cardio-vascular disease
- Chronic health effects of exposure to ozone
- Impacts on ecosystems through acidification and eutrophication
- Impacts of ozone on ecosystems
- Effects on crop quality (as opposed to yield)
- Damage to cultural heritage

For Scenario C it is worth considering the potential effect of omitted impacts for several cases with costs ranging between the RAINS estimate and 120% of the RAINS estimate. Here, we ask the question how large would the unquantified benefits need to be in order to push the likelihood of benefit exceeding cost for the step from Scenario B to Scenario C beyond the levels of 50%, 75% and 90%? Results are shown in Table 35. Results are expressed in absolute terms (€billion per year) and as a percentage of the best estimate of quantified benefit in going from Scenario B to Scenario C.

**Table 35. Sensitivity analysis showing how large unquantified benefits need to be (€billion, % of estimated benefit) in order for the probability of gaining a net benefit when moving from Scenario B to Scenario C is greater than 50%, 75% and 90% for different cost estimates.**

| Cost level | VOLY median | VOLY mean | VSL median | VSL mean |
|---|---|---|---|---|
| For 90% probability of benefits exceeding costs | | | | |
| <100% RAINS | 0 | 0 | 0 | 0 |
| 100% RAINS | 1.5 (36%) | 0 | 0 | 0 |
| 110% RAINS | 2.9 (71%) | 0.94 (12%) | 1.5 (21%) | 0 |
| 120% RAINS | 4.6 (112%) | 2.3 (30%) | 2.7 (38%) | 0 |
| For 75% probability of benefits exceeding costs | | | | |
| <100% RAINS | 0 | 0 | 0 | 0 |
| 100% RAINS | 0.95 (23%) | 0 | 0 | 0 |
| 110% RAINS | 2.3 (56%) | 0 | 0 | 0 |
| 120% RAINS | 3.9 (95%) | 1.1 (14%) | 1.6 (23%) | 0 |
| For 50% probability of benefits exceeding costs | | | | |
| <100% RAINS | 0 | 0 | 0 | 0 |
| 100% RAINS | 0.089 (2%) | 0 | 0 | 0 |
| 110% RAINS | 1.6 (39%) | 0 | 0 | 0 |
| 120% RAINS | 2.9 (71%) | 0 | 0.096 (1%) | 0 |

For cases where mortality valuation is based on the median VOLY it is clear that unquantified benefits need to be substantial (compared to those that have been quantified) in order for benefits to exceed costs by the probability levels shown if it is assumed that the RAINS model underestimates cost of abatement to any degree. However, as noted elsewhere, underestimation by the RAINS seems unlikely, based on broader analysis of ex-ante pollution control cost estimates, so these results may give an unduly pessimistic

appearance to the analysis. For the 50% probability level, unquantified benefits would need only add 2% to quantified effects with mortality valued using median VOLY for there to be a net benefit if the RAINS estimate is accurate. An increase in benefit of 2% seems entirely plausible bearing in mind the list of unquantified effects given in Table 25. This increases to just over a third (36% additional benefit required) when the 90% probability level is considered. At the present time it is not possible to tell from the analytical evidence whether the unquantified effects would add sufficient to total benefits to meet this level.

The scoping analysis of secondary organic aerosol damage to health (Table 27) suggests values in the region of €420 million/year (VOLY-median) to €1.4 billion/year (VSL-mean). Additional damage of this magnitude would be sufficient to pass the probability thresholds of 50% though not quite 75%. Stakeholders should consider whether the omitted effects from SOAs are likely to be larger or smaller than indicated by this analysis, and what the effect of adding in other unquantified effects, particularly those on ecosystems and cultural heritage.

### Conclusion for Scenario C

Overall, it is concluded that the finding that the benefit of moving from Scenario B for 2020 to Scenario C exceeds the cost (as estimated by the RAINS model) is robust to the factors explored in this uncertainty analysis with the following exceptions:

1. When mortality is valued using the median VOLY in combination with a 4% risk factor for the effects of chronic mortality from particle exposure.
2. When the true costs of abatement are greater than those quantified for this analysis (though based on past evidence this seems unlikely to be the case).

Against this, if total costs are overestimated by the RAINS model by only 10%, there is a 90% probability of a net benefit irrespective of the approach adopted for mortality valuation.

It is concluded that whilst there is a case made here for moving to Scenario C, it is not quite as robust as the case for moving to Scenario B.

## Uncertainty analysis for the MTFR Scenario

### Statistical analysis and sensitivity analysis on mortality valuation

The first part of the uncertainty analysis for the MTFR Scenario is to estimate probability distributions for <u>net</u> benefits (total benefit of the core health and crop impacts <u>minus</u> the costs estimated by the RAINS model) for the incremental change from Scenario C to MTFR. The total annual cost for the EU25 estimated by the RAINS model (€25 billion per year for this change) is treated initially as a point estimate with no account taken of its uncertainty, this being considered below. Probability distributions for the benefits are derived from the 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 14, which combines statistical analysis on all 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 with the extremes ranging from a <u>net cost</u> of a little more than €20 billion per year to a <u>net benefit</u> of around €15 billion per year. In none of the four sensitivity cases around mortality valuation do best estimates show a net benefit.

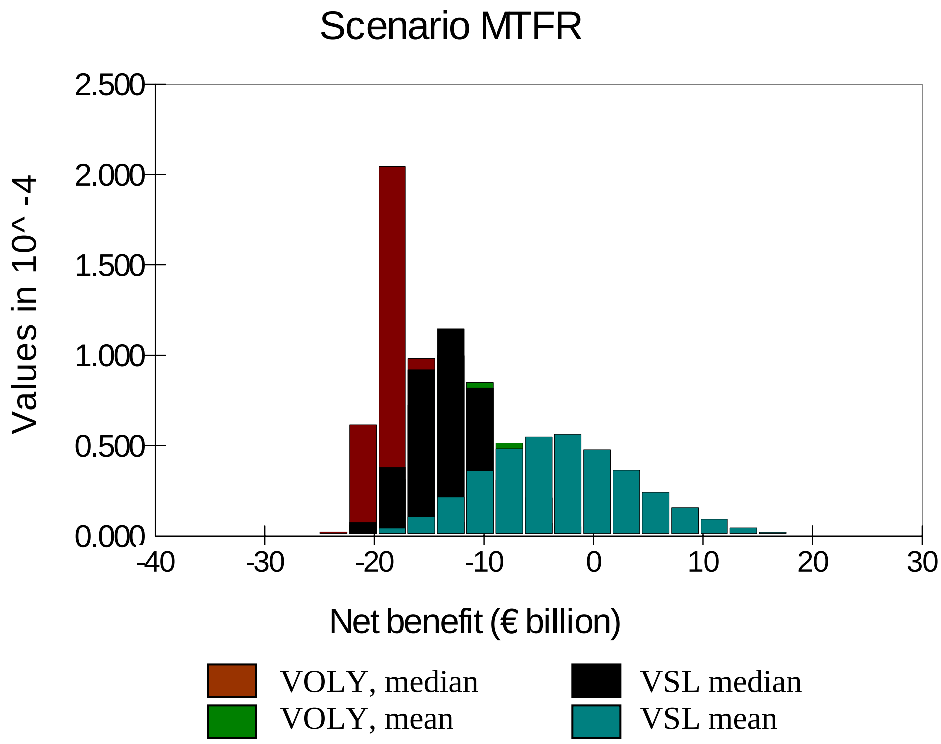



**Figure 14.  Probability distributions showing net benefit (benefit – cost) for proceeding from Scenario C to the MTFR scenario, with sensitivity to different approaches to mortality valuation also shown.**

The probability that benefit exceeds costs is <1% except for the case where mortality is valued using the mean VSL, where the probability rises to 33% (Table 36).

**Table 36.  Annual costs and benefits of proceeding from Scenario C to MTFR, 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 | 25 | 6.9 | -18 | 0% |
| VOLY – mean | 25 | 13 | -12 | <1% |
| VSL – median | 25 | 12 | -13 | <1% |
| VSL – mean | 25 | 22 | -2.9 | 33% |

## Sensitivity of results to risk factor for chronic impacts on mortality

The WHO review suggested that sensitivity to the risk factor for chronic impacts on mortality should be explored in the analysis, with a sensitivity run using 4% rather than 6% per 10 $\mu g.m^{-3}$. [14] As was the case for Scenario A, this change has little effect on the outcome of the analysis, though in this instance the probabilities of benefit exceeding cost remain very low.

[14] As noted above, Section 3.2.1 in Volume 2 of the CAFE CBA Methodology report also makes a case for using a higher risk factor, though this sensitivity is not investigated here.

**Table 37. Annual costs and benefits for the EU25 of proceeding from Scenario C to MTFR, and the probability that benefit will exceed cost, using a risk factor for chronic effects of particles on mortality of 4% per 10 $\mu g.m^{-3}$ instead of 6%.**

| | Cost (core estimate, € billion) | Benefit (core estimate, € billion) | Net benefit (core estimate, € billion) | Probability that benefit > cost |
|---|---|---|---|---|
| VOLY – median | 25 | 5.3 | -20 | 0% |
| VOLY – mean | 25 | 9.3 | -16 | 0% |
| VSL – median | 25 | 8.5 | -16 | 0% |
| VSL – mean | 25 | 15.3 | -9.5 | 9% |

Note that the analysis that follows is based on the core estimate of 6% per 10 $\mu g.m^{-3}$.

### Sensitivity of results to uncertainty in cost estimates

We have considered separately the conditions where uncertainty affects cost estimates across their full range up to the abatement levels of MTFR (Figure 15) and only within the increment from Scenario C to MTFR under investigation in this section (Figure 16). The latter may apply where costs are correct up to the level of Scenario C emissions, but overestimated thereafter, perhaps through the omission from the cost-curve of one or more abatement measures.

Figure 15 demonstrates the following:

- **Benefits with mortality valued using the median VOLY:** Benefit exceeds cost with a probability of 88% when cost equals 50% or less of the RAINS estimate. Over the rest of the cost range examined the probability of a net benefit is 10% or less.
- **Benefits with mortality valued using the mean VOLY:** The probability of benefit exceeding cost only exceeds 50% when costs are reduced to 69% of the RAINS estimate or less. However, if the true cost was half the RAINS estimate the probability of a net benefit would be 98%. With costs equal to or greater than 80% of the RAINS estimate the probability of a net benefit falls to only 14% or less.
- **Benefits with mortality valued using the median VSL:** The probability of benefit exceeding cost only exceeds 50% when costs are reduced to 67% of the RAINS estimate or less. However, if the true cost was half the RAINS estimate the probability of a net benefit would be 98%. With costs equal to or greater than 80% of the RAINS estimate the probability of a net benefit falls to only 7% or less.
- **Benefits with mortality valued using the mean VSL:** The probability of benefit exceeding cost is greater than 50% once costs fall below 90% of the RAINS estimate. The 75% probability is passed with costs reduced to 80% of RAINS, and 90% probability beyond the point where costs equal 70% of RAINS.

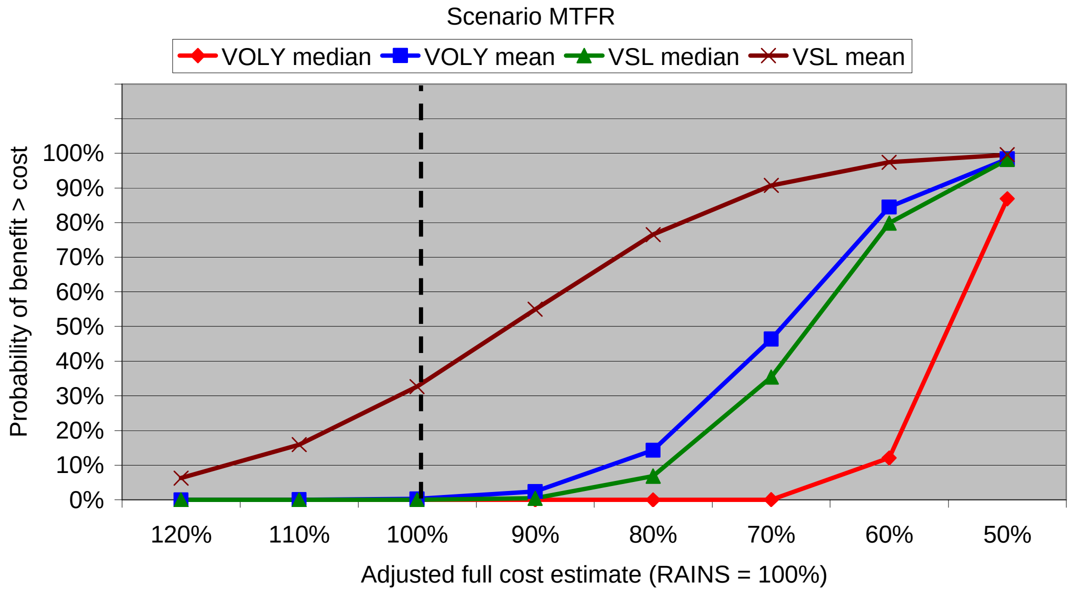



**Figure 15.  Sensitivity to uncertainty in total costs of the probability of a net benefit in moving from baseline to MTFR.**

In Figure 16, where only the incremental cost is adjusted, the 50% probability level is only exceeded for the VOLY mean case at 50% of the RAINS costs and the VSL mean case at 80% of the RAINS costs and lower.

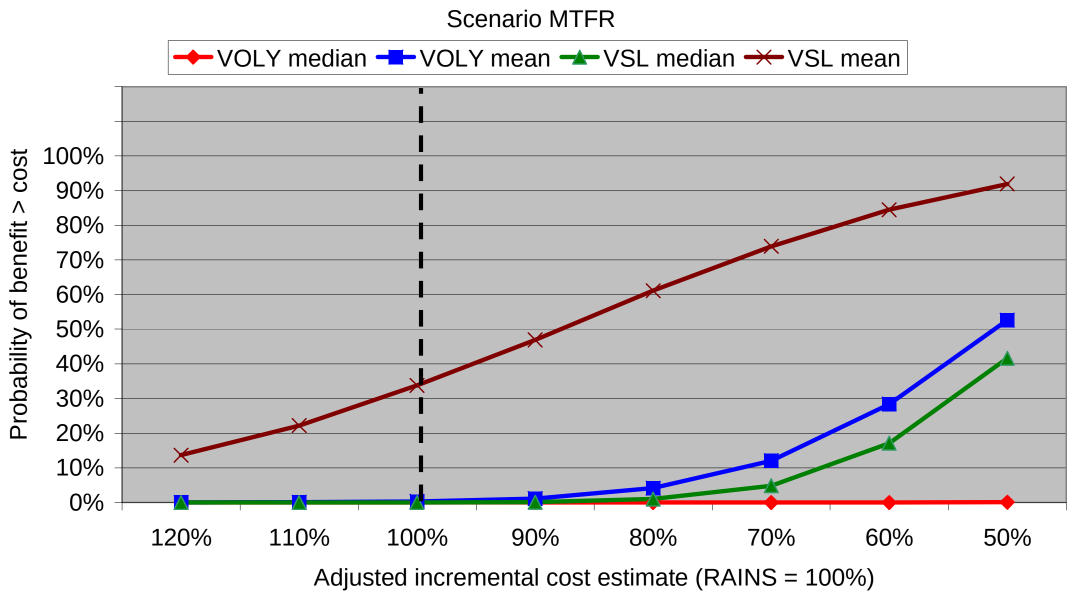



**Figure 16.  Sensitivity to uncertainty in incremental costs of pollution abatement of the probability of a net benefit in moving from Scenario C to MTFR.**

### Sensitivity of results to omission of impacts

From consideration of the results on sensitivity to uncertainty in cost estimates, and the results for Scenario C showing the necessary size of unquantified benefit when there is a low probability that benefit exceeds cost according to the main analysis, it is concluded that it is not necessary to perform additional sensitivity analysis at this point. Any results generated would be so far from the core results that they would be unlikely to be considered seriously against the data generated elsewhere in this report and related documents.

### Conclusion for the MTFR Scenario

Overall, it is concluded that the probability of benefit exceeding cost for the MTFR Scenario, according to the models and assumptions used in the CAFE process, is small, requiring costs to be significantly overestimated by RAINS and unquantified benefits to be large.

## Discussion on the uncertainty assessment

### Main uncertainties

Although assessment of uncertainty is complex, it is simplified to an extent by the fact that a small number of issues are likely to dominate its consideration in the assessment being made here. These are:

1. Quantification of the mortality impact of exposure to fine particles. This is partially addressed in the initial statistical analysis for each scenario, using information regarding the spread of values around the best estimate selected by CAFE-CBA. Assessment of the impact of different assumptions on lag phase has not been addressed specifically here. However, results in the baseline report suggested that the adoption of alternative positions on this issue could reduce mortality benefits by 10%, following a scheme adopted by USEPA.
2. Valuation of mortality impacts from particles and other pollutants. This is addressed using statistical analysis combined with sensitivity analysis that describes, separately, results based on the Value of a Life Year (VOLY) approach, and the Value of a Statistical Life (VSL) approach. Further to this, sensitivity to use of median and mean values of the VOLY and VSL is also investigated.
3. Assessment of effects of chronic exposure to particles on the prevalence of bronchitis. This is addressed in the statistical analysis.
4. Attribution of effects to individual species of particle or other pollutant. This is not addressed in the analysis presented here.
5. Failure to quantify monetary benefits with respect to ecosystem and some other types of damage. This is addressed qualitatively through the bias assessment and associated sensitivity analysis. It is necessary for stakeholders to draw their own conclusions on the relative importance of the unquantified effects against those for which estimates are provided.
6. Omission of secondary organic aerosols from the pollutant dispersion modelling. Quantified estimates of SOA related impacts indicate that they are sufficiently large to influence the balance of costs and benefits significantly under some situations.
7. Omission of some pollutant abatement measures from the cost-curves used in the RAINS model, lack of account of future technical developments.

### Interpretation of reported probabilities from a policy making perspective

It is necessary to consider what level of probability of attaining a net benefit is sufficient for any stakeholder to believe that action is appropriate. In many everyday situations a figure of

50% would be considered appropriate.  Some stakeholders may consider the same here. However, this is not an everyday situation, given that:

- The costs of action are measured in billions of euro per year.  This may encourage stakeholders to look for a higher probability of a net benefit.
- There are substantial impacts on health from the CAFE pollutants in terms of death and illness, and critical loads are exceeded over a large percentage of European ecosystems.  This may encourage stakeholders to accept a lower probability.

It is, however, clear that it is not the job of the authors of this report to instruct stakeholders how to respond to the probabilities defined in this work.  That is a question of political judgement rather than scientific analysis.  It is hoped that the results have been presented in such a way as to assist all stakeholders, whatever their view on the balance of costs and benefits necessary for action to be taken.

### Summary of the uncertainty assessment

The starting point for review of the results given in the preceding sections is consideration of the probability that the total benefit for each scenario according to core estimates would exceed the total cost.  Results, drawn from Table 28, Table 30, Table 33 and Table 36 are shown in Figure 17.  For Scenario A and Scenario B there is a high probability that incremental benefit will exceed incremental cost, irrespective of the approach taken to mortality valuation.  For Scenario C there is again a high probability of excess benefit in all cases except where mortality is valued using the median VOLY, in which case the probability falls to a little under 50%.  For the MTFR scenario (Maximum Technically Feasible Reduction according to the assumptions and measures included in the RAINS model) there is little probability of incremental benefit exceeding cost, irrespective of the approach taken for mortality valuation.

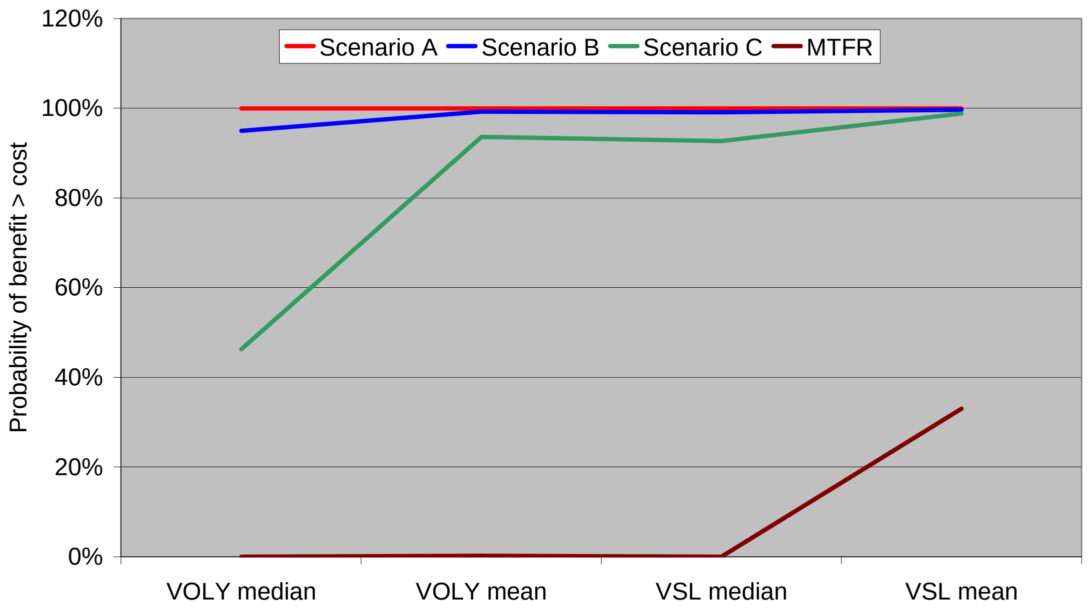



**Figure 17.  Comparison of the probability of benefit exceeding cost.  This does not include consideration of sensitivity to cost uncertainty or unquantified benefits.**

Based on the significant body of evidence that forecasted costs of pollution control are generally overestimated, the results summarised in Figure 17 were combined with sensitivity analysis on estimated costs for each scenario and on the magnitude of unquantified benefits. Variation in costs had little effect on scenarios A or B. The magnitude of unquantified benefits only became significant in one case, for Scenario B, where cost was assumed to be underestimated by the RAINS model by 20% (considered here to be unlikely).

For Scenario C, reductions in total cost have a significant effect in increasing the probability of a net benefit (Figure 12), particularly for the case where mortality is valued using the lower bound, the median VOLY. If, conversely, it were the case that RAINS underestimates the true cost, Figure 12 shows that the probability of a net benefit would fall significantly for all cases except where mortality is valued using the mean VSL, the upper bound. As noted already noted, however, we consider it unlikely that costs are underestimated by RAINS. Table 35 shows that increased cost would need to be balanced by only a small additional benefit (in terms of the unquantified benefits) to pass the 50% probability level for the cases where mortality is valued using mean VOLY or median VSL. The required additional benefits become significant when seeking to pass through the higher (75% and 90%) probability levels under the assumption of RAINS costs being underestimated.

When using the median VOLY for Scenario C, unquantified benefits would need to be equal to only 2% of quantified effects for benefit to exceed the RAINS estimate of cost with a probability of 50%. Moving to higher probabilities, and assuming that RAINS underestimates cost to any degree leads to a significant increase in the required magnitude of unquantified benefits.

For the MTFR scenario it was necessary to reduce costs substantially (typically by 40% or more) in order for the probability of a net benefit to exceed 50%.

## Conclusions

**Scenario A:** The conclusion that benefit would exceed cost across the EU25 for Scenario A appears robust according to the uncertainty assessment performed, with a probability in excess of 95% of gaining a net benefit.

**Scenario B:** Again, the analysis suggests that the conclusion that benefit would exceed cost across the EU25 is robust according to the uncertainty assessment performed, though with a slightly reduced probability compared to Scenario A.

**Scenario C:** There is certainly a case made for moving to Scenario C, though for stakeholders who prefer to use the median VOLY for mortality valuation it is clearly less robust than the case for moving to Scenario B.

**MTFR Scenario:** To make the case that it is appropriate to move to the MTFR as defined by the RAINS model it would be necessary to assume that costs are overestimated significantly, and that unquantified benefits are large. This goes beyond the extremes of the present analysis. We conclude, therefore, that this analysis does not demonstrate a case for adoption of the MTFR.

# Assessment of the Macroeconomic Impact of the CAFE Scenarios

## Introduction

The objective to carry out the assessment of the macroeconomic impact of CAFE scenarios is to complement other parts of the CAFE analysis. The first section describes how the macroeconomic model GEM-E3 (General Equilibrium Model – Energy, Economy, Environment) is calibrated to the RAINS data and results . The second section gives the macroeconomic impact for scenarios A, B and C. Then results are presented for the RAINS scenarios where only the PM health endpoint is considered. Finally, the impacts of the choice of policy instrument for the implementation of the CAFE scenario are examined.

## GEM-E3 and its calibration to RAINS

### The modelling framework for emission reduction

In GEM-E3[15] the emissions of the primary pollutants ($CO_2$, NOx, $SO_2$, VOC, $PM_{10}$ and $NH_3$) are differentiated by countries, sectors, fuels, and durable goods (e.g. cars, heating systems) that use the fuels. They are either linked to the use of oil, coal, and gas for which the link concerns only the energetic use of these inputs or they are linked to the production of the sectors. For private consumption the major links between energy inputs and consuming durable goods are specified: cars and gasoline/diesel, heating systems and electric appliances and oil, coal, gas and electricity.

Three mechanisms of emission reduction are explicitly specified in the model: end-of-pipe abatement (where appropriate technologies are available), substitution between fuels and/or between energetic and non-energetic inputs for production, and emission reduction due to a decline in production and/or consumption.

For the emissions linked to energy the abatement activities are modelled such as to increase the user cost of the polluting input (here the price of energy) in the decision process of the polluter. When an environmental tax is imposed it is paid to the government by the branch generating the pollution. This has the following implications for the *energy price* modelling:

- the price of energy, inclusive abatement cost and taxes, is used in the decision by the firm on production factors (at the energy level and implicitly at the level of aggregates); it represents the user's cost of energy;
- the price of energy, exclusive taxes and abatement cost, is used to value the delivery of the energy sectors to the other sectors;

For the emissions linked to production, the abatement activities increase directly the cost of the product.

In the modelling of the *abatement activities*, installing abatement technologies has been considered as an input for the firms and not as an investment. The major advantage of this formulation is its simplicity, especially as the available abatement cost functions are in terms

15 A detailed description of the model can be found on www.gem-e3.org

of annualised cost, and because, with this framework, the abatement costs do not directly increase GDP as it would if modelled as investment. For the latter purpose a depreciation and replacement mechanism would have to be introduced. The user's cost of the abatement equipment would have to be added to the capital income, avoiding however any double counting. The input demand for abatement is modelled in the following way:

- the demand for abatement inputs is allocated to the delivery sectors through fixed coefficients;
- the total delivery for abatement is added to the intermediate demand and these inputs are valued as the other intermediate deliveries.

### The calibration

The emissions of the different pollutants (NOx, $SO_2$, VOC, $PM_{10}$ and $NH_3$) have been calibrated to the RAINS baseline scenario, associating the RAINS activities with the GEM-E3 sectors. A distinction is made between emissions linked to energy consumption and emissions linked to the production of a sector, depending on the source of emission identified in RAINS. Emission coefficients were computed for 2000 and then a trend factor for 2000-2020 was applied, based on the trend in the RAINS emission factors. For the emissions linked to production only the PM and VOC emission coefficients were adapted. $NH_3$ emissions were only modelled for the agricultural sector, given that agriculture is the source of some 90% of $NH_3$ emissions.

The marginal abatement cost curves per sector and per country, either linked to energy or to production, were estimated based on the cost curves from RAINS, after allocating the RAINS data to the GEM-E3 classification. It was not possible to derive abatement cost curves for all pollutants and all sectors, because the number of abatement technologies considered in RAINS were too small for some pollutants and sectors. For some pollutant and sector combinations (mostly PM emissions in the domestic sector) the marginal abatement cost can increase sharply when the reduction target is very ambitious.

It is important to mention that the translation of RAINS bottom up data into data for the GEM-E3 aggregate sectors can only be approximate and still needs a further double checking given the short time to implement them into GEM-E3. This increases the error margins in the results with GEM-E3. We believe, however, that at the aggregate EU level, GEM-E3 gives a first assessment of the macroeconomic impact of air pollution policies.

The benefits of reducing air pollution are evaluated using the damage figures per tonne of pollutant emitted in each EU member state computed by AEAT. These figures give per country the damage to the whole EU from one tonne emitted in that country. This allows computing the total EU benefit from air pollution reduction in the EU member states but does not allow allocation of this benefit to each country. The evaluations are done with the ‘low’ damage figure corresponding to use of the median estimate of the value of a life year.

# The policy scenarios

## The Reference scenario (CAFE baseline up to 2020)[16]

The reference scenario for the evaluation of the CAFE scenarios imposes, besides the assumptions regarding autonomous energy efficiency and labour productivity improvement, a climate policy. For the world oil and gas prices an average growth of 1.6% till 2020 is assumed. The climate policy is modelled in GEM-E3 as an EU wide $CO_2$ tax imposed from 2010 onwards (from 12€/ton in 2010 to 20€/ton in 2020) and the revenues from the tax are recycled through a reduction of the employers' social security contribution. It is also assumed that the resource allocation induced by the policy occurs within the EU by imposing that the EU current account remains constant relative to GDP compared to the reference through a flexible interest rate. These assumptions remain valid for the policy scenarios. It implies that already a great effort for the reduction of energy consumption has been made. The cost curves implemented in GEM-E3 from RAINS take this into account, as they are derived in RAINS with the same climate policy assumption thus ensuring that the reference scenario in GEM-E3 is consistent with the CAFE baseline scenario.

The projected average EU growth rate is 2.4% till 2020 with a higher growth rate for the new member states (around 3.5%). The $CO_2$ tax reduces the $CO_2$ emissions by 13% compared to the case without tax but emissions still increase over time at approx. 0.5% per year in this reference scenario.

## Scenarios of increasing ambition for environmental and health improvement

**Assumptions**

Scenarios A, B and C have been implemented as sectoral constraints into GEM-E3 in 2020. The associated costs are then computed endogenously in the model given the marginal abatement cost curves by sector estimated from the RAINS marginal cost curves. The additional measures in transport to control NOx and PM emissions above the actual legislation have also been implemented, though in a slightly different way as there are no abatement cost curves available for transport. The policy scenarios as implemented in these first simulations assume the use of a type of performance standard (maximum emission per unit of output) for the implementation of the abatement measures. The allocation of effort over the sectors is based on the allocation determined by RAINS. In RAINS this allocation is cost-efficient. There are neither information costs for the regulator, nor monitoring, nor enforcement cost in these scenarios. In a later section we examine the impact of the policies using other policy instruments.

As in the reference scenario, the public deficit relative to GDP is assumed to remain constant and is obtained through the flexibility of the employer's social security contribution.

**Results**

The overall economic welfare impact (excluding the environmental benefits) is estimated to be negative because of the reduction in private consumption, but remains small. Consumers would lose in terms of income because of a decrease of real wages and the cost of the emission reduction for heating equipment and transport. The estimated real wage decrease is partly due to the increase in the social security rate. The social security rate would need to increase slightly to compensate the loss in energy and environmental tax revenues. The type

[16] Given the time schedule it was not possible to calibrate GEM-E3 and PRIMES jointly; therefore this exercise is based on a baseline constructed at CES for their policy studies which is in line with DGTREN "European Energy and Transport – Trends to 2030" (Jan. 2003)

of instrument used in this scenario, a ‘command and control’ type, would not generate any additional tax income.

**Table 38: Macroeconomic impact at EU level of the CAFE air pollution scenarios in 2020 (% difference compared to reference scenario except for * where difference compared to reference share[17])**

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Macroeconomic Aggregates** | | | |
| *Gross Domestic Product* | -0.04% | -0.08% | -0.12% |
| *Employment* | 0.00% | 0.00% | 0.00% |
| *Private Consumption* | -0.06% | -0.13% | -0.20% |
| *Investment* | -0.01% | -0.02% | -0.03% |
| *Final Energy Consumption* | -0.12% | -0.24% | -0.34% |
| *Share Coal** | -0.04% | -0.06% | -0.07% |
| *Share Oil** | 0.01% | 0.03% | 0.04% |
| *Share Gas** | 0.00% | -0.01% | -0.02% |
| *Share Electricity** | 0.03% | 0.05% | 0.06% |
| *Exports to RW* | 0.00% | 0.01% | 0.02% |
| *Imports* | 0.04% | 0.10% | 0.15% |
| *Real Wage Rate* | -0.04% | -0.09% | -0.14% |
| *Relative Consumer Price* | 0.00% | 0.00% | 0.00% |
| *Real Interest Rate* | 0.01% | 0.02% | 0.03% |
| *Terms of Trade* | 0.04% | 0.08% | 0.12% |
| *Public Surplus (% of GDP)** | 0.00% | 0.00% | 0.00% |
| **Total Atmospheric Emissions** | | | |
| *$CO_2$ Emissions* | -0.32% | -0.56% | -0.86% |
| *NOx Emissions* | -22.52% | -29.74% | -33.35% |
| *$SO_2$ Emissions* | -35.37% | -39.41% | -43.18% |
| *VOC Emissions* | -11.42% | -17.61% | -19.71% |
| *PM Emissions* | -15.96% | -19.14% | -20.26% |
| *$NH_3$ Emissions* | -28.94% | -37.63% | -41.57% |
| **Environmental Policy** | | | |
| *Energy Tax (% of GDP)** | 0.00% | 0.00% | 0.00% |
| *Environmental Tax (% of GDP)** | -0.01% | -0.01% | -0.01% |
| *Employer’s Social Security Rate** | 0.06% | 0.08% | 0.11% |
| *$CO_2$ marginal abatement cost (Euro95/tn $CO_2$)* | 20.07 | 20.08 | 20.08 |
| **Welfare** | | | |
| *Economic Welfare* | -0.06% | -0.12% | -0.18% |
| *Benefits from air pollution reduction (% of GDP)* | 0.79% | 0.85% | 0.88% |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

The benefits from the reduction of air pollution are around 0.8% of GDP, largely above the loss in GDP, but at the margin, the increase in welfare in the high ambition scenario does not compensate for the cost increase in terms of GDP. Note, however, that the environmental damage has been estimated with median VOLY (i.e. the lowest of the four alternatives).

[17] The * relates to a difference in shares, e.g. if oil has a share of 32.50% in the total energy consumption in the reference and 32.51% in Scenario A, the difference is 0.01% in the table

Imposing a cost-effective air pollution policy associated with a climate policy is estimated to have very little impact on the $CO_2$ emissions.

The cost-effectivess of the measures derived from RAINS, i.e. the cost-effective allocation of the reduction between sectors and countries, ensures that the air pollution policies are cost-effective also when their macro-economic impacts are estimated in GEM-E3. Also, no information, monitoring or enforcement costs are taken into account as they are estimated to be low compared to the abatement costs.

The cost of the air pollution reduction measures are estimated to be mainly shifted towards the domestic consumers through the decrease in the real wage. For the firms, the real wage decrease would partly compensate the increase in the social security rates and would allow them to maintain their position on the export market, especially in the more labour intensive sectors. The fact that all EU member states would participate in this abatement effort would also limit the impact on competitiveness.

The distribution of the cost between the EU countries depends on the reduction target imposed on each member state (Table 39).

As can be seen from Table 40 below, the reduction effort needed to attain the environmental targets chosen is estimated to be generally higher in new member states. This would be the case for nearly all pollutants except for VOC where the emission reductions are more evenly spread over the member states. The higher reduction target is reflected in the cost of the policy for these countries which in terms of welfare and GDP is above the EU average. This feature is due to the higher share of energy consumption of the GDP in new member states as well as the higher economic growth rates assumed in the reference scenario (i.e. CAFE baseline).

On the sectoral side (Table 41), the equipment goods sectors would see their demand for abatement equipment increase while the consumer goods industry would suffer from lower private consumption. In the export market there is a shift between member states because the loss in competitiveness is greater in the countries with the highest reduction targets.

**Table 39: Macroeconomic impact in member states of the CAFE air pollution scenarios in 2020 (% difference compared to reference scenario, GDP = gross domestic product, FEC = final energy consumption).**

| | Scenario A | | | | | Scenario B | | | | | Scenario C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC |
| Austria | -0.03% | -0.02% | 0.00% | 0.03% | -0.13% | -0.07% | -0.04% | 0.00% | 0.08% | -0.26% | -0.10% | -0.05% | 0.00% | 0.15% | -0.29% |
| Belgium | -0.06% | -0.05% | 0.00% | -0.01% | -0.15% | -0.11% | -0.08% | 0.01% | 0.01% | -0.22% | -0.27% | -0.23% | 0.01% | 0.03% | -0.32% |
| Germany | -0.04% | -0.02% | 0.01% | 0.03% | -0.06% | -0.08% | -0.05% | 0.01% | 0.07% | -0.13% | -0.13% | -0.07% | 0.02% | 0.10% | -0.21% |
| Denmark | -0.04% | -0.03% | 0.01% | 0.00% | -0.10% | -0.09% | -0.08% | 0.01% | -0.01% | -0.18% | -0.13% | -0.12% | 0.02% | -0.01% | -0.24% |
| Finland | -0.03% | -0.03% | 0.00% | -0.01% | -0.17% | -0.07% | -0.06% | 0.00% | -0.01% | -0.29% | -0.12% | -0.09% | 0.00% | -0.03% | -0.45% |
| France | -0.06% | -0.04% | 0.00% | 0.00% | -0.15% | -0.15% | -0.09% | 0.00% | 0.03% | -0.32% | -0.18% | -0.11% | 0.00% | 0.05% | -0.37% |
| Greece | -0.06% | -0.04% | -0.01% | 0.02% | -0.19% | -0.11% | -0.07% | -0.01% | 0.06% | -0.32% | -0.18% | -0.12% | -0.01% | 0.10% | -0.46% |
| Ireland | -0.06% | -0.06% | -0.01% | 0.01% | -0.16% | -0.14% | -0.15% | -0.03% | 0.03% | -0.32% | -0.25% | -0.27% | -0.05% | 0.04% | -0.41% |
| Italy | -0.04% | -0.02% | 0.00% | 0.02% | -0.11% | -0.09% | -0.05% | 0.01% | 0.05% | -0.20% | -0.13% | -0.07% | 0.01% | 0.08% | -0.31% |
| Netherlands | -0.03% | -0.02% | 0.01% | 0.02% | -0.05% | -0.09% | -0.07% | 0.01% | 0.04% | -0.14% | -0.11% | -0.07% | 0.02% | 0.07% | -0.15% |
| Portugal | -0.04% | -0.02% | 0.00% | 0.02% | -0.14% | -0.09% | -0.05% | 0.00% | 0.05% | -0.31% | -0.16% | -0.10% | 0.00% | 0.12% | -0.42% |
| Spain | -0.05% | -0.04% | 0.01% | 0.03% | -0.10% | -0.11% | -0.08% | 0.02% | 0.07% | -0.25% | -0.18% | -0.13% | 0.03% | 0.12% | -0.37% |
| Sweden | -0.03% | -0.01% | 0.01% | 0.01% | -0.06% | -0.07% | -0.05% | 0.01% | 0.00% | -0.21% | -0.12% | -0.07% | 0.02% | 0.01% | -0.29% |
| UK | -0.06% | -0.04% | 0.00% | 0.04% | -0.11% | -0.11% | -0.08% | 0.01% | 0.08% | -0.28% | -0.19% | -0.13% | 0.01% | 0.11% | -0.45% |
| Hungary | -0.12% | -0.12% | 0.00% | -0.02% | -0.23% | -0.25% | -0.24% | 0.00% | -0.05% | -0.61% | -0.42% | -0.41% | 0.00% | -0.03% | -0.87% |
| Poland | -0.38% | -0.39% | -0.04% | -0.22% | -1.03% | -0.48% | -0.48% | -0.05% | -0.26% | -1.30% | -0.67% | -0.65% | -0.06% | -0.26% | -1.64% |
| Slovenia | -0.07% | -0.08% | 0.01% | 0.00% | -0.13% | -0.26% | -0.25% | -0.01% | -0.05% | -0.83% | -0.35% | -0.34% | -0.01% | -0.02% | -0.96% |
| Czech Rep. | -0.23% | -0.24% | -0.02% | -0.11% | -0.52% | -0.42% | -0.41% | -0.02% | -0.17% | -0.73% | -0.48% | -0.46% | -0.03% | -0.18% | -0.88% |
| Slovakia | -0.13% | -0.13% | 0.00% | -0.06% | -0.13% | -0.26% | -0.27% | 0.00% | -0.18% | -0.38% | -0.43% | -0.42% | -0.02% | -0.16% | -0.49% |
| Estonia | -0.12% | -0.13% | 0.01% | 0.04% | -0.31% | -0.19% | -0.20% | 0.02% | 0.06% | -0.48% | -0.26% | -0.25% | 0.03% | 0.11% | -0.54% |
| Lithuania | -0.25% | -0.27% | -0.02% | 0.24% | -0.24% | -0.38% | -0.46% | -0.03% | 0.07% | -0.48% | -0.78% | -0.84% | -0.06% | 0.36% | -1.35% |
| Latvia | -0.09% | -0.07% | 0.00% | 0.01% | -0.12% | -0.20% | -0.18% | 0.00% | -0.01% | -0.31% | -0.34% | -0.30% | -0.01% | 0.04% | -0.45% |
| **EU** | **-0.06%** | **-0.04%** | **0.00%** | **0.00%** | **-0.12%** | **-0.12%** | **-0.08%** | **0.00%** | **0.01%** | **-0.24%** | **-0.18%** | **-0.12%** | **0.00%** | **0.02%** | **-0.34%** |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

**Table 40: Emission reduction in the EU member states in 2020 (% difference compared to the reference)**

| | Scenario A | | | | Scenario B | | | | Scenario C | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NOx Emissions | $SO_2$ Emissions | VOC Emissions | PM Emissions | NOx Emissions | $SO_2$ Emissions | VOC Emissions | PM Emissions | NOx Emissions | $SO_2$ Emissions | VOC Emissions | PM Emissions |
| Austria | -17.09% | -13.74% | -4.80% | -6.83% | -21.81% | -14.10% | -12.93% | -10.93% | -23.57% | -14.29% | -18.55% | -11.81% |
| Belgium | -25.17% | -26.68% | -13.51% | -19.28% | -29.28% | -29.47% | -16.34% | -21.02% | -34.82% | -35.28% | -17.42% | -21.42% |
| Germany | -14.05% | -17.22% | -11.11% | -10.13% | -18.74% | -18.80% | -22.96% | -10.31% | -22.84% | -24.73% | -23.01% | -10.60% |
| Denmark | -23.67% | -9.32% | -15.62% | -4.79% | -28.20% | -18.28% | -19.92% | -11.73% | -29.31% | -21.95% | -20.84% | -13.62% |
| Finland | -26.27% | -4.66% | -5.94% | -4.23% | -33.32% | -15.16% | -6.48% | -5.12% | -38.72% | -18.57% | -8.95% | -5.26% |
| France | -25.84% | -45.04% | -9.37% | -18.71% | -31.28% | -46.16% | -18.45% | -23.98% | -32.40% | -50.65% | -18.48% | -24.12% |
| Greece | -25.22% | -18.37% | -19.60% | -12.52% | -32.62% | -24.70% | -25.27% | -13.42% | -36.78% | -32.00% | -27.05% | -19.68% |
| Ireland | -22.14% | -24.11% | -31.31% | -6.15% | -31.23% | -36.01% | -32.84% | -7.42% | -31.45% | -40.12% | -38.86% | -12.35% |
| Italy | -21.18% | -32.06% | -9.06% | -17.17% | -29.93% | -33.71% | -10.71% | -18.68% | -33.04% | -39.18% | -15.72% | -19.87% |
| Netherlands | -9.79% | -11.44% | -17.15% | -8.73% | -24.31% | -12.50% | -21.09% | -9.11% | -24.86% | -12.51% | -21.11% | -9.13% |
| Portugal | -15.40% | -33.42% | -8.95% | -9.48% | -22.31% | -44.13% | -19.63% | -10.89% | -27.83% | -49.93% | -20.62% | -11.27% |
| Spain | -25.34% | -32.71% | -17.11% | -10.87% | -30.68% | -41.06% | -20.05% | -18.17% | -36.56% | -43.67% | -20.75% | -19.13% |
| Sweden | -25.71% | -0.60% | -16.12% | -9.07% | -34.49% | -8.31% | -16.31% | -10.92% | -35.39% | -11.37% | -20.84% | -13.03% |
| UK | -24.25% | -19.51% | -12.16% | -13.47% | -33.25% | -31.22% | -18.48% | -14.49% | -37.99% | -34.58% | -24.08% | -14.81% |
| Hungary | -25.18% | -73.52% | -2.03% | -13.67% | -37.70% | -76.65% | -4.39% | -21.17% | -43.55% | -78.24% | -11.53% | -22.72% |
| Poland | -27.43% | -60.64% | -4.03% | -31.09% | -35.68% | -60.78% | -8.62% | -32.70% | -39.87% | -62.56% | -8.91% | -34.12% |
| Slovenia | -20.05% | -51.03% | -0.42% | -8.98% | -29.02% | -52.95% | -4.17% | -36.63% | -33.06% | -56.50% | -5.64% | -36.82% |
| Czech Rep. | -31.87% | -34.94% | -18.22% | -20.47% | -42.05% | -35.92% | -31.98% | -21.03% | -45.31% | -37.81% | -32.04% | -21.98% |
| Slovakia | -25.66% | -48.29% | -0.11% | -9.87% | -37.82% | -53.92% | -2.61% | -14.91% | -40.07% | -58.44% | -3.58% | -15.30% |
| Estonia | -36.45% | -32.95% | -2.68% | -10.46% | -39.15% | -50.23% | -2.92% | -12.05% | -44.24% | -55.00% | -3.01% | -13.90% |
| Lithuania | -25.87% | -54.89% | -2.24% | -3.58% | -39.13% | -66.83% | -2.49% | -3.97% | -45.04% | -67.60% | -5.41% | -28.33% |
| Latvia | -25.46% | -11.77% | -14.80% | -6.66% | -29.36% | -49.00% | -16.04% | -6.89% | -34.58% | -49.49% | -28.36% | -8.69% |
| **EU** | **-22.52%** | **-35.37%** | **-11.42%** | **-15.96%** | **-29.74%** | **-39.41%** | **-17.61%** | **-19.14%** | **-33.35%** | **-43.18%** | **-19.71%** | **-20.26%** |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

**Table 41: Aggregate sectoral impact at EU level of the CAFE air pollution scenarios (% difference compared to reference scenario)**

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Sectoral Aggregates** | | | |
| **Domestic Production in Volume** | | | |
| *Agriculture* | -0.19% | -0.46% | -0.72% |
| *Energy Production* | -0.09% | -0.16% | -0.23% |
| *Ferrous and non ferrous metals* | -0.01% | 0.03% | 0.07% |
| *Chemical Products* | -0.01% | -0.01% | 0.01% |
| *Other energy intensive* | -0.05% | -0.03% | -0.01% |
| *Electric Goods* | 0.12% | 0.26% | 0.40% |
| *Transport equipment* | -0.01% | -0.02% | -0.04% |
| *Other Equipment Goods* | 0.24% | 0.53% | 0.81% |
| *Consumer Goods Industries* | -0.05% | -0.13% | -0.21% |
| *Construction* | -0.01% | -0.02% | -0.03% |
| *Telecommunication Services* | 0.02% | 0.05% | 0.08% |
| *Transport* | 0.00% | 0.02% | 0.05% |
| *Services of credit and insurances* | 0.01% | 0.03% | 0.04% |
| *Other Market Services* | -0.01% | -0.02% | -0.04% |
| *Non Market Services* | -0.01% | -0.02% | -0.03% |
| **Exports in Volume** | | | |
| *Agriculture* | -0.32% | -0.85% | -1.34% |
| *Energy Exports* | -0.12% | -0.25% | -0.32% |
| *Ferrous and non ferrous metals* | -0.06% | -0.04% | 0.00% |
| *Chemical Products* | -0.01% | -0.01% | 0.03% |
| *Other energy intensive* | -0.09% | -0.08% | -0.06% |
| *Electric Goods* | 0.09% | 0.21% | 0.34% |
| *Transport equipment* | 0.01% | 0.01% | 0.01% |
| *Other Equipment Goods* | 0.17% | 0.38% | 0.60% |
| *Consumer Goods Industries* | -0.07% | -0.18% | -0.33% |
| *Construction* | 0.04% | 0.07% | 0.15% |
| *Telecommunication Services* | 0.07% | 0.14% | 0.23% |
| *Transport* | 0.01% | 0.07% | 0.14% |
| *Services of credit and insurances* | 0.07% | 0.13% | 0.21% |
| *Other Market Services* | 0.04% | 0.09% | 0.13% |
| *Non Market Services* | 0.00% | 0.00% | 0.00% |
| **Price of Exports** | | | |
| *Agriculture* | 0.30% | 0.83% | 1.25% |
| *Ferrous and non ferrous metals* | 0.05% | 0.05% | 0.05% |
| *Chemical Products* | 0.01% | 0.02% | 0.00% |
| *Other energy intensive* | 0.08% | 0.09% | 0.09% |
| *Electric Goods* | -0.02% | -0.05% | -0.07% |
| *Transport equipment* | -0.01% | -0.02% | -0.02% |
| *Other Equipment Goods* | -0.01% | -0.04% | -0.07% |
| *Consumer Goods Industries* | 0.03% | 0.09% | 0.17% |
| *Construction* | -0.03% | -0.05% | -0.11% |
| *Telecommunication Services* | -0.06% | -0.11% | -0.19% |
| *Transport* | -0.01% | -0.04% | -0.10% |
| *Services of credit and insurances* | -0.06% | -0.10% | -0.16% |
| *Other Market Services* | -0.05% | -0.10% | -0.15% |
| *Non Market Services* | -0.06% | -0.13% | -0.15% |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

## Sensitivity analysis around the environmental end points

To assess the sensitivity of the results to the weighting of the environmental endpoints, alternative scenarios were run with RAINS where only the health impacts attributable to PM (primary and secondary) were considered for the optimisation of emission reductions. The derived emission targets for the different pollutants were then implemented in GEM-E3. Further, these results were helpful to understand the macroeconomic impact of reducing $PM_{2.5}$ concentrations in the EU.

Table 42 shows that by focussing only on the health impact from $PM_{2.5}$, the cost in terms of welfare and of GDP at EU level is reduced for the three scenarios as the imposed reduction targets are lower than in the previous scenarios. The benefits in terms of GDP are also reduced.

**Table 42: Macroeconomic impact in 2020 at EU level of the different ambition levels for reducing the health impacts of $PM_{2.5}$in the CAFE air pollution scenarios (% difference compared to reference scenario except for * where difference compared to reference)**

| | Ambition level for $PM_{2.5}$ | | |
|---|---|---|---|
| | **Scenario A** | **Scenario B** | **Scenario C** |
| **Macroeconomic Aggregates** | | | |
| *Gross Domestic Product* | -0.03% | -0.06% | -0.10% |
| *Employment* | 0.00% | 0.00% | 0.00% |
| *Private Consumption* | -0.06% | -0.11% | -0.16% |
| *Investment* | -0.01% | -0.01% | -0.02% |
| *Final Energy Consumption* | -0.11% | -0.17% | -0.26% |
| *Share Coal** | -0.03% | -0.05% | -0.06% |
| *Share Oil** | 0.00% | 0.01% | 0.02% |
| *Share Gas** | 0.01% | 0.01% | 0.00% |
| *Share Electricity** | 0.02% | 0.03% | 0.05% |
| *Exports to RW* | 0.00% | 0.02% | 0.03% |
| *Imports* | 0.04% | 0.09% | 0.13% |
| *Real Wage Rate* | -0.04% | -0.08% | -0.12% |
| *Relative Consumer Price* | 0.00% | 0.01% | 0.00% |
| *Real Interest Rate* | 0.01% | 0.02% | 0.02% |
| *Terms of Trade* | 0.03% | 0.05% | 0.09% |
| *Public Surplus (% of GDP)** | 0.00% | 0.00% | 0.00% |
| **Total Atmospheric Emissions** | | | |
| *$CO_2$ Emissions* | -0.25% | -0.39% | -0.63% |
| *NOx Emissions* | -12.22% | -15.77% | -23.07% |
| *$SO_2$ Emissions* | -37.15% | -41.37% | -44.93% |
| *VOC Emissions* | -0.21% | -0.30% | -0.45% |
| *PM Emissions* | -17.27% | -19.62% | -20.54% |
| *$NH_3$ Emissions* | -24.26% | -34.38% | -39.23% |
| **Environmental Policy** | | | |
| *Energy Tax (% of GDP)** | 0.00% | 0.00% | 0.00% |
| *Environmental Tax (% of GDP)** | -0.01% | -0.01% | -0.01% |
| *Reduction of Social Security Rate** | -0.05% | -0.07% | -0.09% |
| *$CO_2$ marginal abatement cost (Euro95/tn $CO_2$)* | 20.1 | 20.1 | 20.1 |
| **Welfare** | | | |
| *Economic Welfare* | -0.05% | -0.10% | -0.15% |
| *Benefits from air pollution reduction (% of GDP)* | 0.41% | 0.50% | 0.55% |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

The results per member state show the same tendency (Table 43). However for some countries one observes a higher loss in terms of welfare than in the previous scenarios. The same mechanisms are at play as described in the previous sections and the changes are entirely due to the differences in the reduction targets.

## Choice of policy instruments

As said above, in the scenarios analysed in the previous section the policy instrument is a 'command and control' type instrument associated with a cost-effective allocation of the emission reduction estimated by RAINS. As the welfare effect can vary depending on the policy instrument used especially when there are pre-existing taxes, it is important to examine this aspect.

From the literature on the 'double dividend' it is known that the presence of pre-existing distortionary taxes increases the cost of pollution abatement but their impact is not the same for all instruments. The possibility of recycling revenues to reduce distortionary taxes can improve the relative cost-effectiveness of the instruments as shown e.g. by Goulder et al. (1999). They compare the impact of policy instruments such as pollution tax, grandfathered allowances and command and control type instruments such as performance standards or mandated technologies. Pollution taxes or auctioned allowances are the most cost-effective because of the revenue recycling effect, while 'command and control' instruments or grand-fathered tradeable allowances do not collect revenue and thus do not allow any positive impacts of recycling.

To evaluate the impact of the choice of policy instruments in the CAFE exercise we have considered three types of instrument for reaching the same reduction in air pollution:

- a 'command and control' instrument such as a performance standard with a cost-effective allocation of the reduction effort as optimised in the RAINS model
- an emission tax in each member state, with recycling of revenues through a reduction of the employer's social security rate,
- a member state based , grandfathered tradeable allowance system.

These instruments are applied on the NOx and $SO_2$ emissions only, the 'command and control' instrument being imposed for the other pollutants in all scenarios. In the scenarios, only member stated based allowance or tax is considered as the location of the emissions is important for the benefits generated.

It should be noted that analytically a member state based emission tax in this modelling framework is equivalent to a system based on auctioned tradeable allowances. When implemented in real life, the government fixes the quantity of emission with the allowance system and the price is the outcome while with a tax it is the reverse.

The computation was done for Scenario B and the results are given in Table 44.

**Table 43: Macroeconomic impact at member state level of the CAFE PM2.5 air pollution scenarios in 2020 (% difference compared to reference scenario, GDP = gross domestic product, FEC = final energy consumption)**

| | Scenario A PM target | | | | | Scenario B PM target | | | | | Scenario C PM target | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC |
| Austria | -0.02% | -0.01% | 0.00% | 0.02% | -0.07% | -0.05% | -0.02% | 0.01% | 0.07% | -0.12% | -0.11% | -0.06% | -0.02% | 0.18% | -0.32% |
| Belgium | -0.05% | -0.04% | 0.00% | 0.00% | -0.11% | -0.14% | -0.12% | 0.01% | 0.01% | -0.22% | -0.26% | -0.23% | 0.01% | 0.02% | -0.33% |
| Germany | -0.04% | -0.02% | 0.00% | 0.03% | -0.05% | -0.09% | -0.06% | 0.01% | 0.07% | -0.12% | -0.11% | -0.06% | 0.01% | 0.09% | -0.18% |
| Denmark | -0.02% | -0.01% | 0.00% | 0.01% | -0.05% | -0.04% | -0.02% | 0.01% | 0.02% | -0.10% | -0.09% | -0.08% | 0.01% | 0.00% | -0.16% |
| Finland | -0.01% | 0.00% | 0.00% | 0.01% | -0.04% | -0.03% | -0.01% | 0.01% | 0.02% | -0.08% | -0.05% | -0.01% | 0.01% | 0.03% | -0.13% |
| France | -0.06% | -0.04% | 0.00% | 0.00% | -0.18% | -0.12% | -0.07% | 0.00% | 0.04% | -0.21% | -0.17% | -0.10% | 0.00% | 0.06% | -0.28% |
| Greece | -0.04% | -0.03% | 0.00% | 0.01% | -0.14% | -0.06% | -0.03% | 0.00% | 0.04% | -0.15% | -0.09% | -0.05% | 0.00% | 0.06% | -0.21% |
| Ireland | -0.02% | -0.01% | 0.00% | 0.02% | -0.09% | -0.03% | -0.01% | 0.00% | 0.04% | -0.12% | -0.05% | -0.03% | 0.00% | 0.06% | -0.20% |
| Italy | -0.04% | -0.02% | 0.00% | 0.02% | -0.09% | -0.07% | -0.04% | 0.01% | 0.04% | -0.17% | -0.13% | -0.08% | 0.01% | 0.06% | -0.32% |
| The Netherlands | -0.03% | -0.02% | 0.01% | 0.02% | -0.05% | -0.09% | -0.07% | 0.01% | 0.03% | -0.13% | -0.11% | -0.08% | 0.02% | 0.05% | -0.19% |
| Portugal | -0.03% | -0.02% | 0.00% | 0.01% | -0.14% | -0.06% | -0.03% | 0.00% | 0.03% | -0.23% | -0.12% | -0.07% | 0.00% | 0.10% | -0.30% |
| Spain | -0.03% | -0.02% | 0.01% | 0.02% | -0.07% | -0.06% | -0.04% | 0.01% | 0.04% | -0.13% | -0.09% | -0.05% | 0.02% | 0.07% | -0.17% |
| Sweden | -0.01% | 0.00% | 0.01% | 0.01% | -0.01% | -0.03% | 0.00% | 0.01% | 0.03% | -0.03% | -0.05% | -0.01% | 0.02% | 0.05% | -0.04% |
| UK | -0.05% | -0.03% | 0.00% | 0.03% | -0.07% | -0.08% | -0.06% | 0.01% | 0.08% | -0.10% | -0.14% | -0.09% | 0.01% | 0.11% | -0.26% |
| Hungary | -0.14% | -0.15% | 0.00% | -0.04% | -0.33% | -0.24% | -0.24% | 0.00% | 0.01% | -0.38% | -0.42% | -0.41% | 0.02% | 0.09% | -0.45% |
| Poland | -0.35% | -0.36% | -0.04% | -0.19% | -0.97% | -0.44% | -0.43% | -0.05% | -0.21% | -1.23% | -0.60% | -0.57% | -0.06% | -0.18% | -1.44% |
| Slovenia | -0.15% | -0.15% | -0.01% | -0.06% | -0.56% | -0.22% | -0.21% | -0.01% | -0.06% | -0.73% | -0.33% | -0.33% | -0.01% | -0.02% | -0.88% |
| Czech Republic | -0.18% | -0.18% | -0.01% | -0.08% | -0.43% | -0.36% | -0.35% | -0.02% | -0.12% | -0.59% | -0.73% | -0.71% | -0.05% | -0.23% | -0.95% |
| Slovakia | -0.11% | -0.11% | 0.00% | -0.04% | -0.11% | -0.18% | -0.16% | 0.00% | -0.04% | -0.19% | -0.35% | -0.31% | -0.01% | 0.00% | -0.24% |
| Estonia | -0.08% | -0.07% | 0.01% | 0.04% | -0.15% | -0.11% | -0.10% | 0.01% | 0.05% | -0.24% | -0.15% | -0.12% | 0.02% | 0.08% | -0.25% |
| Lithuania | -0.07% | -0.09% | 0.00% | -0.06% | -0.15% | -0.25% | -0.31% | -0.02% | -0.21% | -0.92% | -0.33% | -0.36% | -0.02% | -0.18% | -1.13% |
| Latvia | -0.07% | -0.07% | 0.00% | -0.03% | -0.14% | -0.10% | -0.09% | 0.00% | -0.02% | -0.18% | -0.19% | -0.15% | 0.00% | 0.00% | -0.36% |
| **EU** | **-0.05%** | **-0.03%** | **0.00%** | **0.00%** | **-0.11%** | **-0.10%** | **-0.06%** | **0.00%** | **0.02%** | **-0.17%** | **-0.15%** | **-0.10%** | **0.00%** | **0.03%** | **-0.26%** |

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

**Table 44: Macroeconomic impact of CAFE Scenario B in member states with alternative policy instruments (% difference compared to reference scenario, CC = command and control mechanism, SS = social security, GDP = gross domestic product, FEC = final energy consumption)**

| | Tax on NOx and $SO_2$ emissions*), CC on the other pollutants (EU $CO_2$ tax with SS recycling) | | | | | Grand-fathered allowance system for NOx and $SO_2$ emissions, CC on the other pollutant | | | | | Command control instrument on all pollutants | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC | Economic Welfare | GDP | Employ. | Exports | FEC |
| Austria | -0.06% | -0.03% | 0.02% | -0.01% | -0.80% | -0.09% | -0.07% | -0.04% | -0.03% | -0.83% | -0.07% | -0.04% | 0.00% | 0.08% | -0.26% |
| Belgium | -0.06% | -0.06% | 0.05% | -0.09% | -0.56% | -0.09% | -0.10% | -0.03% | -0.12% | -0.59% | -0.11% | -0.08% | 0.01% | 0.01% | -0.22% |
| Germany | -0.07% | -0.05% | 0.02% | 0.00% | -0.45% | -0.09% | -0.07% | -0.01% | -0.01% | -0.46% | -0.08% | -0.05% | 0.01% | 0.07% | -0.13% |
| Denmark | -0.04% | -0.08% | 0.02% | -0.11% | -0.77% | -0.11% | -0.09% | -0.01% | -0.06% | -0.80% | -0.09% | -0.08% | 0.01% | -0.01% | -0.18% |
| Finland | 0.00% | -0.04% | 0.14% | -0.13% | -1.03% | -0.10% | -0.11% | -0.09% | -0.14% | -1.08% | -0.07% | -0.06% | 0.00% | -0.01% | -0.29% |
| France | -0.13% | -0.09% | 0.07% | -0.10% | -0.80% | -0.18% | -0.15% | -0.07% | -0.13% | -0.86% | -0.15% | -0.09% | 0.00% | 0.03% | -0.32% |
| Greece | -0.10% | -0.08% | 0.14% | -0.18% | -0.99% | -0.11% | -0.12% | -0.10% | -0.22% | -1.02% | -0.11% | -0.07% | -0.01% | 0.06% | -0.32% |
| Ireland | -0.10% | -0.15% | 0.13% | -0.06% | -1.04% | -0.17% | -0.22% | -0.14% | -0.08% | -1.11% | -0.14% | -0.15% | -0.03% | 0.03% | -0.32% |
| Italy | -0.07% | -0.04% | 0.06% | -0.04% | -0.80% | -0.09% | -0.07% | -0.03% | -0.07% | -0.83% | -0.09% | -0.05% | 0.01% | 0.05% | -0.20% |
| The Netherlands | -0.07% | -0.05% | 0.06% | -0.01% | -0.76% | -0.10% | -0.09% | -0.02% | -0.04% | -0.77% | -0.09% | -0.07% | 0.01% | 0.04% | -0.14% |
| Portugal | -0.04% | -0.05% | 0.03% | -0.09% | -0.82% | -0.07% | -0.08% | -0.03% | -0.09% | -0.85% | -0.09% | -0.05% | 0.00% | 0.05% | -0.31% |
| Spain | -0.05% | -0.06% | 0.09% | -0.16% | -0.79% | -0.09% | -0.11% | -0.03% | -0.13% | -0.82% | -0.11% | -0.08% | 0.02% | 0.07% | -0.25% |
| Sweden | -0.04% | -0.05% | 0.04% | -0.10% | -0.53% | -0.09% | -0.08% | -0.03% | -0.09% | -0.56% | -0.07% | -0.05% | 0.01% | 0.00% | -0.21% |
| UK | -0.11% | -0.09% | 0.04% | -0.01% | -1.05% | -0.15% | -0.13% | -0.04% | -0.01% | -1.09% | -0.11% | -0.08% | 0.01% | 0.08% | -0.28% |
| Hungary | -0.21% | -0.20% | 0.09% | -0.22% | -1.29% | -0.23% | -0.26% | -0.07% | -0.25% | -1.33% | -0.25% | -0.24% | 0.00% | -0.05% | -0.61% |
| Poland | -0.51% | -0.53% | 0.28% | -0.80% | -2.65% | -0.54% | -0.61% | -0.17% | -0.64% | -2.73% | -0.48% | -0.48% | -0.05% | -0.26% | -1.30% |
| Slovenia | -0.26% | -0.26% | 0.05% | -0.21% | -1.37% | -0.28% | -0.32% | -0.09% | -0.24% | -1.43% | -0.26% | -0.25% | -0.01% | -0.05% | -0.83% |
| Czech Republic | -0.35% | -0.38% | 0.20% | -0.44% | -1.96% | -0.50% | -0.51% | -0.16% | -0.40% | -2.09% | -0.42% | -0.41% | -0.02% | -0.17% | -0.73% |
| Slovakia | -0.19% | -0.22% | 0.18% | -0.46% | -0.87% | -0.24% | -0.29% | -0.08% | -0.44% | -0.93% | -0.26% | -0.27% | 0.00% | -0.18% | -0.38% |
| Estonia | -0.14% | -0.17% | 0.04% | -0.07% | -0.73% | -0.18% | -0.20% | -0.03% | -0.05% | -0.76% | -0.19% | -0.20% | 0.02% | 0.06% | -0.48% |
| Lithuania | -0.30% | -0.40% | 0.18% | -0.42% | -1.17% | -0.30% | -0.45% | -0.10% | -0.37% | -1.23% | -0.38% | -0.46% | -0.03% | 0.07% | -0.48% |
| Latvia | -0.13% | -0.13% | 0.06% | -0.13% | -0.43% | -0.16% | -0.15% | -0.04% | -0.11% | -0.47% | -0.20% | -0.18% | 0.00% | -0.01% | -0.31% |
| **EU** | **-0.10%** | **-0.08%** | **0.08%** | **-0.11%** | **-0.72%** | **-0.14%** | **-0.12%** | **-0.05%** | **-0.76%** | **-0.09%** | **-0.12%** | **-0.08%** | **0.00%** | **0.01%** | **-0.24%** |

*) In modelling terms this is equivalent to an auctioned allowance system for NOx and $SO_2$.

Note: Reference scenario in 2020 is consistent with the CAFE Baseline Scenario of RAINS in 2020.

As expected from the theoretical literature, the tax instrument (which is analytically the same as an auctioned allowance system)  the model output confirms that the tax instrument incurs the lowest costs in terms of welfare and GDP growth, because of the positive effect of tax recycling. It also has a positive effect on employment with the recycling strategy chosen.

The ‘command and control’ instrument is slightly better than the grandfathered allowance system mainly for two reasons. First, the allocation over the sectors was already optimised in RAINS so it is an “intelligent” ‘command and control’ system. Second, the impact on product prices is smaller than in the grandfathered allowance case. With a tax or a allowance system the damage from the remaining emissions are also charged. The substitution effect in production and consumption are thus further triggered and this is reflected in the higher decrease in final energy consumption in those two scenarios compared to the command and control scenario. It is respectively -0.72% and –0.76% for the tax and allowance scenario while only -0.24% in the ‘command and control’ scenario at the  EU level.

## Summary

The simulations with GEM-E3 remain at an aggregate level but 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:

- The macroeconomic cost of air pollution reduction remains limited compared to the benefits obtained in terms of air quality, health and ecosystem improvement, though at the margin (moving from Scenario B to Scenario C) the additional benefits do not compensate  for the additional cost in terms of GDP.
- The benefits of reduced air pollution return mainly to the EU citizens.
- The effect on the competitiveness of the sectors remains small because the price effect is limited and all EU member states participate in the abatement effort.
- Depending on the policy instrument used the allocation of the burden is different.  With a quantity instrument (a grandfathered allowance or performance standard) the cost burden falls mostly on the domestic consumers and therefore on the consumer goods industry.  With the tax instrument (which is analytically equivalent to an auctioned allowance system) the burden can be more evenly spread by the recycling of revenues through the social security system.  This benefits employment and net real wages.  This, in turn, reduces the loss of income to consumers leading to a smaller decrease in private consumption than with the other instruments, favouring the consumer goods industries and services.

There are a few important caveats. First, these results hold as long as the allocation of effort over the sectors and countries is cost-effective.  Second, no implementation and monitoring cost have been taken into account because these are likely to be very small compared to the abatement costs.  Third, all results are based on the low benefit estimate based on use of the median VOLY (value of a life year) for mortality valuation.

# Overall conclusions

The analysis presented in this report has calculated impacts to health, crops, materials and ecosystems across the EU25 for the baseline in 2020, the three policy scenarios (A, B, C), and the MTFR.

***Ozone concentrations:*** The progressive ambition levels in scenarios A, B, C reduce ozone related mortality in 2020 by 1600 to 2500 cases, from a baseline of 21,000 case.  A similar level of benefits is predicted for respiratory hospital admissions.  For other morbidity endpoints of lower individual severity, the reduced incidence is larger in terms of number of cases, for example with the scenarios estimated to have benefits of 1.5 million to 2.5 million reduced cases of respiratory medication use, and 3 million to 5 million minor restricted activity days. There is a greater incremental benefit in moving from scenario A to B, than from scenario B to C.

***PM concentrations:*** The progressive A, B, C ambition levels reduce the total impacts from PM on health by 500,000 to 650,000 years of life each year – this can also be expressed as 54,000 to 72,000 avoided premature deaths.  There is also an additional benefit from avoiding between 70 and 90 infant deaths.  It is also estimated that the A, B, C scenarios would avoid 14,000 to 18,000 hospital admissions, 4.5 million to 6 million cases of respiratory medication use, and tens of millions of restricted activity days.  The incremental analysis again shows that a greater incremental benefit occurs in moving from scenario A to B, than from scenario B to C.

The monetised equivalent of the health effects is dominated by PM and mortality, though PM related morbidity is also significant.

Health benefits of the alternative ambition levels range from €37 to €120 billion/year (scenario A) up to €49 to 160 billion/year (scenario C), the ranges reflecting alternative approaches to mortality valuation.  The additional (incremental) benefits fall with successive scenario, i.e. the incremental benefits of moving from the scenario A to scenario B are greater (at €8 to €26 billion/year) than from scenario B to C (at €4 to €13 billion/year).

The analysis has estimated the non-health impacts across EU25 – reduced crop yield and damage to materials.  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 described, using results generated by the RAINS model.  Extremely high levels of exceedance of the critical level for ozone and forests, and for nitrogen deposition to ecosystems are highlighted. Despite significant improvements with respect to acidification, these two problems pose serious threats to the health of European ecosystems.

Monetised benefits (which exclude a variety of effects, such as the improvements in ecosystem health and several health impacts) have been compared against the annualised costs from the RAINS scenario analysis.

Comparing the increment between baseline and each of the A, B, C scenarios, the scenarios all lead to net benefits (i.e. benefits outweigh costs).  On this basis, the scenarios have benefit:cost ratios greater than one. As expected, the ratio of benefits to costs falls as ambition increases, due to the rise in costs of measures per unit abatement (the benefit curve, in contrast, is reasonably flat).

The incremental analysis, investigating the change between each scenario, shows a slightly different pattern, though against the same general trend of lower net benefits and lower benefit:cost ratios with higher ambition levels.  The following conclusions are drawn:

- There is a net benefit when moving from Scenario A to Scenario B.
- When going from scenario B to scenario C, the estimated costs are broadly equal to the low estimate of benefits – though they are lower than the high estimate.   The benefit:cost ratios for the main analysis range from 1 to 3, depending on how mortality is valued.
- When going from scenario C to the MTFR scenario, the additional costs of measures do not lead to net benefits, i.e. for this policy step, the costs outweigh the quantified benefits.

As stated already, this analysis does not include all benefits – notably it excludes benefits to ecosystems and cultural heritage and some health impacts.  Investigation of one omitted impact, health effects of secondary organic aerosols, indicates that these omissions would generate significant additional benefits.

A substantial amount of work has been performed to investigate the effect of uncertainties in the analysis.  This has investigated the response of the probability that benefits will exceed costs for each scenario to a range of factors, the principal ones being:

- Statistical uncertainty in incidence rates, response functions and valuation of health impacts;
- Variation in method used for mortality valuation;
- Variation in response function for chronic mortality assessment;
- Variation in estimated costs of abatement.

Decision makers may take differing views on the probability threshold – the level of probability of benefit exceeding cost that would persuade them that action is appropriate.  For this reason, results are presented for a variety of probability thresholds.

Results demonstrate that there is a robust case for moving to Scenario A and Scenario B. There is a good case made for proceeding to Scenario C also, though this is not quite as robust.  There is no case made for moving to the MTFR scenario unless it is assumed that costs are vastly overestimated and benefits substantially underestimated.

The final part of the report deals with the macroeconomic effects of the policies under each scenario, based on use of the GEM-E3 model.  The following conclusions are drawn:

- The macroeconomic cost of air pollution reduction is limited compared to the benefits obtained in terms of air quality, health and ecosystem improvement, though at the margin (moving from Scenario B to Scenario C) the additional benefits do not compensate for the additional cost in terms of GDP. Note, however, that the GEM-E3 assessment was performed only for the low benefit estimate using the median value of life year (VOLY) which is the lowest in the range.
- The benefits of reduced air pollution return mainly to the EU citizens.

- The effect on the competitiveness of the sectors remains small because the price effect is limited and all EU member states participate in the abatement effort.
- Depending on the policy instrument used the allocation of the burden is different: with a quantity instrument (allowance or performance standard) the cost burden falls mostly on the domestic consumers and therefore on the consumer goods industry, while with the tax instruments (which is analytically the same as an auctioned allowance system) the burden is more evenly spread through the recycling of the revenues.

It is concluded that the macroeconomic analysis confirms the conclusions drawn from the core analysis and sensitivity analysis. It is appropriate to choose an ambition level of at least Scenario B and possibly Scenario C.

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