AEAT/ED51014/Methodology Paper Issue 4

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

Methodology for the Cost-Benefit analysis for CAFE:

Volume 1: Overview of Methodology






February 2005

AEA Technology Environment

Title	**Final Methodology Paper (Volume 1)** for Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme
Customer	European Commission DG Environment
Customer reference	ENV.C.1/SER/2003/0027
Confidentiality, copyright and reproduction	This document has been prepared by AEA Technology plc in connection with a contract to supply goods and/or services and is submitted only on the basis of strict confidentiality. The contents must not be disclosed to third parties other than in accordance with the terms of the contract.
Validity	Issue 4
File reference	AEAT/ED51014/Methodology Issue 4
Reference number	AEAT/ED51014/ Methodology Issue 4

AEA Technology Environment
Bdg 154 Harwell Business Centre
Didcot, Oxon, OX11 0QJ
United Kingdom

Telephone +44 (0) 870 190 6592
Facsimile +44 (0) 870 190 6327
Email: paul.watkiss@aeat.co.uk

AEA Technology Environment is a business division of AEA Technology plc

AEA Technology Environment is certificated to ISO9001 & ISO 14001

	Name	Signature	Date
Authors	Mike Holland, Alistair Hunt, Fintan Hurley, Stale Navrud, Paul Watkiss		24/2//2005
Reviewed by	Paul Watkiss		24/2//2005
Approved by	Paul Watkiss		24/2//2005

Executive Summary

1. Purpose

This document presents the methodology for the '*Service Contract for Cost-Benefit Analysis (CBA) of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme*'. The objective of the service contract was to establish the capability to assess the costs and benefits of air pollution policies, and to conduct analysis on scenarios generated within the CAFE programme. To meet this objective this methodology document[1]:

- Defines the overall rationale for the CBA, in particular by demonstrating how it builds on the impact assessment being carried out in the RAINS integrated assessment model and the TREMOVE transport model;
- Identifies a general framework for quantifying impacts, including links to the other models;
- Identifies the assumptions and data (stock at risk inventories, response functions, unit valuations) that will form the basis of the quantification of benefits;
- Sets out the approaches for extending the CBA to unquantifiable impacts and for addressing other uncertainties;
- Accounts for the views of stakeholders as expressed during the consultation process from December 2003 to October 2004;
- Takes account of the suggestions of the independent scientific peer review which was carried out from July to September 2004.

2. The role of cost-benefit analysis in the CAFE Programme

The CAFE programme addresses mainly the following air pollutants and impacts (table i)[2]:

Table i – Direct and indirect impacts addressed in the CAFE CBA

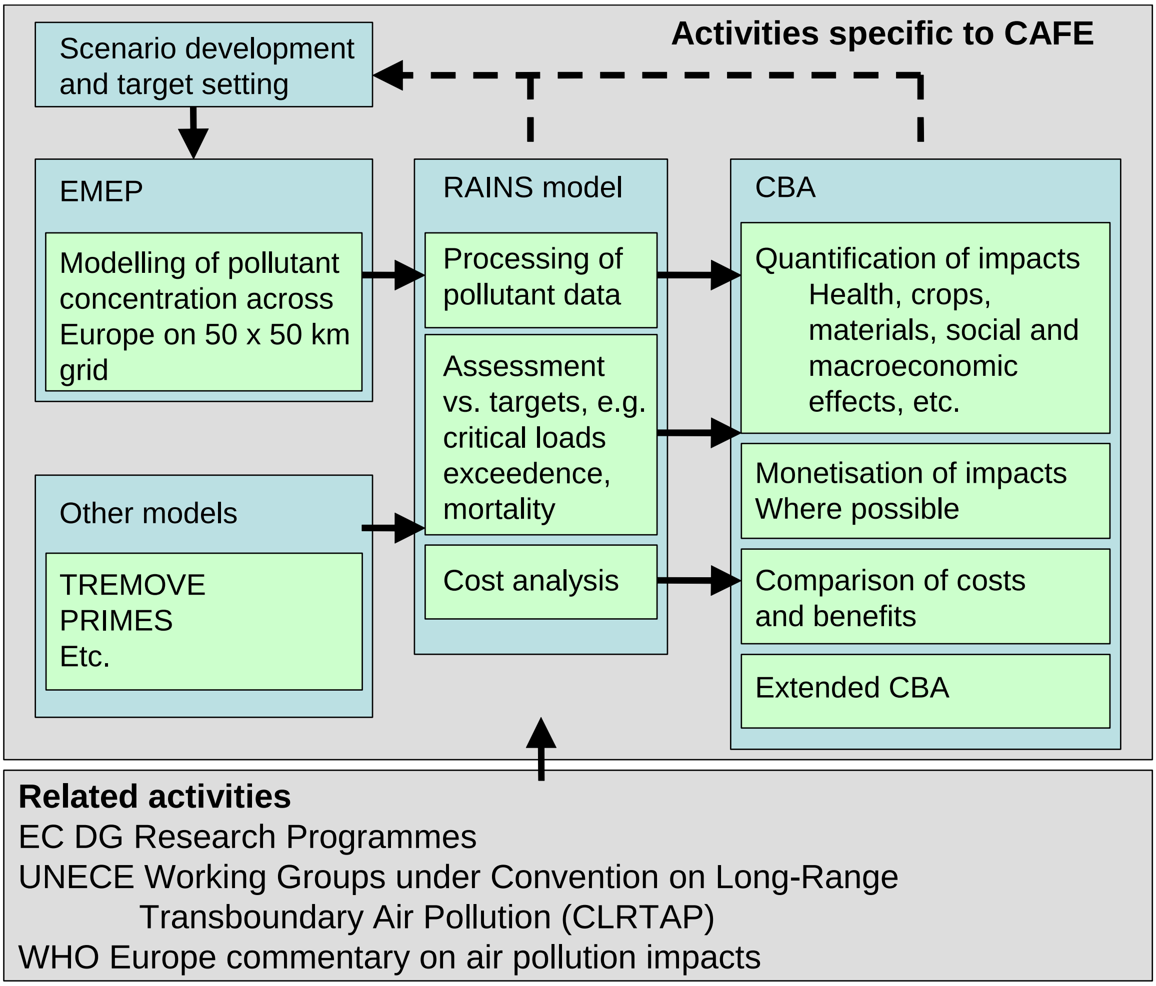
	$PM_{2.5}$	SO_2	NO_x	VOCs	NH_3
Direct impacts					
Tropospheric ozone formation, leading to effects on health, crops, materials and ecosystems			✓	✓	
Health impacts from primary pollutants and secondary pollutants (ozone and aerosols)	✓	✓	✓	✓	✓
Ecosystem acidification		✓	✓		✓
Ecosystem eutrophication			✓		✓
Damage to building and other materials		✓	✓		
Indirect impacts					
Changes in greenhouse gas emissions as a result of measures employed to control CAFE pollutants	✓	✓	✓	✓	✓
Wider social and economic effects from impacts and the measures recommended for their control	✓	✓	✓	✓	✓

[1] This report, and other documentation on the CAFE CBA are available at http://europa.eu.int/comm/environment/air/cafe/ and www.cafe-cba.org
.

[2] The word 'impacts' is synonymous to 'effects' throughout this document.

The links between different pollutants and the direct effects listed in the table defines the rationale for the CAFE programme: the most cost-effective strategies for control of these impacts can only be developed through consideration of the simultaneous reduction of the CAFE pollutants.

The relationship between the CBA and the other models and activities linking to the CAFE Programme is shown in the diagram below. The links from RAINS and CBA models to scenario development and target setting are shown with a dashed line to highlight the fact that although these processes will be influenced by model outputs, they are not direct outputs of the models.



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 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.

3. Quantification of benefits and comparison with costs

The effects listed in the table above and in more detail below, are quantified to the extent possible using the ‘impact pathway’ or ‘damage cost’ approach. This follows the standard approach applied in all modern cost-benefit analysis. The methodology has been refined over the last 15 years particularly under the ExternE (and related) projects of EC DG Research. 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 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;
4. Quantification of the impacts of air pollution;
5. Valuation of the impacts; and
6. Description of uncertainties (in CAFE, with specific reference to their effect on the balance of the costs of pollution control quantified by the RAINS model and their associated benefits).

The quantification of impacts varies depending on the availability of data and models:

1. For health impacts, damage to crops and damage to building materials, it is generally possible to quantify the impacts including their values. Uncertainties can be addressed using statistical methods and sensitivity analysis.
2. For damage to ecosystems and cultural heritage, it is possible to quantify the impacts relative to a measure of risk. However, it is not possible to value these impacts in the analysis. Examples of risk measures include:
    - the rate of deposition of acidifying pollutants relative to the critical load for acidification (as an indicator of the risk of acidification to biodiversity), and;
    - the rate of corrosion of building materials as an indicator of risks to historic monuments.
3. Other impacts may not currently be quantifiable in terms of impact or monetary value, permitting only a qualitative analysis. Examples include reduced visibility from air pollution and the social dimensions of health impacts.

Given the limits to quantification an ‘extended CBA’, has been developed. The purpose is to provide a complete picture of whether the effects that have not been valued or quantified could have a significant effect on the balance of cost and benefits. For each impact a data sheet will be prepared containing the following types of information:

- Definition of impact
- Knowledge of the link to air pollution
- Distribution of impacts across Europe
- Contextual information on the scale of associated economic effects
- Consideration of whether the impact seems likely to be important so far as the CAFE programme is concerned, with justification for conclusions reached.

4. Assessing the benefits of reduced air pollution on human health

Earlier cost-benefit analysis has shown that health impacts will generate the largest quantified monetary benefits when air pollution is reduced. The pollutants of most concern here are fine particles and ground level ozone both of which occur naturally in the atmosphere. Fine particle concentration is increased close to ground level by emissions from human activity. This may be through direct emissions of so-called ‘primary’ particles, or indirectly through the release of gaseous pollutants (especially SO_2, NO_x and NH_3) that react in the atmosphere to form so-called ‘secondary’ particles. Ozone concentrations close to ground level are increased by anthropogenic emissions, particularly of VOCs and NO_x.

The quantification of health impacts addresses the impacts related to both long-term (chronic) and short-term (acute) exposures. The quantification deals with both mortality (i.e. deaths) and morbidity (i.e. illness). The mortality effects quantified in the CAFE cost-benefit analysis include impacts on infants as well as adults. The morbidity effects that can be quantified include major effects, such as hospital admissions and the development of chronic respiratory disease. They also include less serious effects, which are likely, however, to affect a greater number of people. Examples of these are as changes in the frequency of use of medicine to control asthma, and days of restricted activity. When the impact and the values are combined in the analysis, the most important health related issues relate to mortality, restricted activity days and chronic bronchitis.

Major advances have been made in health valuation in recent years. The latest European willingness to pay estimates[3] have been included in the CAFE CBA methodology. Thus, we adopt the most up-to-date information for a range of morbidity effects and mortality in a context relevant to air pollution. Methodologically, there is still debate with respect to how mortality should be valued. The two methods that can be used – 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) – have contrasting strengths and weaknesses. For the CAFE CBA methodology, the independent external peer reviewers suggested that both the VSL and the VOLY approaches be used to show transparently the inherent uncertainty that is attached to these two approaches.

5. Assessing the benefits of reduced air pollution on environment

5.1 Agricultural and horticultural production

Ozone is recognised as the most serious regional air pollution problem for the agricultural sector in Europe. Some air pollutants other than ozone have been linked in the literature to crop damage (e.g. SO_2, NO_2, NH_3), but generally at higher levels than are currently experienced. When developing the CAFE CBA methodology it has been concluded that direct impacts of these pollutants on agriculture are likely to be small. On the contrary, indirect effects of these pollutants may be significant. This is mainly because air pollution could stimulate the performance of insects and other agricultural pests, enabling them to impact more severely on crop yield than in the absence of air pollution. The development of methods in this area has been informed particularly by the Integrated Cooperative Programme (ICP) on Vegetation, and ICP/MM (Mapping and Modelling).

5.2 Materials

The methods for quantification of damage to materials follow work carried out by the Europe-wide ICP Materials and quantification under various studies for DG Research, particularly ExternE and associated projects such as GARP (Green Accounting Research Project). The most significant impacts are those on natural stone and zinc coated materials. The ‘impact pathway’ approach works well for those applications that are used in every day life. This could in theory be applied to cultural and historic buildings. However, in practice there is a lack of data at several points in the impact pathway with respect to the stock at risk and valuation. As a result, effects of air pollution on cultural heritage cannot be quantified and thus need to be addressed qualitatively through the extended CBA framework.

[3] See NexExt (2004): New Elements for the Assessment of External Costs from Energy Technologies Project Report for European Commission DG Research, Brussels, Belgium. Contract no.NNE5-2000-00045.

5.3 Ecosystems

The effects of acidification, eutrophication and ground level ozone can be expressed in general terms as ranging from loss of species (e.g. trout and salmon from rivers and lakes in northern Europe) to more subtle effects, for example the relative abundance of different species in grassland or moorland. Stock at risk data for ecosystem impacts have been collated over a period of many years through the Coordination Center for Effects in the Netherlands. A modelling framework for describing exceedance of critical loads and levels is included within the RAINS model. Valuation of these impacts is not yet possible because of limited research in this area that has specific relevance to reductions in air pollutant emissions. Thus, the effects of reduced air pollution on ecosystems will be carried out as part of the extended CBA, drawing extensively on the results generated by RAINS.

6. Summary of air pollution impacts and how they are analysed in the CAFE

A number of other potential impacts have been reviewed in the CAFE CBA. These are listed in the Table ii, along with the impacts already discussed. The principal methods to be used in the appraisal of each effect are also shown. ‘Qualitative assessment’ refers to the ‘extended CBA’ approach. While it is clear that it is not possible to quantify all impacts of air pollution, it is likely that most of the unquantified impacts are less significant than those that are quantified. For instance, a specific improvement in the concentrations of particulate matter is likely to be more significant on human health than on soiling of the buildings. However, for completeness and transparency, the methodology applied in CAFE cost-benefit analysis includes all impacts.

7. Social and macro-economic effects

Social and macro-economic impacts on employment and GDP will be considered outside of the main benefits analysis using the GEM-E3 model. This is an applied general equilibrium model for the European Union Member States, which is suitable for analysing policies that have major impacts to the economy. Thus, GEM-E3 model will investigate the effects of a selected range of the scenarios investigated under CAFE.

Table ii – Effects of the CAFE pollutants, and the extent of assessment

Effect	Impact quantified and valued	Impact only quantified	Qualitative assessment	Comments
Health				
Primary PM, NO_3 and SO_4 aerosols				
acute – mortality, morbidity	✓	✓		Care taken to avoid double counting with chronic effects
chronic – mortality, morbidity	✓	✓		
infant mortality	✓	✓		
Ozone				Less clear linkage between O_3 and mortality than for PM_{10}
acute – mortality	✓	✓		
chronic – mortality			✓	No information on possible chronic effects
acute – morbidity	✓	✓		
chronic – morbidity			✓	
Direct effects of SO_2			✓	Limited importance to CAFE
Direct effects of VOCs			✓	Lack of data on speciation, etc.
Direct effects of NO_2			✓	Lack of clear information of effects at ambient levels
Social impacts			✓	Limited data availability
Altruistic effects			✓	Reliable valuation data unavailable
Agricultural production				
Direct effects of SO_2 and NO_x			✓	Negligible according to past work
Direct effects of O_3 on crop yield	✓	✓		
Indirect effects on livestock			✓	
N deposition as crop fertiliser			✓	Negligible according to past work
Visible damage to marketed produce		✓	✓	
Interactions between pollutants, with pests and pathogens, climate…			✓	Exposure-response data unavailable
Acidification/liming			✓	Negligible according to past work
Materials				
SO_2/acid effects on utilitarian buildings	✓	✓		
Effects on cultural assets, steel in re-inforced concrete			✓	Lack of stock at risk inventory and valuation data
PM and building soiling	✓	✓		
Effects of O_3 on paint, rubber	✓	✓		
Ecosystems				
Effects on biodiversity, forest production, etc. from excess O_3 exposure		✓	✓	Valuation of ecological impacts is currently too uncertain
Effects on biodiversity, etc., from excess N deposition		✓	✓	Valuation of ecological impacts is currently too uncertain
Effects on biodiversity, etc., from excess acid deposition		✓	✓	Valuation of ecological impacts is currently too uncertain
Visibility: Change in visual range			✓	Impact of little concern in Europe.
Change in greenhouse gas emissions		✓	✓	Valuation too uncertain
Macroeconomic effects	✓	✓		Addressed using the GEM-E3 model
Drinking water supply and quality	✓		✓	Limited data availability

Contents

1. Introduction

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 exceedence of critical loads and levels for acidification or eutrophication'*.

The integrated policy advice from the CAFE programme is planned to be ready by early 2005. The European Commission will present its Thematic Strategy on Air Pollution during the first half of 2005, outlining the environmental objectives for air quality and measures to be taken to achieve the meet these objectives.

This report presents the methodology for the Service Contract for Cost-Benefit Analysis (CBA) of Air Quality Related Issues, in particular for the CAFE Programme. The objectives are to establish the capability to assess the costs and benefits of air pollution policies, and to conduct analysis on the scenarios, generated from the CAFE process.

1.1. Project workplan

The work programme for the CAFE CBA is organised into the following series of tasks, some of which are a primary concern of this paper, others of which are not, though the link to them is shown. This paper is primarily focussed on tasks 1, 2, 3, 4 and 7.

Task	**Main issue for this paper?**	**Comments**
1. Developing conceptual framework for the analysis	✓	
2. Development of extended CBA framework	✓	
3. Ensuring costs and benefits are measured with the same metric	✓	
4. Review and consultations on the key monetary unit values and other parameters used in the benefit analysis	✓	
5. Estimating marginal damage of different pollutants for 2010, 2015 and 2020		Follows from development of the methodology
6. Inclusion of costs and benefits at the local scale	✓	
7. Developing the framework to carry out the analysis of social and macro-economic impacts of improved air quality	✓	
8. Creation of a modelling and reporting tool		Follows from development of the methodology
9. Preliminary assessments		Follows from [Task 8]
10. Scenario analysis		Second phase of the project

1.2. Structure of this paper

The paper starts with consideration of the range of impacts that will be associated with options considered under the CAFE framework. It then discusses the general approach to quantification of air pollution impacts, based around the 'impact pathway analysis' developed to an advanced state in the ExternE Project of European Commission (EC) DG Research, and used already in a number of projects for EC DG Environment and others, including:

- Economic evaluation of the National Emission Ceilings Directive and the Gothenburg Protocol (AEA Technology, 1998; Holland et al, 1999);
- Cost-benefit analysis of the daughter directives to the Framework Directive on Ambient Air Quality (AEA Technology, 1999, 2001);
- Cost-benefit analysis of the Incineration Directive (AEA Technology, 1996);
- Economic evaluation of waste management options for PVC (AEA Technology, 2000).

Only some of the impacts originally identified will be quantifiable in the course of this work. Others cannot currently be quantified with an acceptable level of confidence because of a lack of information on stock at risk, exposure-response, economic value, etc. In such cases it is important that the analysis provides a mechanism for retaining whatever information is available. For this we have developed an 'extended CBA' approach. This is intended to provide policy makers with a more complete appreciation of the issues faced when they decide what level of action on further improvement of air quality is desirable or necessary.

Further details on methodology are given in the appendices to this report and in a series of companion volumes. Volume 2 will provide more detail on health impact assessment specifically for the CBA. Suitable methodological material already exists for description of other environmental impacts, most notably through the guidance published by ICP/MM (2004). Volume 3 will provide a more detailed overview of the treatment of uncertainty in the CBA.

1.3. Consultation and peer review

This report has been developed over the period October 2003 to December 2004. It has been the subject of intense consultation, through the release of three previous draft reports, two workshops and a formal peer review process. Details of those who provided written comments during this process, along with details of the peer review team, are given in Appendix 2. The peer review report is available at http://europa.eu.int/comm/environment/air/cafe/activities/krupnick.pdf .

2. Overview of Methods and Relationship to Other Models

In general terms cost-benefit analysis carried out to support policy development on air quality proceeds through the following stages:

- Scenario development, to include assessment of demand, etc., for the services of polluting activities over whatever time frame is of interest;
- Quantification of emissions under the baseline scenario;
- Quantification of emissions under scenarios involving further abatement than that specified in the baseline scenario;
- Quantification of the costs of abatement in the new scenario;
- Modelling the dispersion of emissions, including the formation of secondary pollutants (e.g. the products of reaction of SO_2, NO_x, VOC emissions in the atmosphere);
- *Estimation of exposure of receptors (people, building materials, ecosystems, etc.) that are sensitive to pollutants, combining maps of pollutant dispersion with maps of stock at risk;*
- *Application of exposure-response functions to determine various impacts, or changing levels of risk, concerning the sensitive receptors;*
- *Monetary valuation of impacts to the extent possible;*
- *Comparison of quantified costs and benefits;*
- *Consideration of the effect of uncertainties in the analysis on the balance of costs and benefits, including the omission of known and possible impacts.*

The CBA contract under CAFE deals specifically with the second half of this process (the steps shown in *italics*). The first half of the process is carried out using other models, such as RAINS for the cost-effectiveness optimisation against specified environmental quality constraints, EMEP for dispersion modelling and TREMOVE for assessment of the transport sector. The next section demonstrates how these models fit together.

2.1. Position of CBA in European air quality analysis

It is important to appreciate precisely how the work fits with the other components of CAFE and other activities being undertaken in this area in Europe through WHO, EC DG Research and under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). Linkages are summarised in Figure 1. WHO is involved in review of health impact data for both CLRTAP and the European Commission as part of CAFE. DG Research has funded the development of several of the models used, including PRIMES, and methods for benefits assessment through the ExternE Project series[4]. Activities[5] carried out under CLRTAP provide the analysis with a great deal of information, for example, in terms of stock at risk data, critical levels and critical loads databases and response functions.

It is envisaged that the chief link between EMEP and the CBA will be through the RAINS model. However, for some parts of the analysis a more direct link may be appropriate. It is

[4] See http://www.externe.info/
[5] See http://www.unece.org/env/lrtap/

also to be noted that air quality modelling within this framework is based on the EMEP model, and not the Windrose Trajectory Model developed under the ExternE Project.

The link from the RAINS analysis and the CBA to 'Scenario development and target setting' is not direct, involving the use of computer based models, but is made through consideration of the model outputs by expert panels, for example the CAFE Steering Group and the Task Force on Target Setting and Policy Appraisal. For this reason the link is shown with a dashed line in Figure 1.

There is some overlap between RAINS and the CBA with respect to quantification of impacts, specifically with respect to:

- Quantification of the effects of chronic (long-term) exposure to fine particles on mortality ("chronic mortality").
- Quantification of the effects of acute (short-term) exposure to ozone on mortality ("acute mortality").
- Quantification of the extent of critical loads exceedance of ecosystems to acidification and eutrophication.

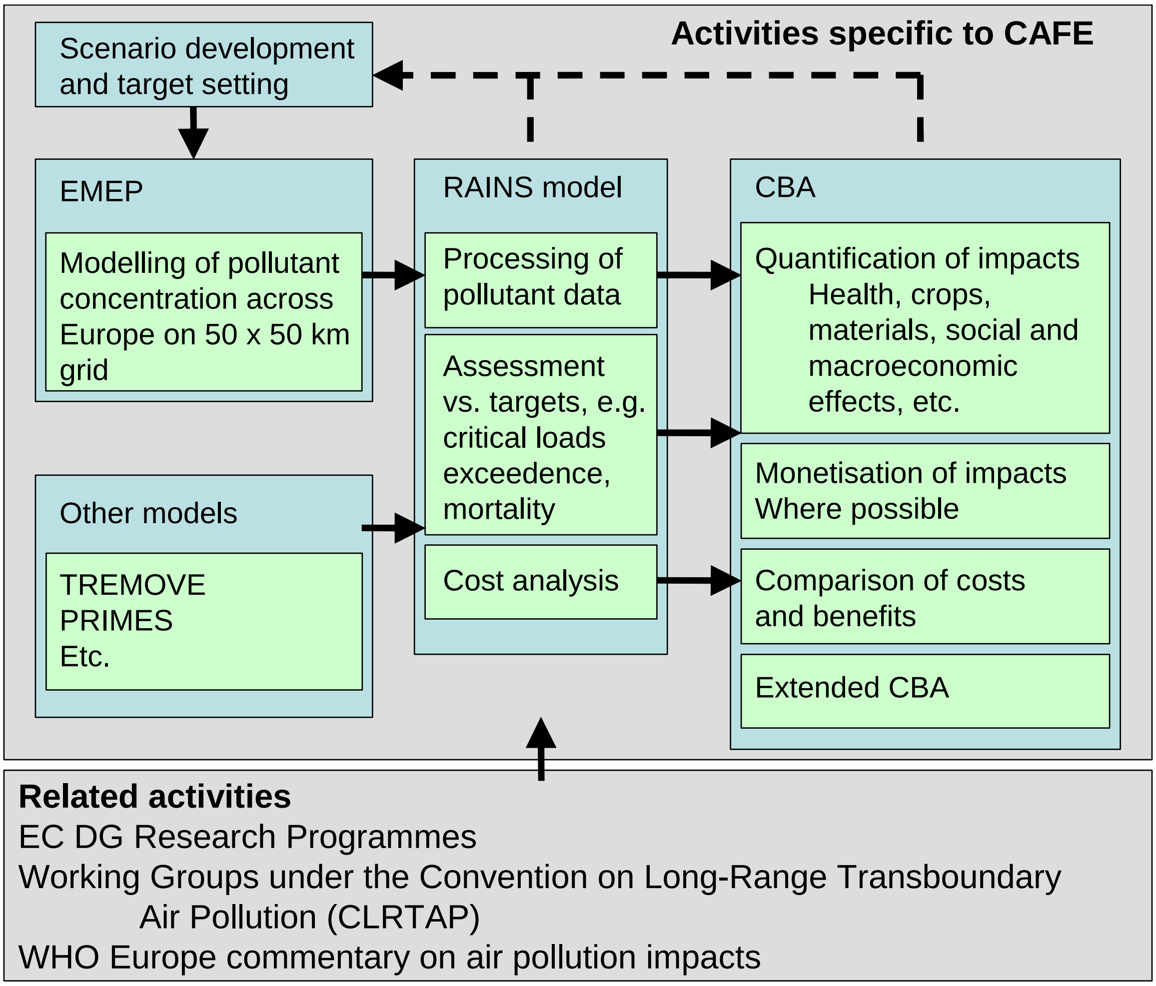


Figure 1 – Links between the CBA, RAINS and EMEP models and other related activities in Europe.

There is no feedback from the CBA into the RAINS model, in other words, no attempt is to be made to optimise RAINS using CBA outputs. It would be desirable to do this in an ideal situation where there was no uncertainty in the analysis of either costs or benefits. However, it is apparent that there are significant uncertainties on both sides of the cost-benefit equation. In this situation a fully integrated model has major drawbacks as it reduces the opportunity for assessment of the effects of uncertainty on the outcome of the analysis.

In combining the different models it is necessary to ensure that they adopt common assumptions and data where relevant. In some cases this is obvious, for example with respect to pollution data. In other areas it is less obvious, for example with respect to economic issues, such as the treatment of taxes and discount rate. A further issue relates to the way that the different models deal with uncertainties. These issues are discussed in this paper.

Final cost and benefit outputs can be expressed either as totals by scenario or in terms of marginal costs and benefits. The convention in past work has been to report by total only, reflecting the difficulty of marginal analysis. For CAFE there is the possibility of generating marginal benefits data as well for a number of scenarios, using figures from an updated version of the BeTa (Benefits Table) database currently on the EC DG Environment website. Data and underlying methods for the updated version of BeTa will be generated through the main CAFE benefits assessment models.

2.2. Consistency of the RAINS and CBA models

This section provides an overview of the appraisal of consistency between the RAINS and CBA models. A more detailed account is provided in Appendix 3.

The following issues have been considered:

- **Currency, currency year:** The models are consistent through the use of the EURO (€), year 2000, as the basis for calculation.
- **Variation in values between countries:** The benefits analysis seeks to take European average unit values (for health impacts, etc.), and hence implicitly assumes that these values are the same throughout the EU25. RAINS does the same for capital costs, but not for all elements. Of these, labour costs seem most significant, though the impact of this difference on the overall comparison of costs and benefits seems likely to be limited.
- **Taxation:** No areas of inconsistency were identified with respect to the treatment of taxation.
- **Discounting:** The treatment of discounting in the two models is similar.
- **Quantification of impacts:** The requirements for impact quantification in RAINS are different to those of the CBA. Most obviously, RAINS optimises against a representative group of effects, whilst the CBA seeks to quantify all that can be reasonably quantified. This is not a problem of inconsistency, simply a reflection of the different ways the two models are used.
- **Basis for comparison of costs and benefits** (e.g. total costs, marginal costs, costs and benefits accruing to each country): The two models are capable of generating outputs in the same format, so in principle they are consistent. This is certainly the case when outputs are aggregated to the full, Europe-wide, modelling domain. From a theoretical

perspective there is inconsistency in the basis of comparison of costs and benefits at the national level according to standard output tables (see Appendix 3). This can be addressed, if necessary, at a later stage in the analysis.

- **Treatment of uncertainty.** The principal approach to uncertainty assessment in RAINS is the use of sensitivity analysis, varying certain inputs (e.g. energy scenarios) to investigate their effect on emissions, costs, etc. However, time and other constraints limit the ability of the model to take account of uncertainty using sensitivity analysis. The effects of combined uncertainties are particularly difficult to forecast. In contrast, the CBA modelling under CAFE can be more flexible in its treatment of uncertainty largely because it is not tied into optimisation procedures[6].

[6] It is noted that CONCAWE (1999) calculated that the scale of uncertainty of RAINS model is of “factor of around 2”.This seems to have gained some acceptance as an indicator of the scale of uncertainty within the RAINS model. However, it should be recognized that this represents only one component of uncertainty within the RAINS model. Other sources of error, for example associated with assumed future emissions of each pollutant, also need to be taken into account and are additional to the errors surrounding unit cost-effectiveness.

3. Impacts Relevant to the CAFE Programme

3.1. Issues

The CBA should ideally account for all of the impacts likely to be linked to the measures that will be introduced as a result of the CAFE programme. This includes not only impacts caused by the pollutants targeted under CAFE, but also other effects of measures that may be recommended through CAFE, for example on greenhouse gases, the economy and society. The purpose of this chapter is therefore to highlight the breadth of impacts that could arise as a result of control measures that could be adopted as a result of CAFE recommendations. Consideration extends beyond the subset of measures considered in the RAINS model to other options, such as local controls on traffic and fiscal measures.

The chapter starts with consideration of the types of measure that could be adopted, proceeds to consideration of their impacts, and then summarises, briefly, how different groups of impact may be characterised within CAFE. In some cases this will be a full quantitative assessment, proceeding through to monetisation, in others a purely qualitative one, depending on data availability.

3.2. Measures that can improve air quality

3.2.1 Types of measure

We identify the following option categories:

1. End-of-pipe controls (catalytic converters, flue gas desulphurisation (FGD), etc.)
2. Use of cleaner fuels and fuel switching
3. Promoting the use of cleaner vehicles (e.g. through establishment of low emission zones and use of fiscal incentives)
4. Increasing efficiency in the use of fuels and other inputs
5. Increasing system efficiency (e.g. through travel planning, increased adoption of CHP)
6. Generating modal shift in transport by promotion of walking and cycling, better provision of public transport, etc.
7. Use of planning controls
8. Use of fiscal incentives, such as subsidies to promote energy efficiency or green electricity, congestion charging and differential fuel taxation.

Clearly, some of these measures would be introduced primarily for reasons such as reducing congestion or increasing profit (e.g. from various efficiency measures) rather than air quality improvement per se. In the interests of developing ‘joined up’ policy it is important that opportunities offering benefits in different areas are identified.

The measures included in the RAINS model are a subset of those listed here, covering those that can reasonably be generalised at the European scale in terms of availability, state of technology, etc. These tend to be end-of-pipe controls, improvements in fuel quality, and fuel switching (the latter through sensitivity analysis using different energy projections). RAINS thus excludes measures that operate on a more local scale, such as the use of congestion charging and the implementation of sustainable procurement mechanisms. These are being considered in a separate contract under the CAFE programme entitled "Ex-post" Evaluation of Short-term and Local Measures in the CAFE Context[7].

Some of these measures will be more cost-effective than those contained in the RAINS model database. They may also be implemented irrespective of air quality concerns, for example, to reduce congestion or control greenhouse gas emissions.

3.2.2 Associated impacts

A generalised mapping of the categories of pollution control option given above to environmental and social burdens is given in Table 1. The presence of possible negatives in the table stresses the point that care needs to be taken to optimise abatement strategies such that they do not threaten other policy initiatives and vice-versa.

Table 1 – Abatement options and general trends in associated burdens

	CAFE pollutants	Greenhouse gases	Noise	Social impacts	Macroeconomic effects	Performance of SMEs
End-of-pipe controls	+	-	+/-	+/-	+/-	+/-
Use of cleaner fuels and fuel switching	+	+/-		+/-	+/-	+/-
Use of cleaner vehicles	+	+/-	+	+/-	+/-	+/-
Increased energy (etc.) efficiency	+	+		+	+	+
Increased system efficiency	+	+	+	+	+	+
Generating modal shift in transport	+	+	+	+	+/-	+/-
Use of planning controls	+	+	+	+	+/-	+/-
Use of fiscal incentives	+	+	+	+/-	+/-	+/-

Key:
'+' = positive effect
'-' = negative effect
'+/-' is given where direction of effect is measure-specific
'Burdens specific to transport' include congestion, traffic accidents, etc.

Some further appreciation of the differences in impacts between the RAINS – pan-European measures and options implemented at the local scale is important. Local measures may be very cost-effective for reducing the exposure of individuals living in 'hot-spots', but of limited effectiveness for protection of society as a whole. A question that thus needs to be asked is whether protection of the individual is adequately covered under existing legislation on air quality standards.

[7] http://europa.eu.int/comm/environment/air/cafe/activities/expost_evaluation.htm#expost

3.3. Impacts to be addressed in the CAFE CBA

The main focus of this CBA is on the impacts of those air pollutants that are specifically of interest to the CAFE process – particles, SO_2, NOx, VOCs and ammonia, and the control options contained in RAINS that may be applied at the pan-European level. These impacts are listed in summary format below (Table 2), together with indication of whether they are to be addressed quantitatively, typically using the impact pathway methods through to monetisation (see Section 4.2), are mainly a subject for qualitative appraisal using the extended CBA approach described in Section 4.4, or are considered likely to be negligible. Where possible the quantification of impacts and monetary values using the impact pathway approach is preferred. However, where this is not possible the extended CBA provides a mechanism whereby impacts may be considered in a more systematic manner than previously. It also provides a mechanism for increasing understanding of the impacts that can be quantified.

3.4. Treatment of impacts that are not included in RAINS

There are no plans for a systematic quantification of effects of the mainly local measures that are not included in RAINS as part of the CBA work described here. These measures include options such as:

- Congestion charging
- Driver training
- Implementation of sustainability criteria to procurement
- Establishment of low emission zones
- Local infrastructure changes, e.g. to improve public transport interchanges or develop new routes
- Introduction of development controls

However, in the event that scenarios are investigated on the local scale it should be possible to use the outputs of the database being developed under the ‘Ex-post evaluation study’ to generate a matrix of benefits. At its simplest level this would take the form of Table 1, though expanded in key areas, for example to show which impacts of transport are affected by a measure, rather than bulking them together.

At a more sophisticated level the cell entries in the table could be expanded to give an indication of the scale of impacts, whether they are likely to be large or small, not just positive or negative. It is not clear at this stage whether it would be possible to provide figures from the ex-post evaluation study to substantiate the ratings further.

Links to other policies (e.g. climate, transport) should also be highlighted where relevant, particularly where an option would be unlikely to implemented as a result of air quality concerns alone. In the event that some of these impacts appear likely to be important in the wider CAFE context, consideration will need to be given as to whether they should be accounted for in more detail in the CBA. Further development of these methods may be necessary once information is available on the types of local scenario and associated measures that may be considered under CAFE.

Table 2 – Effects of the CAFE pollutants, and the extent of assessment.

Effect	Impact quantified and valued	Impact only quantified	Qualitative assessment	Comments
Health				
Primary PM, NO_3 and SO_4 aerosols				
acute – mortality, morbidity	✓	✓		Care taken to avoid double counting
chronic – mortality, morbidity	✓	✓		with chronic effects
infant mortality	✓	✓		
Ozone				Less clear linkage between O_3 and
acute – mortality	✓	✓		mortality than for PM_{10}
chronic – mortality			✓	No information on possible chronic
acute – morbidity	✓	✓		effects
chronic – morbidity			✓	
Direct effects of SO_2			✓	Limited importance to CAFE
Direct effects of VOCs			✓	Lack of data on speciation, etc.
Direct effects of NO_2			✓	Lack of clear information of effects at ambient levels
Social impacts			✓	Limited data availability
Altruistic effects			✓	Reliable valuation data unavailable
Agricultural production				
Direct effects of SO_2 and NO_x			✓	Negligible according to past work
Direct effects of O_3 on crop yield	✓	✓		
Indirect effects on livestock			✓	
N deposition as crop fertiliser			✓	Negligible according to past work
Visible damage to marketed produce		✓	✓	
Interactions between pollutants, with pests and pathogens, climate…			✓	Exposure-response data unavailable
Acidification/liming			✓	Negligible according to past work
Materials				
SO_2/acid effects on utilitarian buildings	✓	✓		
Effects on cultural assets, steel in re-inforced concrete			✓	Lack of stock at risk inventory and valuation data
Effects of O_3 on paint, rubber	✓	✓		
Ecosystems				
Effects on biodiversity, forest production, etc. from excess O_3 exposure		✓	✓	Valuation of ecological impacts is currently too uncertain
Effects on biodiversity, etc., from excess N deposition		✓	✓	Valuation of ecological impacts is currently too uncertain
Effects on biodiversity, etc., from excess acid deposition		✓	✓	Valuation of ecological impacts is currently too uncertain
Visibility: Change in visual range			✓	Impact of little concern in Europe.
Change in greenhouse gas emissions		✓	✓	Valuation too uncertain
Macroeconomic effects	✓	✓		Addressed using the GEM-E3 model
Drinking water supply and quality	✓		✓	Limited data availability

4. Basic Structure of the Benefits Analysis

4.1. Pathways from emission to impact

At the start of the EC's ExternE project in 1991 a series of diagrams were produced that sought to illustrate the main effects of air pollution on health, crops, forests and other terrestrial ecosystems, freshwater ecosystems and building materials (ExternE, 1995a). One such diagram, for crops, is reproduced in Figure 2.

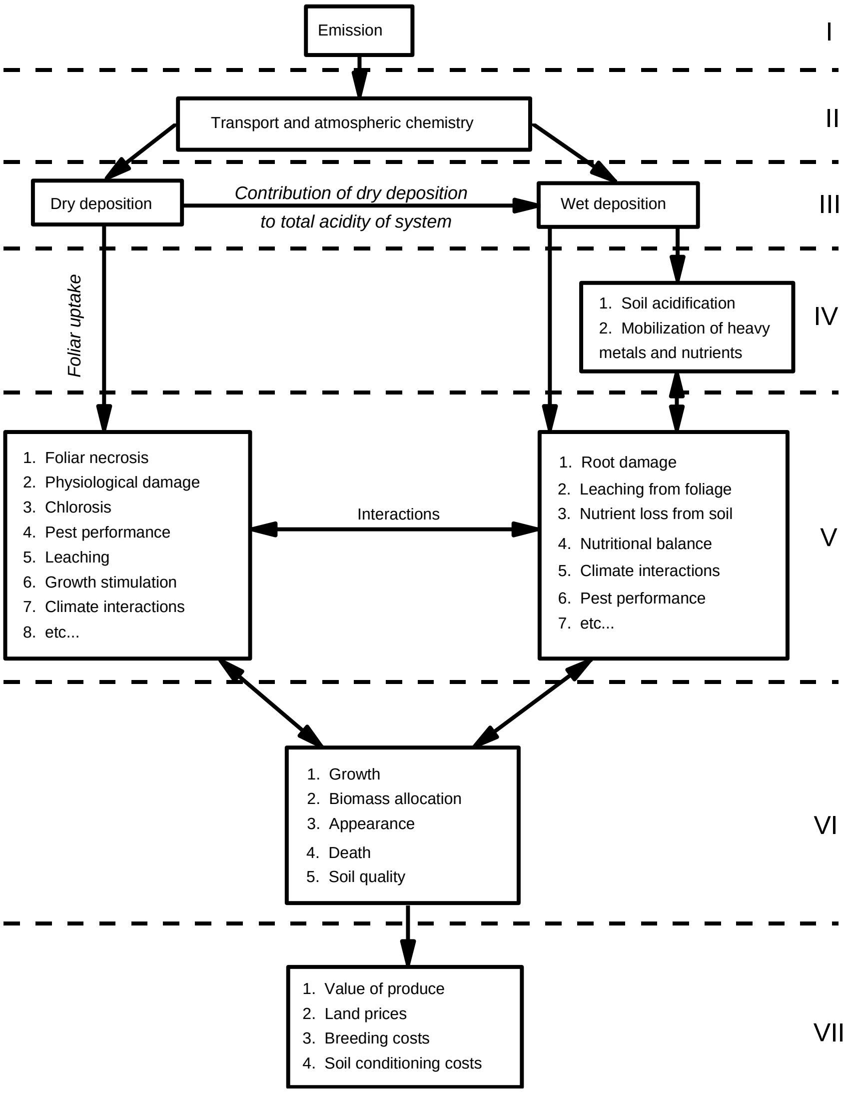


Figure 2 – Detailed impact pathway to describe the way that air pollution affects crop production

These pathways contain numerous potential feedbacks and synergies that would ideally be brought together in a modelling framework. Whilst it is not possible to model at the level of complexity identified in these diagrams, they are useful for highlighting the complexity of the situation.

4.2. Quantifying air pollution impacts and monetary damages

4.2.1 Impact pathway approach

The approach taken for quantification of the benefits of air pollution emissions through to monetisation is often referred to as the ‘impact pathway approach’ (Figure 3), a logical progression from emission, through dispersion and exposure to quantification of impacts and their valuation (reflecting the overall structure of Figure 2). This approach was developed through the series of EC DG Research projects under the ExternE banner (and its predecessor, the EC/US Fuel Cycles Study) through which it has been widely disseminated (ExternE, 1995a, 1999a). It has also been used extensively in past work on European air quality legislation (e.g. AEA Technology, 1999) and thus has been widely debated through the air quality steering group and the working parties that informed it.

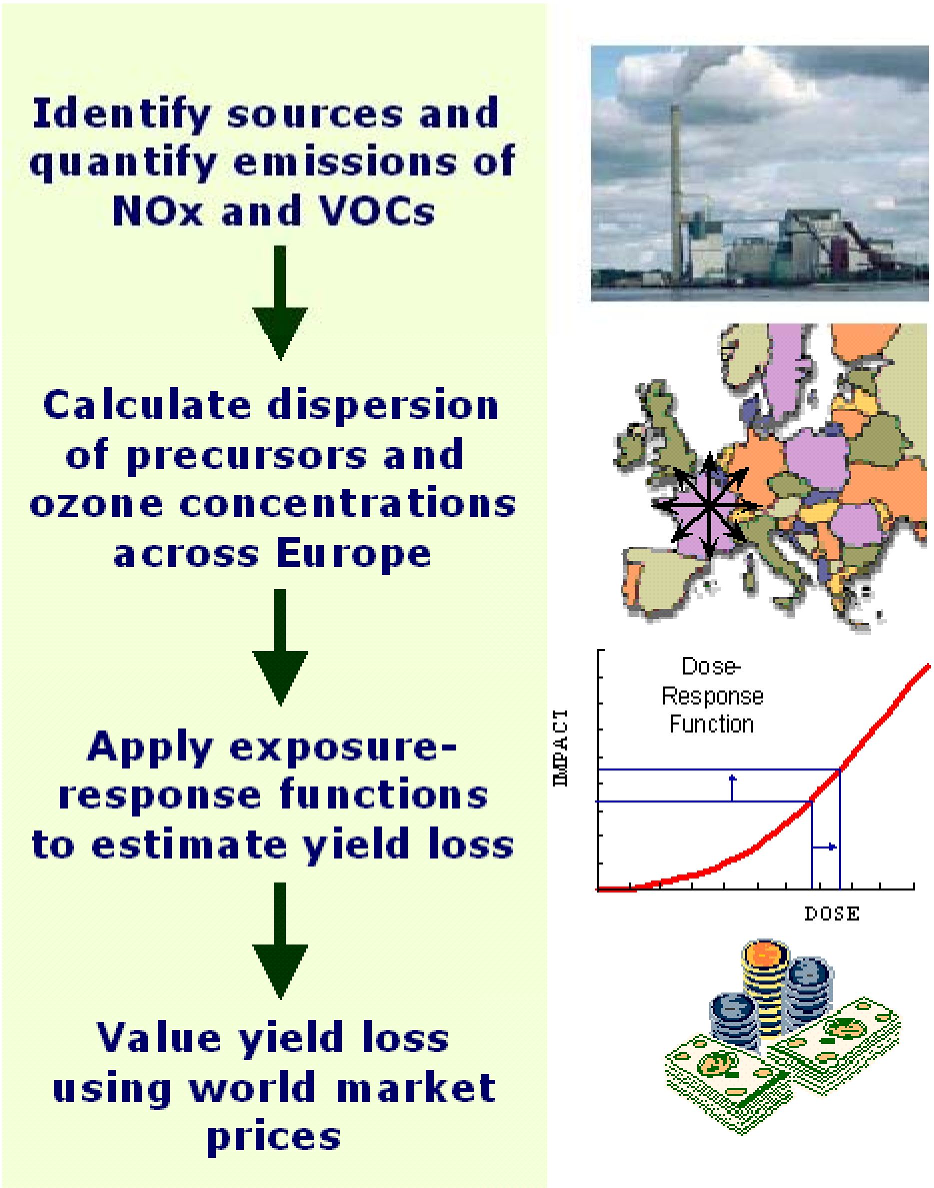


Figure 3 – Illustration of the impact pathway approach taking the example of direct effects of ozone on crops

Following from the figure, impacts and damages under any scenario are calculated using the following general relationships:

$$impact = pollution \times stock\ at\ risk \times response\ \ function$$

$$economic\ damage = impact \times unit\ value\ of\ \ impact$$

Pollution may be expressed in terms of concentration or deposition. The term 'stock at risk' relates to the amount of sensitive material (people, ecosystems, materials, etc.) present in the modelled domain.

Calculations are normally made for each cell within a grid system: for the CAFE work the EMEP 50 x 50 km grid will be used for the main analyses, with some possible additional work at finer resolutions (see Section 4.2.2). The basic form of the analysis remains the same no matter what spatial resolution is adopted for the analysis.

Although the underlying form of the above equation does not change, the precise form of the equation will vary for different types of impact. For example, the functions that describe materials damage from acidic deposition require consideration of climatic variables (such as relative humidity) and need to account for several pollutants simultaneously.

For any type of receptor it is necessary to implement a number of these impact pathways to generate overall benefits. So, for example, in the case of impacts of ozone on crop yield, it is necessary to consider, separately, impacts on a series of different crops, each of which differs in sensitivity. For health assessment it is necessary to quantify across a series of different effects to understand the overall impact of air pollution on the population.

The final stage, valuation, is generally done from the perspective of 'willingness to pay' (WTP). For some effects, such as damage to crops, or to buildings of little or no cultural merit this can be done using appropriate market data. Some elements of the valuation of health impacts can also be quantified from 'market' data (e.g. the cost of medicines and care), though other elements such as willingness to pay to avoid being ill in the first place are clearly not quantifiable from such sources. In such cases alternative methods are necessary for the quantification, such as the use of contingent valuation (for discussion of this and other valuation techniques see ExternE, 1999a; EAHEAP, 2000). Where impacts arise in the future it is necessary to discount monetised values (but not the impacts themselves).

Worked examples of the calculations made using impact pathway analysis of health endpoints are shown in Appendix 4.

4.2.2 Quantification of benefits at different geographic scales

There is a need to quantify effects not only at the European scale on the EMEP 50 x 50 km grid, but also at more local scales, to enable investigation of measures for addressing air quality problems in cities.

To some extent this is already factored into the Europe-wide RAINS analysis, through the use of a factor to elevate concentrations in urban areas in line with the results of the CITYDELTA project. However, it may be envisaged that the analysis will be carried out for individual cities for which air quality data are available at a much finer resolution, based on results of monitoring and urban-scale modelling.

Should analysis be required for individual cities, the main analytical complexity would be to ensure that data on stock at risk (principally population, and relevant fractions of it) can be described on the same grid system as pollutant concentration data. This should not represent a significant problem as detailed maps of population are now available for many cities, given that health impacts will dominate urban assessments.

For the core analysis, the response functions and valuations used for quantification at the local scale will be the same as those used for the pan-European assessment described above. For some cities in which epidemiological studies have been performed it is appropriate to also use functions taken from the data collected locally for comparison with the standard set of CAFE functions. The position adopted here is that the locally collected response data would be used for sensitivity analysis rather than for the core assessment, on the grounds that the core functions are drawn from a much larger population sample, and so are likely to minimise error. Where locally collected incidence data are available, however, it would seem preferable to use those rather than European averages.

For materials damage there may be some merit as part of a local scale analysis in quantifying deterioration rates for specific buildings to illustrate the extent of problems for cultural heritage through comparison with the 'acceptable rates' of damage recommended by ICP Materials. As noted elsewhere in this report, monetisation of damage to cultural heritage will not be possible, given the lack of information on stock at risk, concerning not just the number of buildings but also descriptions of the materials from which they are made, and a lack of data on valuation of damages. However, knowledge of deterioration rates can be compared with the 'acceptable rates'

Full quantification of the damages of emissions within cities needs to take account of damages that occur outside the city, from long-range transport and chemical transformation of pollutants. This can be done by adding in the damage quantified for emissions in rural areas, subtracting out damages within a certain distance of the source to represent the area of the city of interest.

4.3. Overview of presentation of the results of the analysis

Considerable attention has been given to the way that the results of the analysis are presented, particularly with respect to the way that uncertainties are reported. The following describes the sequence of the assessment:

1. Quantification of costs (RAINS)
2. Quantification of impacts (RAINS/CBA)
3. Monetisation of impacts where possible
4. Initial comparison of costs and benefits
5. Extended CBA
6. Further uncertainty analysis for benefits
    a. Bias analysis
    b. Statistical analysis
    c. Sensitivity analysis for benefits
7. Overview of the likely effect of uncertainties
8. General equilibrium analysis providing outputs on competitiveness and employment

Stages 1 to 3 need to be done at the level of totals for the EU25 and non-EU states and also at the level of the Member States.

Stage 4 is a simple comparison of best estimates of costs and benefits. This will be focused on the following series of questions:

- Across Europe, do quantified benefits exceed costs?
- What is the ratio of benefits to costs?
- If quantified benefits do not exceed costs, does it seem likely that underestimation of effects could have a significant impact on the balance between the two?
- For each country individually, do benefits exceed costs?
- What is the ratio of benefits to costs for each country?
- For countries where quantified benefits do not exceed costs, does it seem likely that underestimation of effects could have a significant impact on the balance between the two?

Stage 5, the extended CBA, has been developed with three objectives. The first is simply to increase understanding of impacts, whether they have been quantified or not. The second is to provide contextual information to assist in validation of quantified estimates. The third objective is to provide a mechanism whereby decision makers can develop a better understanding of the likely importance of impacts that have not been quantified, specifically, whether they are likely to be significant enough to alter the balance of costs and benefits. All three aspects represent major advances with respect to previous CBAs of European air quality policy.

Stage 6 addresses the uncertainties present in the analysis. The first part of the uncertainty assessment is a straightforward bias analysis, where the assessment of costs and benefits is reviewed and biases identified along with the direction of bias. This will indicate, for both costs and benefits, whether either is likely to be systematically over-or under-estimated.

The second part of the uncertainty assessment involves statistical analysis of the more important endpoints for the quantified benefits assessment. This will focus initially on effects that contribute most significantly to total benefits, to highlight potential ranges for individual parameters. It will be supplemented by further analysis that considers the distribution of estimates of aggregated benefits.

This is followed by a sensitivity analysis, addressing specific uncertainties identified during the development of the methodology. A key example relates to the approach taken to mortality valuation. The sensitivity analysis will also consider the effect on the balance of costs and benefits of inclusion of a number of additional health endpoints, which can be quantified at the present with only limited confidence.

This detailed approach to quantification and description of uncertainty will need to be brought together to provide an overview of the robustness of the initial conclusions from Stage 4 of the relationship between costs and benefits (Stage 7). Without this, the work done on the characterisation of uncertainty is as likely to confuse rather than to inform.

Finally, Stage 8 will bring in the outputs of the macro-economic analysis made using the GEM-E3 model. The results of this model will highlight any concerns that there may be about effects on employment or competitiveness of the policies to be considered under the CAFE Programme.

The following sections review the methodology with respect to stages 5 to 8 in more detail. A separate report on uncertainty analysis will be issued once first results are available, in order to illustrate the use of these different methods.

4.4. Extended CBA

4.4.1 Introduction

It was considered at the beginning of the CAFE Programme that multi-criteria analysis (MCA) could be useful for bringing impacts that could not be quantified into the analysis. MCA is based around the elicitation of a series of weightings from stakeholders to show preference across various environmental criteria. It is finding increasing application in policy making circles.

It was concluded, however, that MCA would not be sufficiently robust to make a useful contribution to the CAFE debate. Also, the complexity of the analysis, with its wide variety of endpoints (see Table 2) is not well-suited to MCA. The approach developed here (named ‘extended CBA’) instead seeks to supply decision makers with more contextual information on impacts, so that they can understand them better and, if they wish, factor their own views on the importance of unquantified impacts into the CBA.

The extended CBA is based around the provision of a series of datasheets containing a significant amount of descriptive information (qualitative and quantitative), to enable better understanding of the effects and their likely importance. Information will be provided in greatest depth for effects that are not quantified through to monetisation. However, it will also be provided for effects that can be monetised, for example, in order to increase understanding of the health impacts. It is intended that decision makers and stakeholders refer to this information when considering how costs and benefits compare.

4.4.2 Development of datasheets for the extended CBA

The extended CBA datasheets will contain the following types of information:

a. Description of the impact, including components of ‘total economic value’
b. Discussion of related impacts
c. Confidence in attribution of impact to a specific pollutant
d. Information on the distribution of impact across Europe (is it a ‘European issue’ or something to be considered at a more local level?)
e. Information on importance in economic or other terms, where available (e.g. from results of willingness to pay case studies, past estimates of expenditure to deal with specific problems, etc.)

An assessment will be made in the extended CBA of the likely significance of each unquantified effect, using a three point scale:

★★★	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
No stars	Negligible

Example datasheets are provided in Appendix 5. The first is provided for the case of visible injury to agricultural crops following exposure to ozone, an impact that cannot currently be quantified at a European scale. Some limited analysis may be possible in areas that are more frequently subject to this problem.

A second datasheet is supplied for chronic impacts of exposure to particles on the prevalence of chronic bronchitis in the adult population. This example deals with an impact that will be quantified, but demonstrates that additional information is extremely useful in order to develop a proper understanding of effects.

Datasheets for other impacts will be presented in a separate volume. Their development is taking account of the views of a variety of stakeholders

a) Health: WHO/CAFE group
b) Materials: ICP Materials and experts from studies such as MULTI-ASSESS
c) Crops: ICP Vegetation
d) Ecosystems: ICPs Mapping and Modelling, Vegetation, Forests, Freshwaters

4.4.3 Integrating data from the extended CBA with quantified estimates

Results for the overall CBA need to be presented at two different levels. The first should be suitable for use in summary materials, the second should provide a sufficiently high level of detail for expert readers. In both cases attention needs to be drawn to the impacts that are not quantified – otherwise there is no mechanism for consideration of the relative importance of these impacts. For the summary materials we will adopt the following general structure (Table 3) for integration of the results of the extended CBA with monetised results.

Table 3 – Proposal for summarising results and including outputs from the MCA

Costs	[quantified costs]
Benefits	
Health	[quantified benefits]
etc.	[quantified benefits]
Sub-total benefits	[quantified benefits]
Ecosystem effects	
Physical impact	Summary RAINS results, e.g. % ecosystems affected
Economic effect	★★★ see reference…
Cultural heritage	★★ see reference…
Crops – visible injury	★ see reference…
Effects of ozone on paint	Negligible
…	…
…	…

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
Negligible	Impacts unlikely to be significant at a national or local level.
'see reference…'	To guide readers to summary information, such as that presented above for visible injury to crops from ozone exposure. This may be facilitated using hyperlinks for electronic versions of reports, or page numbers for hard copies.

The intention in providing information in this way is to prompt stakeholders to consider whether the impacts that have not been quantified are likely to be important enough to change the balance of costs and benefits. It is not intended that anyone should add together the star ratings given to the various impacts – they are simply intended as 'flags' to distinguish what is probably important from what is probably not. Stakeholders are of course free to come to their own conclusions on the relative importance of the different impacts considered in this process.

4.4.4 A preliminary view on the ratings for effects to be considered in the extended CBA

The star ratings shown below Table 3 for the extended CBA are developed on the datasheets. In the case of visible injury to crops from ozone exposure it has been concluded by the project team that the effect would merit one star, denoting that it is unlikely to be important across Europe, but may well be important locally, and so may be of interest to policy makers representing areas where the critical level for visible injury is likely to be exceeded and where there is significant production of sensitive crops. The reasoning why this impact only merited the one star was that only a subset of European crops would be affected (mainly leaf crops like lettuce, spinach, etc.). However, there is evidence that losses to some farmers can be substantial, and so it would be inappropriate to say that it was negligible from all perspectives. Other datasheets are being developed and the following summarises the star ratings arrived at:

Table 4 – Preliminary view on ratings to be used in the extended CBA. Effects considered likely to be negligible are omitted from this table.

Effect	Preliminary rating
Health	
Ozone: chronic effects on mortality and morbidity	★★
SO_2: chronic effects on morbidity	★
Direct effects of VOCs	★
Social impacts of air pollution on health	★★
Altruistic effects	★★
Materials	
Effects on cultural assets	★★
Crops	
Indirect air pollution effects on livestock	★
Visible injury following ozone exposure	★
Interactions between pollutants, with pests and pathogens, climate...	★★
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	★★★
Visibility	
Change in amenity	★
Groundwater quality and supply of drinking water	
Effects of acidification	★

It is not envisaged that these star ratings will change from scenario to scenario (to do so would involve some form of quantification, the lack of data for which is precisely the reason for needing to use an extended CBA). However, indications of change in risk (e.g. extent of critical loads exceedance) will be provided on a scenario by scenario basis where possible.

4.5. Further characterisation of uncertainty

The extended CBA described above deals with two elements of uncertainty:

- Understanding what is meant by the short titles given to impacts (e.g. 'chronic bronchitis', 'acute mortality', 'critical loads exceedance').
- The omission of impacts through a lack of data for quantification.

This section discusses other elements of uncertainty, particularly numeric uncertainty, and how they will be assessed in the analysis.

4.5.1 Uncertainty and the comparison of costs and benefits

If the costs and benefits of air pollution control were known with absolute confidence there would be no problem in comparing the two. However, costs and benefits are subject to uncertainties and some of them (on both sides of the cost-benefit equation) are significant. Knowledge of these uncertainties is variable, as is the availability of information to describe them. Further to this, some uncertainties are statistical and continuous in nature, some relate to discrete choices (e.g. selection of approaches for the valuation of air pollution – related mortality) whilst some simply relate to a lack of knowledge. It is clear from this that the development of a fully consistent approach to description of uncertainty across the CAFE analysis will be difficult.

Consideration of uncertainty in comparison of costs and benefits cannot, therefore, be an automatic process. Awareness needs to be raised of the component uncertainties of each part of the analysis. The most important of the component uncertainties should be highlighted and quantified to the extent possible. Account also needs to be given to how satisfactory the assessment of uncertainty is.

4.5.2 Key issues in uncertainty for air pollution benefits assessment

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 any consideration of uncertainty. These are:

1. Quantification of the mortality impact of exposure to fine particles;
2. Valuation of mortality impacts from particles and other pollutants;
3. Assessment of effects of chronic exposure to particles on the prevalence of bronchitis;
4. Attribution of effects to individual species of particle or other pollutant;
5. Failure to quantify monetary benefits with respect to ecosystems;
6. Inter-annual variability in meteorology;
7. Various types of uncertainty in cost estimates.

In some situations other uncertainties may become important, though in general, those listed here will dominate.

4.5.3 Techniques for examination of uncertainty

Section 4.2.2 listed the following components of the uncertainty analysis that will be done under the CAFE CBA in addition to the extended CBA described above:

- Bias analysis
- Statistical analysis
- Sensitivity analysis

Outline details of these approaches are given below, though a separate volume is in preparation that quantifies uncertainties through the initial analysis of scenarios being considered under CAFE.

4.5.4 Bias analysis

The purpose of the bias analysis is to highlight those issues that are considered likely to cause a systematic bias in the results. This is illustrated in Table 5.

Table 5 - Illustration of the bias analysis, showing the effects of each bias on the total of quantified effects.

Bias	Direction/magnitude	Reference
Omission of eutrophication impacts on ecosystems	---	(to extended CBA datasheet)
Omission of acidification impacts on ecosystems	---	(to extended CBA datasheet)
Omission of impacts of organic aerosol	--	(to discussion)
Use of health functions from western Europe	--?	(to discussion)
Use of incidence data from all of Europe	++?	(to discussion)
Limited availability of crop ozone-flux data	+/-	(to discussion)
Etc.	…	…

The scoring system used in the second column is as follows:
---/+++ to effects likely to lead to a significant under-/over- estimation of benefits
--/++ to effects that may lead to a significant under-/over- estimation of benefits
-/+ to effects likely to lead to insignificant under-/over- estimation of benefits

The references in the third column are either to the datasheets prepared under the extended CBA which will include an estimate of the likely significance of each impact, or to a separate discussion of biases. In each case a justification will be given for allotting each impact to its given rating.

It is intended that a similar table will be generated for the costs analysis based on the RAINS model also.

Interpretation of the data given in this kind of analysis is not straightforward, as one extremely significant cause of over-estimation may more than negate a large number of sources of under-estimation. However, the picture given by this form of analysis will give an indication of whether, overall, under-estimation or over-estimation of benefits and (separately) costs, is likely.

4.5.5 Statistical analysis

Whilst statistical analysis is often considered to provide a benchmark for uncertainty assessment it is important to recognise that a variety of uncertainties cannot be described using standard statistical techniques. This is illustrated with the following examples:

- Quantification of the morbidity effects of air pollution requires (as a minimum) information on pollution levels, exposure-response, and baseline incidence. Despite work to standardise definitions, there is extensive and unexplained variation in baseline incidence data between countries. This means that it is necessary to introduce assumptions on the transferability of data when performing quantification.
- In a multi-pollutant environment, epidemiological health studies struggle to distinguish which pollutant or pollutants of the several that are present are most likely to be responsible for the observed effects (accepting that epidemiological studies do not prove causality). Again, some assumption on causality is required.
- The effects of air pollutants, particularly ozone, on crops are dependent on climatic factors that are not accounted for in simple (‘Level I’) response functions. The preference is for more sophisticated ‘Level II’ functions to be used that seek to

account for at least some of the interaction between climate and ozone. However, the data to support such models are only now becoming available, and for only a small number of crops. How should the analysis be broadened to account for more crop species?

Although a statistical treatment of these uncertainties is not possible, it is still necessary to account for them in the analysis in some way if they seem likely to have a significant effect on the balance of costs and benefits. This can be done using the other techniques described here, bias analysis and sensitivity analysis.

The method to be used for the statistical analysis is as follows. Uncertainty is being described for each stage of analysis of each quantified endpoint. These component uncertainties will be combined using @RISK to provide a range for each endpoint. They will then be combined across endpoints to give a confidence interval around the estimate of total (quantified) benefits.

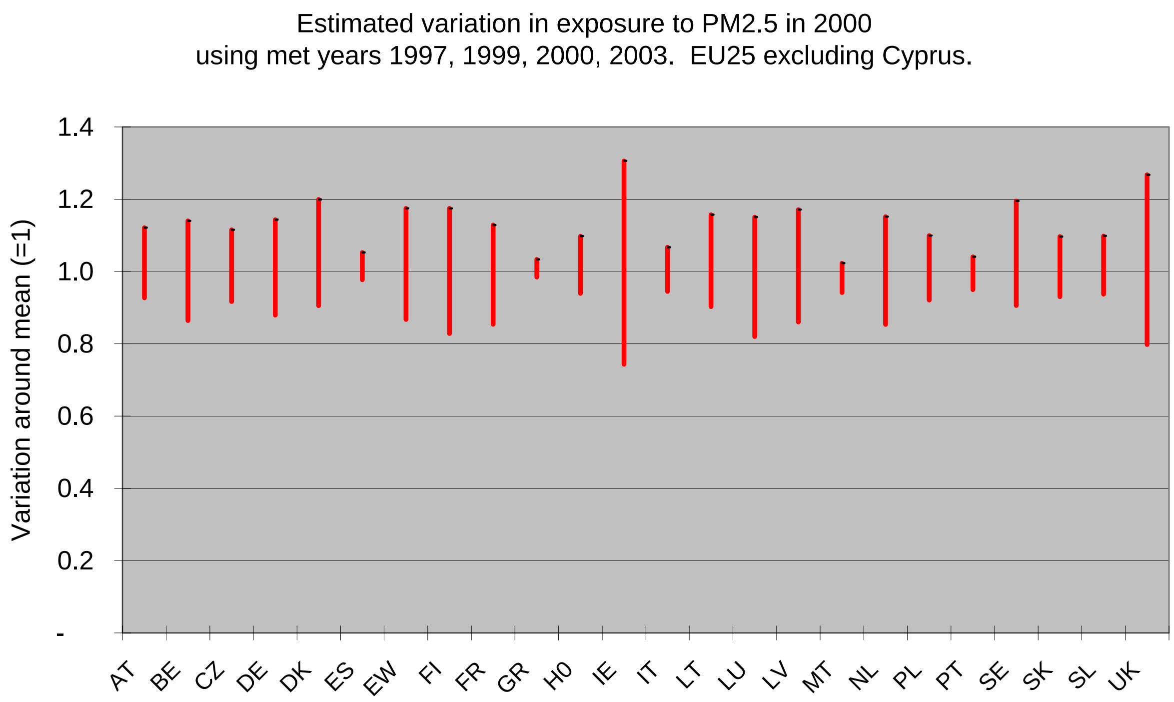
4.5.6 Sensitivity analysis

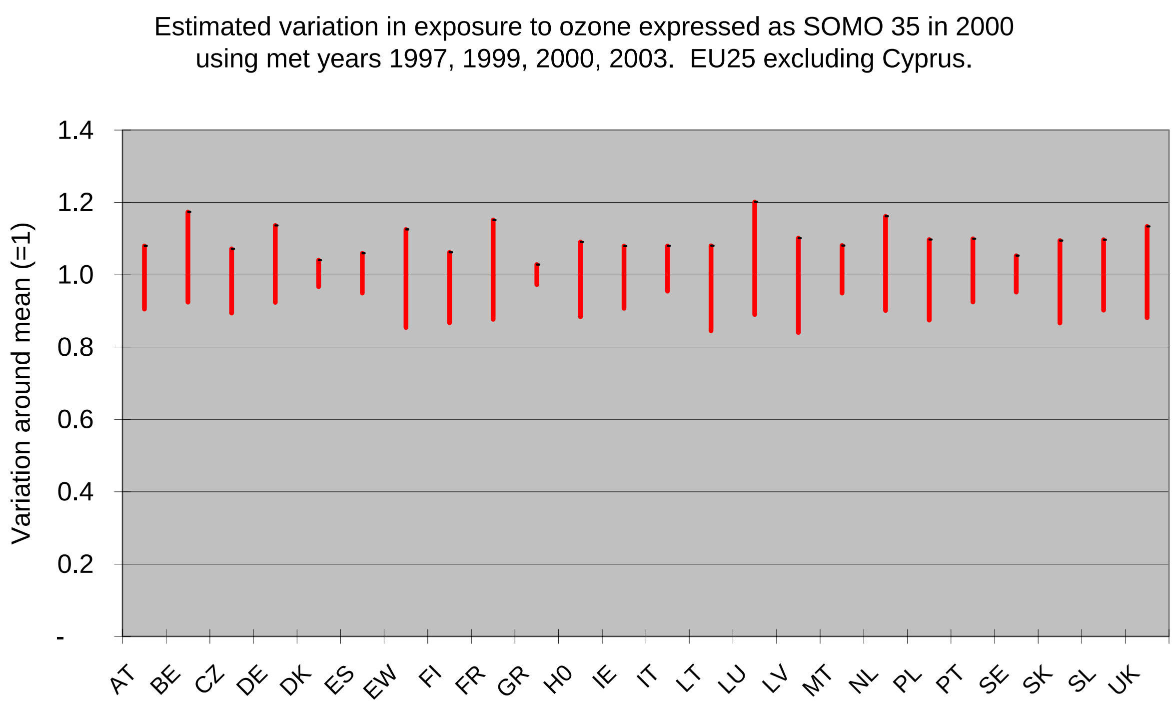
From consideration of the data used to quantify impacts, the following key areas for sensitivity analysis are apparent (excluding sensitivity to the omission of impacts from quantification):

1. Response function selected for quantification of chronic effects of particles on mortality.
2. Response function selected for quantification of acute effects of ozone on mortality.
3. Valuation of mortality in terms of lives impacted or life years lost.
4. Use of a cut-point for the ozone-health analysis.
5. Inclusion of some health endpoints which are supported by limited research.
6. Use of concentration and flux based approaches to quantification of ozone impacts on crop production.
7. Inter-annual variability in meteorology.

These will be dealt with in two ways. First, some of the most important effects will be assessed in isolation to define their importance in terms of total quantified benefits. Issue 7 (inter-annual variability in meteorology, and its effects on pollutant concentrations) has already been investigated. The EMEP model has been run for the years 1997, 1999, 2000 and 2003. Variability in exposure in each country for the EU25 (excluding Cyprus) is shown in Figure 4. This shows a difference between low and high within countries up to around 60% in an extreme case ($PM_{2.5}$, Ireland). Closer inspection of data also revealed that there was significant variability in the performance of individual countries within any assumed met year.

Figure 4 – Variability in national exposure estimates for annual mean $PM_{2.5}$ (top) and SOMO 35 (sum of ozone daily 8-hr max means over 35 ppb, bottom).





The second approach is similar to the 'stratified sensitivity analysis' carried out in the CBA work for the NEC and ozone directives and the Gothenburg Protocol (AEA Technology, 1998; Holland et al, 1999). Impacts were split into groups starting with those that can be quantified with most confidence and going down to those that are quantifiable with least confidence. The work on these earlier studies used 5 confidence bands. This level of differentiation looks excessive for the current analysis, given that:

- Some effects considered to be very uncertain have been dropped from the CAFE quantification (e.g. loss of forest production, effects of visibility);
- Whilst the quantification of others (most notably effects of chronic exposure to particles on mortality) is now looked on with more confidence.

The stratified sensitivity analysis to be used here is likely to use only three bands.

One stakeholder[8] suggested the use of 'uncertainty scenarios' which we understood as identifying key input parameters and to attach to each a low, medium and high value and then to undertake 'low', 'medium' and 'high' runs. Given the potential for errors to cancel out this would give an unrealistic spread in benefits estimates (i.e. "worst case" and "best case" in all parameters). As the purpose of uncertainty analysis is to understand the robustness of the results, it was not considered methodologically correct to construct the "worst" and "best" case scenarios. However, statistical analysis based on the confidence intervals surrounding input parameters will be carried out, as defined above.

[8] CONCAWE, July 2004

5. Health Impacts and Valuation

5.1. Introduction

This section provides a summary of our general approach to health quantification, together with more precise recommendations than previously given for response modelling and valuation. A more complete account is provided in Volume 2.

In summary, we will evaluate the impacts on health of air pollution, concentrating on the two main pollutants of concern to CAFE – PM and ozone. We aim to generate an unbiased set of estimates of the effects of air pollution on health, along with guidance on the reliability of those estimates. To do this we have recommended an approach that is designed to neither systematically *over*-estimate or *under*-estimate the health effects.

In preparing this chapter, we have aimed for consistency with the World Health Organisation's (WHO) "Systematic Review of Health Aspects of Air Quality in Europe" (http://www.euro.who.int/document/e79097.pdf) and answers to follow-up questions (http://www.euro.who.int/document/e82790.pdf) asked by the CAFE Steering Group. These are an excellent resource on hazard identification regarding the health effects associated with or caused by particulate matter (PM), ozone (O_3) and nitrogen dioxide (NO_2) but are not a 'tool-kit' for HIA of the effects of air pollution.

For quantification, our core recommendations for mortality related to PM and ozone are based on recommendations of WHO-CLRTAP Task Force on Health (TFH) (http://www.unece.org/env/documents). However, the aim of the benefits assessment is to compare costs and benefits of specific policies and so:

(i) We proceed to valuation, paying special attention to the linkage of epidemiology and valuation for mortality; and
(ii) Include other effects (morbidity, infant mortality).

For morbidity we have used a wider set of HIA sources that includes the work of ExternE and of Hurley et al. (2000), Künzli and colleagues (e.g.; Künzli N, Kaiser R, Medina S et al., 2000), major projects as APHEIS, the Global Burden of Disease project, and the Benefits Assessment of the US EPA in evaluating the US Clean Air Act (Second Prospective Analysis) and, in particular, the WHO-sponsored meta-analyses of the acute effects of PM and ozone based on studies in Europe (http://www.euro.who.int/document/e82792.pdf). We have also drawn from the peer review, and subsequent correspondence with the peer review team in the identification of additional relevant studies.

5.1.1 Coverage of 'acute' and 'chronic' health effects

Most available studies examine the effects of *acute* exposure (usually known as ***acute health effects*** or effects of daily variations in pollution); i.e. the ways that air pollution on a given day or adjacent days can affect the health of people on the same day or on the days immediately following – typically within one week[9].

[9] Some analyses of acute exposure now include effects that occur up to 40 days from the relevant pollution days

A limited set of studies examines the relationships between *chronic* (longer-term, possibly lifetime) exposure and health (usually known as ***chronic health effects***). Here the strength of evidence is less than for acute effects, but the estimated impacts are greater, because the effects of long-term exposure capture, at least partially, the acute effects, as well as including aspects not captured by the acute effects.

The key recommendations are presented in turn below for seven key areas of analysis:

- Chronic mortality from PM;
- Acute mortality from ozone;
- Infant mortality from PM;
- Valuation of mortality;
- Morbidity impacts from PM and ozone;
- Valuation of morbidity;
- Sensitivity analysis.

5.2. Chronic mortality from PM

Chronic effects, particularly on mortality have become the main focus for quantification of the health impacts of particulate exposure. Past CBA work building on the findings of ExternE, (e.g. AEA Technology, 1998) demonstrated that these effects dominated benefits estimates made for the Gothenburg Protocol and the original NEC Directive. Quantification is already being undertaken in RAINS, but for subsequent analysis (including monetary valuation) the benefits model needs to reproduce the quantification analysis.

- Consistent with WHO/THF advice to RAINS and wider current practice, we will use the recent extended follow-up by Pope *et al.* (2002) of the American Cancer Society (ACS) cohort.
- Following WHO/THF, for core analyses we adopt the coefficient:

  6% change in mortality hazards (95% CI 2-11%) per 10 $\mu g/m^3$ $PM_{2.5}$

- This is the coefficient relating mortality to average exposure throughout the follow-up period, unadjusted for the possible effects of other pollutants, notably SO_2. Uncertainty analyses will include a coefficient of 4%, based on exposures measured at the start of follow-up in Pope et al. (2002).

The WHO answers to CAFE concluded that the burden of evidence - both theoretical and empirical - was very strongly against the view that there is a population threshold. This is to say that there is no background level that is safe, i.e. with no increase in risks for any in the population. Following WHO advice to the RAINS analysis as well as the views of others, such as ExternE (1999a), we will apply the function without threshold to anthropogenic PM.

There are numerous well-conducted studies of the acute effects of PM on mortality. The results from European studies were included in the WHO meta-analysis. However, to avoid double-counting, we will follow what has become standard practice, as reflected by WHO advice to RAINS, and not include these alongside the chronic mortality impacts above in the main analysis, though we will quantify the impacts separately.

In terms of the physical impacts quantified, the CAFE CBA core analysis will be consistent with the guidance from WHO, and the output from the RAINS model, with our own long-established practice, and with an emerging consensus in HIA work, and express chronic mortality effects principally in terms of change in longevity. We also recommend that given the WHO guidance, change in longevity aggregated across the population (otherwise referred to as ‘years of life lost’) is the most relevant metric for valuation. In order to value the benefits of reduced air pollution the concept of the value of a life year (VOLY) needs to be applied. This “VOLY” approach is preferred by the ExternE project team (see, e.g., ExternE, 1999a and Rabl, 2003). However, the peer review of the CBA methodology pointed out that direct, credible estimates of the VOLY are lacking, that the estimates to be used in CAFE are derived computationally and that to be applied correctly, VOLYs should be age specific (p. 33). Thus, while the physical impacts (reduced life years) can be derived without major difficulties, the derivation of values for these impacts has methodological problems.

Due to the difficulties in valuation of life years, we will also quantify premature mortality benefits based on the cohort studies in terms of ‘attributable deaths’ (or, for pollution reductions, attributable deaths delayed). A more complete discussion of these issues is given in Volume 2. In summary, there are two possible approaches to estimating numbers of deaths (attributable cases) associated with long-term exposure to PM.

- The first approach attempts to use life tables, because this is the methodology used to give results in terms of life expectancy. As far as we know, life tables are not used currently to estimate ‘attributable deaths’. Indeed, there are some important methodological problems in attempting to do so.
- The second approach does not use life tables. It is simple to implement and is widely used. It is however an over-simplification and, as such, over-estimates effects.

In CAFE CBA we will use the second simpler method because (i) it is both simple to do and, despite its limitations, is widely-used; and (ii) the methodological problems associated with using deaths from life tables have not been tackled and resolved sufficiently for us to use the methods at this point. We stress that these methodological differences imply that there is no easy equivalence or ‘conversion’ between the estimates of life years and attributable deaths in CAFE CBA, even though both are derived using the same coefficient from the US cohort studies, and using the same pollution data. In particular, it is not valid to ‘convert’ between life years and deaths, from the results of CAFE CBA.

This application of the cohort study data for attributable deaths is less reliable than the when attributing air pollution to life years lost. On the other hand premature mortality due to air pollution can be attributed to valuation in terms of the Value of a Statistical Life (VSL), though some question the applicability of this value to air pollution deaths. The peer review concluded that the empirical basis for using values of statistical life is fit for purpose. As both VOLY and VSL approaches have methodological issues, the peer review suggested that both approaches be applied in a transparent manner. A more complete discussion of these issues is given in Volume 2.

There are some differences in how CAFE CBA and RAINS use life table methods to implement the WHO guidance about C-R functions and thresholds. These derive from differences in purpose. In particular, CAFE CBA examines the specific benefits of individual policies, over different time-scales, for comparisons with costs. This requires standardising benefits to capture the effects of one year’s pollution change (‘annualisation’), compared to the sustained pollution targets assessment in the RAINS model. Other differences concern the need for CAFE CBA to link flexibly with monetary valuation.

It will be possible to examine a number of sensitivities. Most HIAs that use cohort studies assume no time-lag between changes in pollution and consequent changes in death rates. This is the approach taken by RAINS and, for consistency, we will adopt this also for the main analyses for CAFE CBA. However, we will also carry out sensitivity analyses based on various assumed time-lags between changes in pollution and changes in death rates.

The other main area of sensitivity analysis is in relation to the potential effects of different toxicities for the components of the PM mixture, i.e. primary $PM_{2.5}$, sulphates and nitrates. We believe this is an extremely important issue for policy, though we recognise that any attempt at quantification will be speculative. WHO Task Force on Health (TFH) considered this issue in 2003, and again in the CAFE follow-up questions and reached the following conclusions:

- 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.

5.2.1 A comparison of the CAFE approach with that used in the WHO Global Burden of Disease Project

In the last two years, estimates of the mortality effects of chronic exposure to fine particles by the WHO Global Burden of Disease (GBD) Project (see Ezzati et al, 2002) have become a focus for European decision makers. Ezzati et al report European impacts to be equal to 107,000 deaths and 725,000 years of life lost[10]. It is, however, anticipated that the estimate of this impact to be made in the CAFE programme will be substantially higher for several reasons, including;

- Differences in the total population considered – GBD studied people in cities of more than 100,000 inhabitants, whereas CAFE CBA considers effects in the entire population;
- Application of lower risk factors (percentage change per $\mu g.m^{-3}$) by GBD compared with CAFE CBA;
- Quantification by GBD within a more restricted concentration range;
- Differences in factors used to convert PM_{10} to $PM_{2.5}$.

These differences reflect the separate objectives of the GBD Project and CAFE. Specifically, GBD developed and implemented a methodology whose focus was to give good estimates

[10] Ezzati et al (2002) describe the 725,000 figure in units of DALYs (Disability Adjusted Life Years), but it is understood that the units for this number should be years of life lost. The corresponding DALY estimate is 849,000.

world-wide, whereas CAFE is focused on Europe only. There are no fundamentally different views about health impact assessment methodology between the authors of the two studies. Indeed, for mortality and chronic exposure to $PM_{2.5}$, CAFE is based on recommendations from WHO-TFH; and there is a substantial overlap between members of WHO-TFH and the air pollution team of GBD.

5.3. Acute mortality from ozone

The cohort studies preferred for assessment of PM related mortality do not show a clear effect of ozone. For ozone it is therefore necessary to use data from time-series studies which clearly link ozone to mortality. Consistent with the existing analysis within RAINS, and the CBA team's own long-standing practice, we will therefore include the acute mortality effect from short-term exposure to ozone from the time-series studies. Quantification within RAINS has again been guided by WHO/TFH, whose main conclusions were:

- Quantification should focus on ozone characterised as a daily maximum 8-hr mean, in relation to daily all-cause mortality.
- There is not robust evidence for the presence of a threshold for ozone effects, though quantification is less reliable at low ozone concentrations.
- With this caveat in mind, the main quantification of ozone effects on mortality should use the metric SOMO35 (sum of means over 35 parts per billion (ppb)). This measure represents accumulated exposure to concentrations greater than 35 ppb daily maximum 8-hr mean. This should not be taken as an indication that there are no effects under 35 ppb.
- A risk estimate of 0.3% increase in daily mortality (95% CI 0.1-0.4%) per 10 $\mu g/m^3$ O_3 should be adopted.

The direct output from analysis that follows these recommendations is the effect of ozone in terms of number of deaths brought forward, which can be valued using the VSL approach[11]

To quantify using the VOLY approach as an alternative, it is necessary to convert the number of deaths into the number of life years lost. This is difficult, as there is a lack of direct evidence for this part of the quantification. Previous work by the study team (ExternE 1999a, Hurley et al. 2000) has involved 'conversion' of attributable deaths from time series studies to changes in life years using an estimate of 6 months per life. When originally made, this estimate was considered by many to be an overestimate, though attitudes have since changed. The peer review of the CAFE-CBA methodology thought that a larger value, on average, was warranted. A US evaluation of ozone and mortality has used an estimate of 12 months, and this will be used for CAFE-CBA also. While there is no direct evidence to justify this figure, it seems an appropriate balance between 'harvesting' and the death of individuals who would

[11] Note that the health impact here can best be characterised as a "deaths brought forward" attributed to ozone. 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. We believe that it is therefore not appropriate to use a full VSL to value these deaths brought forward. In contrast to transport accidents, or other applications where a VSL is used, air pollution is only one of many factors contributing to premature death, and the period of life lost that can be attributed to air pollution is almost certainly small (on average) compared with life expectancy of the population currently alive, or those who die from transport accidents. Use of a full VSL is equivalent to attributing to air pollution the full impact of early death.

have recovered and lived for significant periods. Other values will be investigated in sensitivity analyses, ranging from 2 to 18 months.

WHO/TFH recognised that estimating effects only above a cut-off point is a very conservative approach to the estimation of the mortality effects of ozone. Consequently, it recommended a sensitivity analysis giving estimates with no cut-off point (or equivalently, with cut-point at zero) as an upper bound on the true impacts. This will be included in the sensitivity analysis for the benefits assessment.

5.4. Infant mortality from PM

In Europe the effects of air pollution on mortality and other indices of infant health have been studied most extensively by Bobak and co-workers, initially in the Czech Republic, but also more widely (Bobak and Leon 1992, 1999; Bobak, 2000; Bobak et al., 2001). In quantifying the benefits to health of the US Clean Air Act, it has been recommended that infant mortality be included for quantification. This position is adopted for the CAFE benefits analysis also.

As with the US analysis, the quantification will be based on the cohort study by Woodruff *et al.* (1997). The associations reported by Woodruff et al. are with particulate matter, expressed as PM_{10} (mean outdoor concentrations of PM_{10} in the 1^{st} two months of life) giving

Change in (all-cause) infant mortality of 4% per 10 $\mu g/m^3$ PM_{10}

Results were based on a study of 4 million infants, where post-neonatal infant mortality was considered as death between the ages of one month and one year. This eliminates the first month of life when infants face the highest risk of death. Results are described in terms of numbers of deaths, valued using an adjusted VSL (see below). Quantification using a VOLY approach will not be undertaken in this case.

There is a wider issue of effects on mortality from acute exposure in children under five years; and, more generally, mortality effects (from chronic and acute exposure) in people under 30 years of age (note that the ‘general’ cohort studies are studies of adults, at ages 30 or more). Information on planned sensitivity analysis of these impacts is presented in Volume 2.

5.5. Valuation of mortality

5.5.1 Adult mortality

The valuation of air pollution related mortality has been the subject of much debate in recent years. One of the main areas of debate relates to the selection of the Value of a Statistical Life (VSL or VOSL) or the Value for a Life-Year-Lost (VLYL or VOLY) as the basis for valuation. Comments received from stakeholders during the earlier consultation on the methodology showed a split in opinion between those favouring the VSL and those favouring the VOLY approach. As a result, both approaches will be used, allowing associated sensitivity to be explored.

The CBA is able to take advantage of two new mortality valuation studies, undertaken for the EC DG Research-funded NewExt project and for the UK’s Department for Environment, Food and Rural Affairs (Defra). Both estimate basic VSL and VOLY values and together they provide a significant advance in the primary air pollution valuation literature. As such they have formed the focus for derivation of mortality values in the CAFE CBA. In reaching our recommended values we predominantly use the results from the NewExt work since they are more representative of the EU population. The studies are discussed in more detail in Volume 2 to this report (along with other background material on health valuation). From consideration of the results of these studies we adopt the set of values for chronic mortality impacts presented in Table 6 below[12]. Note that the value for the VSL of just under €1 million (the NewExt median value for VSL) is in line with the earlier recommendation from a workshop convened by DG Environment in 2000.

Table 6 - Values for use in CAFE CBA: Effects of chronic exposure on mortality.

	VSL	VOLY	Derived from:
Median (NewExt)	€980,000	€52,000	Median value 5:1000
Mean (NewExt)	€2,000,000	€120,000	Mean value 5:1000

There are some further issues raised by the peer review that can be addressed here, the principles of which apply to the valuation of other cost and benefit elements to be included in the analysis.

First, the peer review observed that comparison of the WTP results for the immediate risk reductions and the latent risk reduction in the NewExt allows calculation of implicit discount rates of 5%, 6% and 10% for Italy, France and the UK respectively. A pure efficiency-based approach would suggest adoption of these rates for the different countries – just as an efficiency-based approach would suggest using the different WTP values for the different countries. For consistency with the discounting of other costs and benefits we prefer to adopt the common rates used by DG Environment – of 4%, with sensitivities of 2% and 6%.

Whilst the efficiency criterion alone suggests using different WTP values for different Member States, this has not been carried out by any analysis at European level. This is mainly because it would not be politically appropriate to use different values and also because there is also the practical challenge of getting such values from Member States. For instance, a WTP for increasing life expectancy has been derived only for a couple of Member States. Thus, also, data requirements would militate against pursuing a Member State by Member State approach.

The peer review also commented that as incomes are expected to rise over time, so should the WTP valuations be expected to increase. At issue here is whether the two increase at the same rate. A number of studies have reported a positive relationship between income and WTP values, including the NewExt study, Hammitt and Liu (2004) etc. Whilst, we recognise this approach to be correct in itself, we are again constrained by the informational requirement that would arise were we to apply this mechanism across all costs and benefits (with potentially differing income elasticities). We will therefore adopt constant unit values across time.

[12] The values shown here have been adjusted to price year 2000 by multiplying the original data for price year 2003 by a factor of 0.937, derived from the harmonised consumer price index for the EU25 for 2000-2003.

A further sensitivity that could be examined concerns alternative assumptions on time-lags between changes in pollution and death rates. Most health impact assessments that use cohort studies assume no time-lag. This is the approach taken by RAINS and, for consistency, we will adopt this also for the main analyses for CAFE CBA. However, we will also carry out sensitivity analyses based on various assumed time-lags between changes in pollution and changes in death rates.

5.5.2 Infant mortality

It has been observed that parents are more willing to pay to reduce their children's health risks than their own by a factor of up to 2 (a more complete discussion of this is given in Volume 2 to this report), though there are a number of methodological difficulties for valuation of childhood mortality that remain unresolved. This value is broadly consistent with a life-years approach, which attributes a full life expectancy of somewhat less than 80 years to each infant death, and about half as many life-years on average to healthy adults. It is not known whether the infants whose death occurs prematurely from air pollution are a particularly vulnerable subset, with lower than average life expectancy regardless of air pollution.

There is an European Commission funded project (VERHI) that has the remit to undertake new empirical work on valuation of children's mortality risks in Europe, but this will not be available within the study time-scale. At this stage our recommendation is to use values for the adult-child marginal rate of substitution (MRS) of 1, 1.5 and 2 with regard to the adult VSLs of €0.98 million (median) and €2 million (mean). Combined, these data give an overall range of €1 million to €4 million. The core estimate is taken as the combined median VSL with the factor of 1.5, to give €1.5 million.

5.6. Morbidity from PM and ozone

5.6.1 Approaches to quantification

The basic approach to estimating the effects of air pollution on human morbidity is similar to what is done for 'acute' mortality; i.e. use a concentration-response (C-R) function expressed as:

i. % change in frequency of occurrence of an endpoint (relative risk (RR) of new or 'extra' cases) per 10 $\mu g/m^3$ PM_{10} or ozone; link this with:
ii. the background rates of the endpoint (new cases per year per unit population – say, per 100,000 people) in the target population
iii. the population size
iv. the relevant pollution increment, expressed in $\mu g/m^3$ PM_{10} or ozone

and express the result as estimated new or 'extra' cases per year.

Note that where neither the C-R function nor the background rates varies spatially, then these can be combined into a single *impact function* expressed as:

number of (new) cases per unit population (say, per 100,000 people)
per (10) $\mu g/m^3$ PM_{10} or ozone per annum

This impact function can then be linked, as before, with population size and the relevant pollution increment to give estimated impacts.

Where data on background rates of morbidity are unavailable, or in practice too difficult (too resource-intensive) to collate, one approach is not to attempt quantification. However, failure to quantify generates a systematic bias to under-estimation of health effects.

Alternatively it is generally possible to:

- estimate an impact function from where the relevant epidemiological studies were carried out; and
- transfer and use that impact function for quantification in the target population.

This alternative approach allows some quantification, albeit one that is less reliable than if suitable background data were readily available. It is, however, well-established in health impact assessment practice.

The strengths and weaknesses of these approaches and other information relating to the quantification of morbidity effects are discussed in volume 2.

5.6.2 The use of 'Core' and 'Sensitivity' functions

The next section identifies functions for various effects on morbidity and assigns them to 'core' or 'sensitivity' analysis. Core functions are those for which evidence is best, sensitivity functions are those for which there is good evidence of effect, but a weakness at some point in the impact pathway. For the most part, sensitivity functions are therefore additive to the core functions, and will be treated as such in the subsequent analysis. Some other functions are provided for sensitivity analysis in order to better illustrate effects that are part of the 'core' assessment, a good example being 'work loss days' attributable to PM exposure.

5.6.3 Impacts included

Like the mortality analysis discussed above, morbidity impacts will be assessed for both PM and ozone. For PM, these will include the effects of acute exposures (day-to-day variations in ambient PM) and of long-term (chronic) exposures. It may be that there are specific adverse effects of long-term exposure to ozone also, but current evidence permits quantification of acute effects only.

- Ambient PM is associated with effects on the cardiovascular system as well as the respiratory system; effects of ozone on morbidity have been shown clearly for respiratory effects only.
- As for mortality, we will quantify effects of anthropogenic PM, without threshold; and effects of ozone above a 'cut-off point' for the analysis of daily maximum 8-hr mean of 35 ppb and, for sensitivity analysis, with no cut-off point.
- *Emergency hospital admissions:* We will quantify effects of daily variations in PM and ozone on (emergency) hospital admissions for respiratory diseases and for PM only on admissions for cardiac disease. In order to link with available data on background rates, we will use all-ages C-R functions and background rates from the EU-funded APHEIS project, whose 3rd report (APHEIS-3) has recently been published, for PM, and for ozone, analysis by COMEAP. Concentration-response (C-R) functions are given by age-group in the WHO-supported meta-analysis of relevant studies in Europe. To a limited extent we will use these in sensitivity analyses.

- *Consultations with primary care physicians:* We will use impact functions for three pathways, but use them for sensitivity analysis only, because the functions are derived from studies in one city only (London) and may not be representative of all Europe:
    - PM and consultations for asthma
    - PM and consultations for upper respiratory symptoms (excluding allergic rhinitis)
    - Ozone and consultations for allergic rhinitis
- Various HIA studies have shown that restricted activity days (RADs) and minor restricted activity days (MRADs), though rarely studied epidemiologically, can make a major contribution to the benefits of reducing air pollution.
    - Using US studies, we have quantified an effect of PM on RADs, for core analyses. These RADs include relatively severe effects (for example when a person is restricted to bed) as well as minorRADs, and so for subsequent valuation, we have attributed the relative proportion of RAD:MRAD.
    - For sensitivity analysis we have also quantified an effect of PM on work loss days (WLDs) and on MRADs. These two are additive to one another but *not* to RADs, with which they overlap.
    - We have also quantified an effect of ozone on MRADs to be used for adults of working age.
    - Sensitivity analyses will explore the effect of extrapolating from adults of working age, to all adults.
- The WHO meta-analysis also provides C-R functions for cough and respiratory medication usage in individuals with underlying respiratory disease. With regard to respiratory medication, we have used the WHO meta-analysis and the papers cited there to identify impact functions both for PM and for ozone, both for adults and for children with asthma. Several of these functions are not statistically significant, but are included for completeness because air pollution is widely recognized as exacerbating asthma.
- We have developed substantially the evaluation of how PM and ozone affect respiratory symptoms. This has led to the following set of impact functions:
    - For PM: lower respiratory symptoms (LRS), including cough, among adults with chronic respiratory symptoms; and LRS (including cough) among children in the general population – both for core analyses
    - For O_3: respiratory symptoms among adults in the general population, and both cough, and LRS excluding cough, among children in the general population.
- There are some additional endpoints for which there is limited evidence of effects of acute exposures and which we may also be able to include in our central analysis.
- We will also include, where practicable, chronic morbidity effects from PM. The most important of these are likely to be effects of PM on chronic bronchitis, using C-R functions and background rates from the US AHSMOG study.
- The main omission is that we have been unable to quantify an effect of long-term exposure to PM on the development or progression of chronic cardiovascular disease - we have been unable to find any suitable studies that would permit quantification.

Functions and further discussion of impacts are provided in Volume 2.

5.7. Valuation of morbidity

The valuation of morbidity draws extensively on a recent empirical study, covering five countries across Europe (Ready et. al., 2004). The pooled results of this study are used where possible. The generic unit costs for hospital-based health care are derived from Netten and Curtis (2000), and MEDTAP International, reported in Ready et al (2004). The costs of absenteeism are based on figures contained in Confederation of British Industry (CBI, 1998). Further details of both sets of costs are provided in Volume 2, as are details of the CSERGE estimates for willingness to pay. Recommended valuations for acute morbidity effects are shown in **Table 7**.

Table 7 – Values for quantification of acute morbidity impacts Source; Ready et al. (2004), with values adjusted to price year 2000.

Effect	**Value**
Respiratory and cardiac hospital admissions	€2,000/admission
Consultations with primary care physicians	€53/consultation
Restricted activity day (average value for working adult)	€83/day
Minor restricted activity day	€38/day
Use of respiratory medication	€1/day
Symptom days	€38/day

For chronic effects on morbidity, a number of US studies exist, but are related to the most severe definition of chronic bronchitis. Based on these, but adjusted to a case of "average severity" by the scalar estimated by Krupnick and Cropper (1992) we derive the following values in the current context:

Low range estimate: €120,000
Central range estimate: €190,000
High range estimate: €250,000

The validity of using these values in CAFE depends on whether the average severity of a case of chronic bronchitis found in the Krupnick/Cropper study is close to how it is defined in the epidemiological literature (or in baseline rates in Europe).

5.8. Conclusions

The CAFE CBA benefits from a series of recent empirical studies that provide a better basis for quantification of health impacts of air pollution in Europe. Outputs from these studies are provided here. More information is available in Volume 2 to this report, which deals solely with health quantification and valuation.

For the most significant endpoints a range of values has been proposed. These will facilitate uncertainty and sensitivity analysis, to be explored once first results are available. This is particularly important in relation to the valuation of mortality, where opinion is split between use of the VOLY and the VSL. .

6. Agricultural and Horticultural Production

6.1. Introduction

Air pollution is recognised both in Europe and the USA as having had a significant influence on agricultural and horticultural production. Based on information presented in Appendix 6, which provides a more complete overview of the effects of air pollution on crop production and methods for their quantification, the following effects have been identified for specific consideration within the CBA (Table 8):

Table 8 – Impacts for detailed quantitative or qualitative consideration in the CAFE CBA, extent of analysis depending on the availability of data

Ozone only • Visible injury to crops • Reduction in crop yield • Interaction with climate • Reduction in livestock production	• Qualitative discussion, possible inclusion in MCA • Quantitative assessment • Included in Level II modelling of effects on crop yield • Qualitative discussion, possible inclusion in MCA
All pollutants	• Qualitative discussion of interactions with pests and pathogens, possible inclusion in MCA

Ozone is recognised as the most serious regional air pollutant problem for the agriculture and horticulture sectors in Europe at the present time. As will be shown, methods for quantification of ozone effects on productivity are still under development, though sufficient knowledge is now available to enable a reasonable estimate of its direct impacts to be made. In other areas (visible injury, interactions between pollutants and pests and pathogens, impacts on livestock production), quantification is not practicable on the European scale. These impacts will instead be addressed using the extended-CBA.

6.2. Quantification of the direct effects of ozone on yield

The quantification needs the following data:

1. Information on stock at risk, in terms of the distribution of crop production, by species, across Europe.
2. Exposure-response functions for different crops, recognising the variability in response between species.
3. Valuation data.

The stock at risk database is currently under development at the Stockholm Environment Institute (SEI) in York and other European Institutes, in a collaborative exercise that will see the adoption of a unified dataset by the main research groups involved. This will be used as soon as it becomes available. Until that time, however, an earlier database developed by SEI, and used in past analysis for ICP Vegetation will be used.

Exposure-response functions for assessment of crop impacts from ozone take two forms. The first, sometimes called a Level I approach, relates yield change to ozone concentration, typically expressed as AOT40, the accumulated exposure to ozone in excess of 40 ppb during the growing season, measured in units of ppb.days. The second type of relationship, sometimes referred to as a Level II approach, seeks to equate yield change not simply to concentration, but to pollutant uptake, by accounting for crop development and climatic conditions. Quantification would ideally be based on Level II functions, but such functions are currently only available for wheat and potato. Although wheat and potato are very important crops, together they comprise only about 10% of European agricultural production. It is thus desirable that a more comprehensive analysis is undertaken. The most reliable way of doing this at the present time would seem to be adaptation of the flux based functions for wheat and potato based on relative sensitivity of other crops according to available AOT40 data. Table 9 reproduces one view of relative sensitivity, taken from Mills et al (2003) and cited in the current version of the mapping manual (ICP/MM, 2004).

Table 9 – The range of sensitivity of agricultural and horticultural crops to ozone with reference to AOT40 data (see Mills et al, 2003 for response functions)

Sensitive (Critical Level ≤ 5 ppm.h)	**Moderately sensitive (Critical Level of 5 – 10 ppm.h)**	**Moderately resistant (Critical Level of 10 - 20 ppm.h)**	**Insensitive (Critical Level >20 ppm.h)**
Cotton, Lettuce, Pulses, Soybean, Salad Onion, Tomato, Turnip, Water melon, Wheat	Potato, Rapeseed, Sugarbeet, Tobacco	Broccoli, Grape, Maize, Rice	Barley, Fruit (plum & strawberry)

Readers should consult chapter 3 of ICP/MM (2004) for more complete details of the functions and other information provided here. The caveats given in that report have been noted by the authors of this paper, though are not reproduced here.

The valuation of impacts on agricultural production is reasonably straightforward, with estimated yield loss being multiplied by world market prices as published by the UN’s Food and Agriculture Organization. World market prices are used as a proxy for shadow price on the grounds that they are less influenced by subsidies than local European prices (in other words, they are closer to the ‘real’ price of production).

In the event that impacts were large enough to change decisions that farmers take regarding the types of crop under production it would be desirable to perform analysis of the agricultural sector *per se*, rather than just production of a series of individual crops. However, there is very limited evidence that this is currently the case, with other environmental and social variables likely to have a much greater impact on agriculture than air pollution.

6.3. Possible future changes to the methodology for agriculture

Some refinement of methods will be made when the results of another contract funded by UK DEFRA become available in early 2005. This will consider the uncertainties in flux based modelling and AOT40 type modelling, and thus the reliability of methods for extrapolating from one to the other.

7. Materials

7.1. Types of impact

Air pollution is associated with a number of impacts on materials:

- Acid corrosion of stone, metals and paints in 'utilitarian' applications;
- Acid impacts on materials of cultural merit (including stone, fine art, and medieval stained glass, etc.);
- Ozone damage to polymeric materials, particularly natural rubbers;
- Soiling of buildings and materials used in other applications.

Of these, monetary quantification has been carried out for all groups in previous studies, though economic assessments of impacts on cultural heritage are very limited, and do not exist at the European scale. An alternative approach for informing decision makers that has been developed by ICP Materials is based on assessment of 'acceptable rates' of deterioration, on the basis that materials left in the open air will be damaged even in the absence of air pollution. This approach is discussed in more detail below, though of course the concept of an 'acceptable rate' begs the question of what is acceptable.

This section provides an overview of the methods to be used for appraisal of impacts on materials in the CAFE CBA. A more complete account is given in Appendix 7.

7.2. Acid damage to materials in 'utilitarian' applications

This section deals with damages to materials in utilitarian applications, in other words, those used in buildings, etc., of no special cultural merit. This would include most modern houses, factories, railway buildings, etc. Work by ICP Materials shows that the pollutants most implicated in acid damage are SO_2 (most importantly), H^+ and then NO_2.

7.2.1 Framework for assessment

Assessment of acid damage to building materials in everyday applications uses the following framework, which is broadly similar to that described elsewhere in this paper:

1. **Describe the stock-at-risk** in terms of the exposed area of sensitive materials on buildings and other structures within each country. CAFE uses stock-at-risk data collected in a number of studies, particularly Hoos *et al* (1987), Tolstoy *et al* (1990), Kucera *et al* (1993 a,b), ExternE (1995, 1999a) and Ecotec (1996). These studies provide data for individual cities or countries in both eastern and western parts of Europe. Careful consideration has been given to extrapolation of the results of these inventories to parts of Europe for which data would not otherwise exist. The error arising from this extrapolation is not significant in the overall context of the CBA.
2. **Describe background pollution levels**, an issue that is particularly important for material damages because of non-linearities in exposure-response functions. These data are obtained from the EMEP model.
3. **Describe climatic variables relevant to the response functions**. Again, EMEP provides data for this part of the analysis.

4. **Apply material-specific response functions that provide estimates of the rate of corrosion, etc**.; Functions have been taken from the ICP Materials (2003) website, based on exposures over an 8 year period (1987 to 1995). The most important for the CAFE assessment are likely to be those relating to steel, zinc and stone (limestone and sandstone), and application for mortar and rendering.
5. **Assess rate of deterioration against a critical loss of material to define change in maintenance or replacement frequency**. The critical thickness is defined as the amount of material that would need to be lost or damage at the surface to initiate maintenance or repair at the most economically optimal time. For some material-application combinations critical thickness is easily defined: for galvanised steel, for example, the critical thickness is equal to the depth of the protective zinc coating. For other material-application combinations (e.g. stone, mortar) assessment of the critical thickness is more subjective, though estimates made in the ExternE programme (1995a, 1999a) seem to have stood the test of time.
6. **Valuation.** This is based on standard maintenance cost data from reference sources used by builders and architects.

Uncertainties are discussed in Appendix 7. They seem unlikely to make a significant impact on the overall CBA.

7.3. Acid damage to cultural heritage

Corrosion of cultural heritage from acid rain leads to irreversible damage as restoration will never be able to give us the undamaged originals. It is, unfortunately, not possible to quantify damages to cultural heritage in the same way as for materials in utilitarian applications because of a lack of data on stock at risk and restoration and other costs. However, some information is available, for example, valuation studies of cultural heritage that show that people place a significant economic value on cultural heritage (see the review by Navrud and Ready, 2002). A listing of such data sources is provided in Appendix 7. These data can be used in the extended-CBA to illustrate the potential significance of damage to cultural heritage in the CAFE context. The extended CBA will highlight the risks faced by cultural heritage across Europe in a manner that provides decision makers with a better understanding of the current and future situations.

7.4. Ozone damage to polymeric materials

Although ozone is a major determinant of the lifetime of many rubber materials exposed to the ambient air, only two European studies have investigated the problem from an environmental perspective. Lee et al (1996) estimated annual damages to the UK of £170 to £345 million for impacts on surface coatings (paints) and elastomers and the cost of anti-ozonant protection used in rubber goods. These estimates were based on US data from the late 1960s, demonstrating the dearth of information in this area. Lee's work served as a scoping study for a larger project (Holland et al, 1998) that undertook experimental assessments of a range of paints, representative of those in use in the UK market, and rubber formulations.

The analysis on paint found it unlikely that there would be significant ozone-induced damage during the expected service lifetime of the paint, though the possible effects of interactions of ozone with other environmental stresses in damaging paints were not addressed. In contrast, damage to rubber goods from ozone exposure in the UK was estimated at between €51 and

€270 million, with a best estimate of €120 million/year. The effect of a 1 ppb change in ozone was estimated at €5.8 million/year. This estimate can be used to make a rough estimate of ozone damage to rubber products for the CAFE CBA work. Whilst it would not be possible to develop inventories for the whole of Europe under this project, it may be appropriate to extrapolate the UK result based on the size of each country's vehicle fleet (the motor industry dominates rubber product utilisation) using the following expression:

$$Damage / ppb\_change\_in\_O_3 = €5.8 million \times \frac{vehicles\_in\_country\_x}{vehicles\_in\_the\_UK}$$

The use of this function is clearly an approximation. However, it seems unlikely that associated uncertainties will be significant in the context of the overall CBA.

7.5. Soiling of buildings

Soiling of buildings by particles is one of the most obvious signs of pollution in urban areas. The soiling of buildings includes both "utilitarian" and historic buildings and causes economic damages through cleaning and amenity costs. Soiling is an optical effect (a darkening of reflectance) and results primarily from the deposition of airborne particulate matter to external building surfaces. The factors which can affect the degree of soiling are well known and include (QUARG, 1996): the blackness per unit mass of smoke; the particle size distribution; the chemical nature of the particles; substrate-particle interfacial binding; surface orientation; and micro-meteorological conditions.

Different types of particulate emission have different soiling characteristics. For example, diesel emissions have a much higher soiling factor relative to petrol or domestic coal emissions factors (Newby *et al*, 1991; Mansfield *et al*, 1991) due to their particulate elemental carbon (PEC) content (QUARG, 1993). Diesel emissions are the main source of atmospheric PEC in Western Europe.

Although soiling damage has an obvious cause and effect, the quantification of soiling damage is not straightforward. For CAFE a number of different approaches and functions have been considered. Friedrich and Bickel (2001) concluded that a model proposed by Pio et al. (1998) looked most promising, but the function has proved difficult to implement in practice. As a result, a simplified approach is often used that quantifies soiling damage based on cleaning costs (in the absence of WTP data). Rabl et al (1998) extended this to quantify total soiling costs (i.e. the sum of cleaning cost and amenity loss), and Rabl's work will be used as the basis for quantification of soiling damage in the CAFE-CBA. Quantification and valuation of soiling will be carried out for urban emissions only.

As for other impacts of air pollution on materials, further information is available in Appendix 7.

7.6. Future improvements to the methods presented here

1. The most immediate improvement is likely to concern the response functions used here, as these are being reviewed under the EC's Multi-Assess Project. This is expected to report by April 2005. Any changes suggested at that time will be incorporated into the CAFE CBA methodology.
2. Improvement of methods for quantification of damages to cultural heritage will not be made sufficiently quickly for inclusion in the CAFE programme. However, new data emerging from Multi-Assess and other projects will be reviewed for inclusion in the framework of the extended CBA.

8. Ecosystems

8.1. Types of impact

Pan-European action on air quality goes back to the 1970s following the surprise finding that soils in remote areas in Scandinavia were acidifying. The only explanation for these observations was that the problem was caused by long range transport and deposition of acidic pollutants generated in other parts of Europe.

The clearest effect of this long range deposition was probably the loss of salmon and trout from a large number of acidified rivers and streams in northern Europe.

Observations in the Black Triangle between Poland, and the former Czechoslovakia and German Democratic Republic focused concerns about air pollution's links to forest decline which had been seen previously in the English Pennines around industrial cities and in the Ruhr in Germany. Forest decline of this type was clearly linked to emissions of SO_2, and was severe in its impact, though restricted in range to a region of very high SO_2 emission, as opposed to an effect of long-term and long-range deposition. In locations more remote from major sources of emissions unusual symptoms were becoming evident on silver fir, Norway spruce, Scots pine, beech and other species. Declines were also noted in North America, raising concerns about the role of ozone in European forest decline.

A large research effort was mounted to investigate the linkage of air pollution to these forest declines, including initiation of the pan-European forest health surveys. Together with work on other semi-natural terrestrial ecosystems and on freshwater ecosystems this research provided a basis for defining critical loads[13] for both acidification and eutrophication from airborne sources of pollution. However, definition of the precise role of air pollution in the observed forest declines remained elusive, as understanding of the various other stresses faced by forests increased.

Ecological sensitivity to air pollution is seen as being greatest in (semi-) natural vegetation, then forests, and least in crops. This ranking reflects many things, not least the level of human influence over genetic selection and also over processes affecting the soil and growth.

The effects of acidification and eutrophication can be expressed in general terms as causing ecological changes, which may be subtle (as in changes in the relative abundance of species in a particular ecosystem) or obvious (as in the elimination of salmon and trout from rivers and streams). Whilst air pollution should be seen as only one of a number of stresses that affect ecosystems in Europe, a reduction in pollutant emissions will reduce stress on ecosystems, which will assist in halting biodiversity decline. ICP/MM (2004) reports on numerous studies showing negative impacts in the performance of species in natural ecosystems. These impacts (e.g. a reduction in shoot growth or the amount of seed produced) should not of course be seen in isolation, as they affect the ability of species to maintain their status in ecosystems.

---

[13] Critical loads are defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to current knowledge. The sensitivity of different areas is variable, reflecting local conditions such as the availability of base cations in the soil that can neutralise acid inputs.

Risk is not spread evenly across Europe. For acidification the most sensitive areas tend to be those that receive high rainfall (through its effect on deposition rate) and where the bedrock (e.g. granite) weathers slowly and hence releases neutralising base cations at a rate that may be insufficient to match acidifying inputs. For eutrophication the most sensitive areas will again be those subject to high rainfall, but also areas that are naturally low in nitrogen. Ecosystems in these locations and the organisms that they contain have evolved specifically to cope with limited nutrient availability. Additional nutrient inputs enable other species (for example, some of the common grasses) to access areas in which they would previously have struggled to survive, or to grow much more strongly than they were previously able to, out-competing other less aggressive species, leading to changes in biodiversity.

Effects of ozone on natural ecosystems have also been noted (see ICP/MM 2004 for review material in the mapping manual).

8.2. Stock at risk data

Stock at risk data for ecosystem impacts has been collated over a period of many years through the Coordination Center for Effects in the Netherlands. This is already linked into the RAINS database, and no additional information will be required.

8.3. Exposure-response functions

Using methods agreed with the CCE (and hence already subject to extensive discussion with ecological experts across Europe) RAINS quantifies critical loads exceedance for acidification and eutrophication in terms of:

- Area in each country where ecosystems are exceeded;
- Accumulated exceedance of critical loads;
- Damage and recovery delay times.

Key references for this work are the papers by Hettelingh et al (2001) and Posch et al (2001). The recently-finalised guidance from ICP/MM provides the latest consensus on characterising exceedance.

Ideally it would be possible to go beyond this, to describe impacts on different types of ecosystems in terms, for example, of effects on the abundance of different species across Europe, and recovery of ecosystems once critical loads are not exceeded. However, whilst information from the literature provides insight on the types of effect that may be anticipated, there is a lack of information at the present time for going beyond this. Some case studies have been carried out (e.g. Hornung et al’s, 1995 study of trout densities in some Welsh streams, following from Ormerod, 1990), but these tend to require further validation and cannot be extrapolated to the general European situation. The major problems for quantification lie in the need to account for effects over very prolonged timescales and the variability of conditions pertaining to climate, soil, the species that are present, ecological structure, human pressures and so on.

It is thus proposed that the CAFE CBA does not go further in quantifying ecological impacts outside of agriculture than simply using the results from RAINS regarding the area over which critical loads are expected to be exceeded and accumulated exceedance. Results will, however, be fed into the extended CBA in order to assist stakeholders put effects on ecosystems in context against those effects for which a full appraisal is possible.

8.4. Valuation of ecosystem damages

In theory, it would be possible to go straight from critical loads or critical levels exceedance to valuation, were suitable data available from willingness to pay studies. Although the literature in this area is growing (see Appendix 8), it is not currently adequate for a Europe-wide appraisal such as this. Earlier studies tended to take a very simplistic perspective of impacts on ecosystems rendering them unsuitable for use in a policy context. More recent data can, however, be used within the extended-CBA to demonstrate whether available research suggests that impacts on ecosystems will be economically important in the context of the CAFE Programme.

8.5. Ozone and forest damage

One area where there is potential for short term success in quantification of the monetary value of pollution damage relates to ozone effects on forests. Karlsson et al (2004) investigated the response of a forest stand in Sweden to predicted ozone concentrations and found that they had the potential to reduce forest growth by 2.2% and economic returns by 2.6%. Extrapolating this to the national level provides an overall estimate of lost forest production of €56 million per year in response to ozone exposure.

This information will be used in the extended CBA, demonstrating that across Europe these damages to forest production (note: specific to timber and pulp production and not to other benefits provided by forests) are likely to be of the order of a few hundred million euro.

A more in-depth analysis using the same methodology across Europe, capable of providing input to the core quantification, will not be undertaken, given the complexities of modelling forest growth over decades and of forecasting trends in forest management practices in response to changing supply of timber and demand.

9. Other Impacts

9.1. Social effects

There are several issues to take account of here:

1. Variation of exposure to air pollution amongst communities who rate poorly on social deprivation indices (King and Stedman, 2000; Pye, 2001).
2. Variation in susceptibility of different groups to health impacts. Krewski et al (2000); Hoek et al (2002) and Pope et al (2002) have observed links between air pollution impacts and low educational attainment. Abbey et al (1999) and Brunekreef (1999) found higher susceptibility to air pollution effects amongst subjects with poorer nutrition.
3. The ability of individuals to mitigate impacts, for example through the purchase of medicines and access to good quality health care or routine maintenance of buildings.

It may be that other issues should be added to the list provided here – we are unaware of previous reviews in this area, though there is work that deals with some of the elements that are identified.

The assessment of links between air pollution impacts and social deprivation under CAFE will be limited quantitatively because of a lack of data. There are several reasons for this:

1. Systems for reporting social deprivation will vary from country to country;
2. There is a lack of information on:
    a. How the various elements that make up indices of social deprivation are linked to air quality;
    b. How the health of groups that differ in social deprivation responds to changes in air quality (as opposed to the population as a whole);
    c. Response to air pollution effects amongst different groups in the community.
3. The analysis would require data at a much higher resolution than is currently available;
4. Analysis at the required resolution on a European scale would be extremely time consuming, even if data were available.

Requests for more data on links between social deprivation and air pollution have been made to numerous groups by the CBA Team since October 2003, with no response. In view of this we conclude that there is no data to add to that described in earlier draft reports. Given that this is insufficient for quantification purposes it is appropriate that these types of social effect should be considered through the framework of the extended CBA.

To go further in the analysis of social effects would require additional research beyond what is possible within CAFE. The one area where progress could be made in the short term relates to quantification of the expected incidence of the predicted change in pollution exposure and associated health effects using the results of the Krewski study. This will be incorporated within the datasheet on social effects developed for the extended CBA, to show the increased risk faced by some groups of the population.

In describing impacts on equality it is important not to be too alarmist about the role of air pollution in determining social disadvantage as other factors are far more important in this respect (education, structure of welfare systems, etc.). However, it is clear that there are reasons for some concern, and that these should therefore be factored into the CAFE process through commentary, as appropriate.

Some caution is needed with respect to possible response to inequalities. Even if links were strong it would not necessarily be appropriate to target air quality improvement measures specifically on the socially disadvantaged. This could lead to the selection of generally less cost-effective measures, with the consequence that the overall change in population exposure, including exposure of the more vulnerable groups, is less than that achievable without any attempt to account for the more disadvantaged.

9.2. Macroeconomic impacts

The macroeconomic impacts of most interest to the CAFE Programme are effects of measures to reduce air pollution on competitiveness and unemployment. These will be assessed using the GEM-E3 Model, which has been used on a number of occasions already for European policy support (e.g. Capros et al, 1997a,b; Kouvaritakis, et al 2003). This section provides an overview of the model, and comments on its use as part of the CAFE cost-benefit analysis. A more detailed account of the model is given in Appendix 9.

9.2.1 The model

The GEM-E3 model is an applied general equilibrium model, simultaneously representing World regions or EU countries, linked through endogenous bilateral trade. It investigates interactions between the economy, the energy system and the environment (hence the reference to ‘E3’ in the model name).

GEM-E3 allows evaluation of the macroeconomic impact of the environmental policies foreseen in the CAFE project and their distributional effects across countries, economic sectors and agents. The model will permit analysis of:

- the impact on employment and domestic production in the different EU countries,
- the competitiveness and terms of trade impact between EU countries and relative to the Rest of the World, both overall and at sectoral level
- the impact on GDP and welfare, inclusive the environmental benefits
- the impact on emissions and air quality, inclusive of transboundary impacts.

Results can be provided for each EU country separately and for the EU as whole.

The model and its database were updated in 2004 and extended to 8 New Member States (Hungary, Poland, Slovenia, Estonia, Latvia, Lithuania, Czech Republic and Slovakia).

9.2.2 Integration of GEM-E3 with other CBA analysis

The main questions to be addressed through the use of the GEM-E3 model concern:

- Will the air quality improvement policies investigated in CAFE lead to reduced competitiveness for European economies?
- Are these policies likely to have a significant effect on employment across Europe?

It is not intended to convert results on either into a metric that could be combined directly with quantified impacts on health, agriculture, etc, to give a total benefit for comparison with the RAINS-generated cost information. Instead, the GEM-E3 results will be used to provide an indication of the likely direction and magnitude of effects of air quality improvement policies in these areas. If macro-economic effects appear to be significant it could be appropriate to adjust policies or to investigate further before finalising recommendations.

The resolution of the model is not sufficient to permit investigation of the effects of small changes in policy. Instead, the model will be run for a series of scenarios representing a reasonable range of 'ambition levels', for example:

- Baseline with or without climate policies;
- Maximum feasible reduction (MFR);
- A point midway between baseline and MFR;
- In some cases, analysis also for different years (e.g. 2010, 2015, 2020).

The need for additional analysis will be considered once conclusions are reached on the initial model runs.

9.3. Visibility

Analysis in the USA has concluded that reduced visibility is a significant impact of air pollution (USEPA, 1997). The word 'visibility' in this context relates to a reduction in visual range caused by the presence of air pollutants in the atmosphere. The problem is associated largely with particles and NO_2. At pollutant levels typical of Europe and North America this can lead to impacts on amenity in terms of reduced enjoyment of landscapes.

In Europe, the association of air pollution with reduced visibility has received very little attention. There are several possible reasons for this. Perhaps the most important is that there have been significant improvements in visibility already across much of Europe. In London, for example, sunshine hours in January doubled in the 20 years that followed the adoption of the UK's first Clean Air Act in 1956 (Chandler and Gregory, 1976), and air pollution in the city has continued to improve since.

Following review of quantification methods for visibility impacts it was concluded that there was an inadequate base of European data on which to base a credible assessment. The peer reviewers supported this position. Amongst the stakeholders who commented on drafts of the methodology report some supported, none actively disagreed. The impact will not therefore form part of the core analysis for the CAFE CBA, but will be dealt with through the extended-CBA.

9.4. Climate change

9.4.1 Relevance of climate change impacts to CAFE

Climate change is of course not the primary concern of CAFE. However, many of the measures that could be introduced to further control air pollution will have an effect on greenhouse gas emissions:

- Reductions in emissions of the main greenhouse gases will arise (for example) through falls in energy demand via measures that improve energy efficiency or promote less polluting modes of transport;
- Increases in greenhouse gas emissions may also arise (for example) through the use of end-of-pipe pollution controls that require some energy input.

Consideration of these effects is clearly necessary in order that understanding of the links between local and regional air pollution policy, and climate policy are understood. This, in turn, will highlight areas where additional control opportunities exist, and, equally, areas where there needs to be a trade-off between global and regional policy.

9.4.2 Quantification of effects on greenhouse gas emissions in CAFE

The PRIMES and RAINS models will quantify the effect of CAFE policies on emissions of the main greenhouse gases.

9.4.3 Treatment of changes in greenhouse gas emissions in the CBA

Treatment of the effect of the CAFE Programme on greenhouse gas emissions has to be seen in the context of climate policy more generally, particularly in relation to the EU response to the Kyoto Protocol.

For the CAFE CBA analysis, it is appropriate to consider how air pollution reduction measures would change the costs of meeting existing climate change targets. In some cases air pollution reduction (e.g. through increase efficiency of production methods) would reduce the compliance costs in reducing greenhouse gas emissions. In some other cases (e.g. using energy to abate pollution) compliance costs would increase.

The data needed, therefore, are the marginal costs of meeting climate objectives for various years in the future, rather than damage costs such as those generated by ExternE (1999b).

Analysis by European Climate Change Programme (ECCP) working groups in June 2001 identified 42 possible measures, which were estimated to reduce emissions by 664-765 MtCO_2 for a cost of less than 20€/tonne CO_2eq. In a study that underpinned the ECCP[14] process it was found that the EU-15 would be able to comply with its –8% greenhouse gas reduction target at a marginal cost of €20/tCO_2 eq. Given that the enlargement of the EU has given a possibility of lowering compliance costs, and given that through Joint Implementation and Clean Development Mechanism projects it is possible to reduce compliance costs, the Climate Change Unit of DG Environment advised the CAFE programme to apply the following compliance costs

Table 10 – Assumed compliance cost to reduce a tonne of CO_2 equivalent in 2010, 2015 and 2020 in the CAFE CBA calculations

2010	2015	2020
€12 /tonne CO_2 eq	€16 /tCO_2 eq	€20 /t CO_2eq

[14] Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change available at http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

9.5. Effects of CAFE measures on emissions of other pollutants

The measures adopted for further control of air pollution in Europe may affect emissions of a wider range of pollutants than those considered core to CAFE and climate policy (see Section 9.4). These may include PAHs, heavy metals, dioxins, CO and benzene, depending on the abatement techniques adopted and sources addressed. Past CBA work on these pollutants under the Air Quality Framework Directive (AEA Technology, 1999; 2001; Entec, 2001) suggests that benefits of control are less significant than for the main CAFE pollutants. Detailed quantification does not, therefore, seem appropriate. However, the issue will be kept under review through the extended CBA. If necessary it may be appropriate to recommend that further detailed analysis is undertaken outside of the CAFE CBA.

9.6. Effects on groundwater quality and drinking water supply

Recent research in the Netherlands (van der Velde et al, 2004) has investigated the benefits arising from reduced acidification in terms of:

- Lower costs for treatment of groundwater;
- A longer life time for wells, pipelines and other hardware;
- Lower maintenance costs for wells and pipelines;
- The benefits for the water treatment are negligible due to the low margins (WP/NP) in the groundwater.

In total a net present value of €45 million was estimated for the benefits to the Netherlands for the period 1990 to 2040. Benefits may increase significantly if the time frame were to be extended, though the total benefit appears too small to have major consequences in terms of the CAFE CBA.

The authors of the paper discuss possible benefits in the rest of Europe and conclude that they could be much higher than in the Netherlands. Reasons for this were that other countries make more use of vulnerable materials (e.g. cast iron) in wells and water delivery systems, and often make more use of resources where the travel time of water is short (e.g. surface waters).

This effect will be considered in the extended CBA, though it will be concluded that it is unlikely to make a significant contribution to total benefits. Each country should consider the applicability of the findings of the Dutch research within their own boundaries. The CBA team would be pleased to receive further information, particularly if any country believes that this effect is more significant than suggested by van der Velde et al.

10. Summary

This report provides an overview of the methodology to be used for quantification of the benefits of measures considered under the CAFE Programme, and for comparison of costs and benefits.

Quantification of impacts and monetisation should ideally follow the impact pathway approach, as it traces a logical and sequential path from cause to effect. Application of this approach is limited by the availability of data, for example on stock-at-risk, exposure-response and valuation. Hence, whilst it is possible to quantify some damages to health, crops and materials, it is not possible to quantify all impacts. Fortunately, there are grounds for believing that the impacts that can be quantified are amongst the most significant. However, some impacts that are omitted from quantification are important, the most obvious omission being effects on ecosystems from deposition of acidifying pollutants and nitrogen.

With this in mind, an extended CBA method has been defined to help put unquantified effects in context with those that are quantified. The extended CBA will describe impacts, assess the strength of links between pollutants and effects, and consider whether each of the effects of air pollution that cannot be quantified are likely to be significant when compared to those effects that can be quantified – in other words, whether they are likely to affect the balance of costs and benefits. This represents a major advance in air pollution CBA methodology, as unquantified effects have previously been almost ignored from the final analysis. The extended CBA will also be used to develop better understanding of the effects that can be quantified – understanding of a number of morbidity effects, such as ‘lower’ and ‘upper’ respiratory symptoms, could no doubt be improved by straightforward descriptions of impacts.

Attention has also been given to the way in which uncertainties will be reported in the CBA. This is a complex part of the analysis, because different types of uncertainty need to be treated in different ways. We have already discussed the way that omitted effects will be treated through the use of the extended CBA. Further elements of the uncertainty analysis include:

- Assessment of any systematic biases in both costs and benefits;
- Quantification of statistical uncertainties;
- Sensitivity analysis, based on key parameters such as approaches to valuation of mortality.

Section 9 included a number of impacts that were largely excluded from past analysis of the Gothenburg Protocol and NEC Directive:

- Social effects;
- Macroeconomic effects on e.g. employment and competitiveness;
- Attainment of greenhouse gas emission targets;
- Effects on the quality and supply of groundwater.

Although quantification will be limited for these effects, sufficient information should be obtained to enable them to be placed in context against other (quantified) impacts.

The following reports will further document the methodological issues of the CAFE CBA:

- Health Impact Assessment (Volume 2) to be released in January 2005.
- Uncertainty assessment, with worked examples (Volume 3) to be released by mid-February 2005.

These reports, as well as the forthcoming, datasheets for the extended-CBA and the results of cost-benefit analysis of the CAFE scenarios will give further illustration of the methods outlined in this report..

11. References

Abbey DE, Petersen F, Mills PK, Beeson WL. (1993). Long-term ambient concentrations of total suspended particulates, ozone and sulfur dioxide and respiratory symptoms in a non-smoking population. Arch Env Health; 48: 33-46.

Abbey DE, Hwang BL, Burchette RJ, Vancuren T, Mills PK. (1995a). Estimated long-term ambient concentrations of PM10 and development of respiratory symptoms in a nonsmoking population. Arch Env Health; 50: 139-152.

Abbey DE, Ostro BE, Petersen F, Burchette RJ (1995b). Chronic respiratory symptoms associated with estimated log-term ambient concentrations of fine particulates les than 2.5 micron in aerodynamic diameter (PM2.5) and other air pollutants. Journal of Exposure Analysis and Environmental Epidemiology; 5 (2): 137-159

Abbey, D.E. et al (1999) Long-term inhalable particles and other air pollutants related to mortality in nonsmokers. American journal of respiratory and critical care medicine, 159: 373-382.

Adams, R.M., Hamilton, S.A. and McCarl, B.A (1985) An assessment of the economic effects of ozone on US agriculture. Journal of the Air Pollution Control Association, 35, 938-943.

AEA Technology (1996) Cost-benefit analysis of the draft directive on the incineration of non-hazardous waste. Contract report for DGXI of the European Commission.

AEA Technology (1998) Economic Evaluation of Proposals for the Emission Ceilings Directive. Contract Report for DGXI of the European Commission.

AEA Technology (1999) Economic evaluation of air quality limits for CO and benzene. Contract report for European Commission DG XI. http://www.europa.eu.int/comm/environment/enveco/studies2.htm#7

AEA Technology (2000) Economic Evaluation of PVC Waste Management. Contract report for European Commission DG Environment, Brussels, Belgium.

AEA Technology (2001) Economic Evaluation of Air Quality Targets for PAHs. Report for European Commission DG Environment. http://www.europa.eu.int/comm/environment/enveco/studies2.htm#PAHs

AEA Technology (2002) Estimates of marginal external costs of air pollution in Europe. http://europa.eu.int/comm/environment/enveco/studies2.htm#Marginal external costs air pollution.

Agee, M.D. and Crocker, T.D. (2001), “Smoking Parents’ Valuations of Own and Children’s Health”, Paper presented at the Association of Environmental and Resource Economists conference, Bar Harbor, Maine, June 13-15, 2001.

Alcamo, J. and Bartnicki, J. (1990) The Uncertainty of Atmospheric Source-Receptor Relationships in Europe. Atmospheric Environment **24A**(1990): 2169-2189.

Amann, M. et al (2004) The RAINS Review.

Bak, J. and Tybirk, K. (1998) The EU Acidification Strategy: Sensitivity of Calculated Emission Ceilings for Nitrogen and Sulphur for Denmark. Environmental Pollution **102**: 625-633.

Bobak M (2000): Outdoor air pollution, low birth weight and prematurity. Environ Health Perspect 108: 173-176.

Bobak M, Leon DA (1992): Air pollution and infant mortality in the Czech Republic, 1986-88. Lancet 340: 1010-1014.

Bobak M, Leon DA (1999): The effect of air pollution on infant mortality appears specific for respiratory causes in the postneonatal period. Epidemiology 10: 666-670.

Bobak M, Richards M, Wadsworth M (2001): Air pollution and birth weight in Britain in 1946. Epidemiology 111: 207-216.

Brunekreef, B. All but quiet on the particulate front. American journal of respiratory and critical care medicine, 159: 354-356 (1999).

Capros et al (undated) The GEM-E3 Model: Reference Manual. http://gem-e3.zew.de/geme3ref.pdf

Capros P., T.Georgakopoulos, S. Zografakis, S. Proost, D. Van Regemorter, K. Conrad, T. Schmidt, and Y. Smeers (1996): "Double Dividend Analysis: First results of a general equilibrium model linking the EU-12 countries", in C. Carraro and D. Siniscalco (editors) *"Environmental Fiscal Reform and Unemployment"*, Kluwer Academic Publishers.

Capros P., T.Georgakopoulos, D. Van Regemorter, D. Willenbockel (1997a): *"Aggregate results of the Single market Programme"*, joint publication of the Publication office of the European Commission and Kogan Page publishers (forthcoming). Concluding volume of the "Single Market Review 1996" series of publications.

Capros P., T.Georgakopoulos, S. Zografakis, D. Van Regemorter, S. Proost (1997b): "Coordinated versus uncoordinated European carbon tax solutions analysed with GEM-E3 linking the EU-12 countries", in S. Proost (editor) *"Economic Aspects of Environmental Policy"*, forthcoming in Edward Elgar Publishers.

CBI (1998) Missing out: 1998 absence and labour turnover survey. Confederation of British Industry, London.

Chandler, T.J. and Gregory, S. (1976) The Climate of the British Isles. Longman, London.

CONCAWE (1999) EU oil refining industry costs of changing diesel and gasoline fuel characteristics. http://www.concawe.be/Download/Reports/Rpt_99-56.pdf

CSERGE (1999) Benefits Transfer and the economic valuation of environmental damage in the European Union with special reference to health. CSERGE (Centre for Social and Economic Research on the Global Environment), IOS-NLH, IVM, CAS and DAE-UoV.

Defra (2004) Valuation of health benefits associated with reductions in air pollution: Final Report. Department for Environment, Food and Rural Affairs, London.

Duerinck, J. (2000) Statistical Properties of National Emission Reduction Cost Functions. Pollution Atmosphérique **Octobre 2000**: 59-62.

EAHEAP (2000) Economic Appraisal of the Health Effects of Air Pollutants. For the Department of Health, London. http://www.doh.gov.uk/airpollution/ecomain.htm .

EC DG ENV (2000) Papers on the valuation of mortality, from a workshop convened by the Commission in November 2000. http://www.europa.eu.int/comm/environment/enveco/others/value_of_life.htm

Ecotec (1996). An evaluation of the benefits of reduced sulphur dioxide emissions from reduced building damage. Ecotec Research and Consulting Ltd., Birmingham, UK.

Entec (2001) Economic Evaluation of Air Quality Targets for PAHs. Report for European Commission DG Environment.

ExternE (1995a) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 2, Methodology. Prepared by ETSU and others.

ExternE (1999a) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 7, Methodology: Update 1998. Holland, M.R. and Forster, D. (eds.).

ExternE (1999b) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 8, Global Warming. Eyre, N.J., Downing, T., Hoekstra, R., and Rennings, K., with contributions by Tol, R.

ExternE (1999c) DGXII (JOULE Programme) Externalities of Energy, ExternE Project, Report Number 10 National Implementation. Edited by CIEMAT, Spain.

Ezzati, M., Lopez, A., Rodgers, A., van der Hoorn, S., Murray, C.J.L. and the Comparative Risk Assessment Collaborating Group (2002) Selected major risk factors and global and regional burden of disease. The Lancet, **360**, 1347-1360.

Friedrich, R. and Bickel, P. (eds) (2001) Environmental External Costs of Transport (2001). Authors: Schmid, S., Bickel, P., Friedrich, R., Krewitt., Watkiss, P., Holland, M., et al. Published by Springer, 2001. ISBN 3-540-42223-4. Springer Verlag Berlin Heidelberg 2001.

Hammitt, J.K. and J.T. Liu. 2004. Effects of Disease Type and Latency on the Value of Mortality Risk. *Journal of Risk and Uncertainty* 28: 73-95.

Hanley, N. and C.L. Spash, Cost benefit analysis and the environment, Hants: Edward Elgar Publishing Limited (1993).

Haynie, F.H. (1986). Atmospheric Acid Deposition Damage due to Paints. US Environmental Protection Agency Report EPA/600/M-85/019.

Hoek, G. et al (2002) The association between mortality and indicators of traffic-related air pollution in a Dutch cohort study. Lancet, 360: 1203 – 1209.

Holland, M.R., Haydock, H., Lee, D.S., Espenhahn, S., Cape, J.N., Leith, I.D., Derwent, R.G., Lewis, P.M., Falla, N.A.R. and Mower, K.G. (1998) The effects of ozone on materials. Contract report for the Department of the Environment, Transport and the Regions.

Holland, M.R., Forster, D. and King, K. (1999) Cost-Benefit Analysis for the Protocol to Abate Acidification, Eutrophication and Ground Level Ozone in Europe. Report Number: Air and Energy 133, Ministry of Housing, Spatial Planning and Environment (MVROM), Directorate Air and Energy, ipc 640, P.O. Box 30945, 2500 GX The Hague, The Netherlands.

Holland, M.R., Mills, G., Hayes, F., Buse, A., Emberson, L., Cambridge, H., Cinderby, S., Terry, A. and Ashmore, M.R. (2002) Economic assessment of crop yield losses from ozone exposure. Contract EPG 1/3/170, UK Natural Environment Research Council, as a contribution to the UNECE International Cooperative Programme on Vegetation. http://www.airquality.co.uk/archive/reports/cat10/final_ozone_econ_report_ver2.pdf .

Hoos, D., Jansen, R., Kehl, J., Noeke, J., and Popal, K. (1987). Gebäudeschäden durch Luftverunreinigungen - Entwurf eines Erhebungsmodells und Zusammenfassung von Projektergebnissen. Institut für Umweltschutz, Universität Dortmund, 1987.

Hornung, M. and Jones, H. (1999) Impacts on Terrestrial Ecosystems. Chapter 13 of ExternE, 1999a.

Hornung, M. et al (1995) Effects of acidification on recreational fisheries. Chapter 7 of ExternE, 1995a.

Hurley, J.F., Holland, M. R., Markandya, A., Miller, B.G., Anderson, H.R., Ayres, J.G., Donnan, P.T., Harrison, R.M., King, K., Stedman, J. and Stevenson, K. (2000) Towards assessing and costing the health impacts of ambient particulate air pollution in the UK. Contract report for the UK Department of Health.

ICP Materials (2003) Dose-response functions. http://www.corr-institute.se/ICP-Materials/html/dose_response.html

ICP/MM (2004) Mapping Manual Revision. United Nations Economic Commission for Europe, ICP Mapping and Modelling. http://www.oekodata.com/icpmapping/html/manual.html

Jeanrenaud, C. Grosclaude, P., Schwab, N., Soguel, N., and Stritt, M. (1993). Les Couts Sociaux des Transports en Suisse, un Compte Global par Mode de Transport. IRER, Neuchatel, Switzerland..

Karenlampi, L., and Skarby, L. (1996) Critical Levels for Ozone in Europe: Testing and Finalising the Concepts (A UNECE Workshop Report). Department of Ecology and Environmental Science; University of Kuopio.

Karlsson, P.E., Pleijel, H., Belhaj, M., Danielsson, H., Dahlin, B., Andersson, M., Hansson, M., Munthe, J. and Grennfelt, P. An economic assessment of the negative impacts of ozone on crop yield and forest production at the estate Ostad Sateri in south-west Sweden. Ambio, in press.

King, K. and Stedman, J. (2000) Analysis of air pollution and social deprivation. Contract report for the Department for the Environment, Transport and the Regions, The Scottish Executive, The Welsh Assembly and the Department of Environment for Northern Ireland. http://www.airquality.co.uk/archive/reports/cat09/aeat-r-env-0241.pdf .

Kouvaritakis N. , Paroussos L. and D. Van Regemorter (2003): "The macroeconomic evaluation of energy tax policies within the EU, with the GEM-E3-Europe model", report for DG TAXUD

Krewski D, Burnett RT, Goldberg MS, Hoover K, Siemiatycki J, Abrahamowicz M, White WH (2000). Re-analysis of the Harvard Six-cities study and the American Cancer Society Study of air pollution and mortality. Cambridge, MA: Health Effects Institute. Available at http://www.healtheffects.org/pubs-special.htm

Krupnick A and M. Cropper (1992) The Effect of Information on Health Risk Valuation, *Journal of Risk and Uncertainty* Vol. 5, 29-48

Kucera, V., Henriksen, J., Knotkova, D., Sjöström, Ch. (1993b). Model for Calculations of Corrosion Cost Caused by Air Pollution and Its Application in Three Cities. Report No. 084, Swedish Corrosion Institute, Roslagsvägen, 1993.

Kucera, V., Henriksen, J., Leygraf, C., Coote, A.T., Knotkova, D. and Stöckle, B. (1993a). Materials Damage Caused by Acidifying Air Pollutants - 4 Year Results from an International Exposure Programme within UN ECE. International Corrosion Congress, Houston, September 1993.

Kuenzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Herry M, Horak F, Puybonnieux-Texier V, Quénel P, Schneider J, Seetaler R, Vergnaud J-C, Sommer H. (2000). Public health impact of outdoor and traffic-related air pollution: a European assessment. Lancet, 356: 795-801.

Landrieu, G. (1997) Visibility impairment by secondary ammonium, sulphates, nitrates and organic particles. Draft note prepared for the meeting of the Task Force on Economic Aspects of Abatement Strategies. UNECE Convention on LRTAP, Copenhagen 9-10 June 1997.

Lee, D.S., Holland, M.R. and Falla, N. (1996) The potential impact of ozone on materials. Atmospheric Environment, 30, 1053-1065.

Madisson, D. (1997) The Economic Value of Visibility: A Survey. CSERGE, unpublished.

Mansfield, T.A. (1992). Sources of Building Soiling and a Review of the Stone Cleaning Industry, 1991. Paper Presented at 'Stone Cleaning and the Nature, Soiling and Decay Mechanisms of Stone'. 14-16 April, 1992, Aberdeen.

Mansfield, T.A., Hamilton, R.S., Ellis, B. and Newby, P.T. (1991) Diesel Particulate Emissions and the Implications for the Soiling of Buildings. The Environmentalist. Volume 1, **4**, 243-254 (1991).

Miller BG, Hurley JF. (2003). Life table methods for quantitative impact assessments in chronic mortality. J Epidemiol. Community Health, 57: 200-206.

Mills, G., Holland, M., Buse, A., Cinderby, S, Hayes, F., Emberson, L., Cambridge, H., Ashmore, M., Terry, A. (2003). Introducing response modifying factors into a risk assessment for ozone effects on crops in Europe. Establishing Ozone Critical Levels II. UN-ECE Workshop Report. IVL Report B 1523. IVL Swedish Environmental Research Institute, Gothenburg, Sweden, in press.

Navrud, S. and R. Ready (eds.) 2002: Valuing Cultural Heritage. Applying environmental valuation techniques to historical buildings and monuments. Edward Elgar Publishing, UK.

Netten, A. and Curtis, L. (2000) Unit costs of Health and Social Care 2000. Personal Social Services Research Unit (PSSRU). http://www.pssru.ac.uk/index.htm .

Newby, P.T., Mansfield, T.A. and Hamilton, R.S., (1991). Sources and Economic Implications of Building Soiling in Urban Areas. The Science of the Total Environment, **100**, 347.

NEWEXT (2004) New Elements for the Assessment of External Costs from Energy Technologies Project Report for EC DG Research. Contract no.NNE5-2000-00045.

Olszyk, D.M., Thompson, C.R. and Poe, M.P. (1988) Crop loss assessment for California. Modelling losses with different ozone standard scenarios. Environmental Pollution, 53, 303-311.

Ormerod, S.J., Weatherley, N.S. and Gee, A.S. (1990) Modelling the ecological impact of changing acidity in Welsh streams. In “Acid Waters in Wales”. R.W. Edwards, A.S. Gee and J.H. Stoner (eds.). Kluwer Academic Publishers, Dordrecht.

Pearce, D. and D. Moran, The Economic Value of Biodiversity, London: Earthscan Publications Ltd., (1994).

Pio C. A., Ramos M. M. and Duarte A. C., 1998. Atmospheric aerosol and soiling of external surfaces in an urban environment. Atmospheric Environment, Vol. 32, pp. 1979-1989.

Pitchford, M. L. *et al* (1994) Development and applications of a standard visual index. Atmospheric Environment **28**, issue 5.

Pope, C. A. et al. (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of the American medical association, 287: 1132 - 1141.

Posch, M. (1999) Critical Load Exceedance and Gap Closure Methods – A Summary. Presented to the 23rd meeting of the Task Force on Integrated Assessment Modelling (TFIAM), 10-12 March 1999, LesDiablerets, Switzerland. http://www.iiasa.ac.at/~rains/reports/critical%20loads.pdf

Pye, S (2001) Further analysis of NO_2 and PM_{10} air pollution and social deprivation. http://www.aeat.co.uk/netcen/airqual/reports/strategicpolicy/2001socialdeprivation_v4.pdf

QUARG (1993) Urban Air Quality in the United Kingdom. First Report of the Quality of Urban Air Review Group, January 1993. Prepared at the request of the Department of the Environment.

QUARG (1996). Airborne Particulate Matter in the United Kingdom. Third Report of the Quality of Urban Air Review Group. May 1996.

Rabl, A, Curtiss, P. and Pons (1998). Air Pollution and Buildings: An Estimation of Damage Costs in France. Environmental Impact Assessment Review.

Rabl, A. (2003) Interpretation of air pollution mortality: Number of deaths or years of life lost? Journal of the Air & Waste Management Association; Vol.53(1), 41-50 (2003).

Ready, R., Navrud S., Day B, Dubourg R., Machado F., Mourato S., Spanninks F., and M. X. V. Rodriquez. (2004) Benefit Transfer in Europe: How Reliable Are Transfers Across Countries? Environmental & Resource Economics 29: 67-82

Ruijgrok, E., Klop, P and Botterweg, T. (2003) Reducing acidification: the benefits of increased nature quality: Investigating the possibilities of the Contingent Valuation Method. Report to Ministry of Housing, Spatial Planning and the Environment, the Netherlands.

Shortle, S., Dunn, J.W. and Philips, M. (1986) Economic Assessment of crop damage due to air pollution: The role of quality effects. Staff paper 118. Department of Agricultural Economics, Pennsylvania State University, State College, PA.

Sisler, J. F. *et al* (1994) The relative importance of soluble aerosols to spatial and seasonal trends of impaired visibility in the United States. Atmospheric Environment, **28**, no. 5.

Syri, S., Suutari, R. and Posch, M. (2000) From Emissions in Europe to Critical Load Exceedances in Finland - Uncertainty Analysis of Acidification Integrated Assessment. Environmental Science & Policy 2(2000): 263-276.

Tolstoy, N., Andersson, G., Sjöström, Ch., and Kucera, V. (1990). External Building Materials - Quantities and Degradation. Research Report TN:19. The National Swedish Institute for Building Research, Gävle, Sweden, 1990.

USEPA (1997) The benefits and costs of the Clean Air Act: 1970 to 1990. United States Environmental Protection Agency, Office of Air and Radiation/Office of Policy, Washington D.C.

Van der Eerden, L.J., Tonneijk, A.E.G and Wijnands, J.H.M. (1988) Crop loss due to air pollution in the Netherlands. Environmental Pollution, 53, 365-376.

Van der Velde, R.T., Stuyfzand, P.J., Hiemstra, P., Kooiman, J.W and Mesman, G. (2004) Benefits of the policy against atmospheric acidification on groundwater quality and drinking supply in the Netherlands. Witteveen-en-Bos, PO Box 233, 7400 AE Deventer, The Netherlands.

Van Sluijs, J. (1996) Integrated Assessment Models and the Management of Uncertainties. WP-96-119, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Watt, J. (ed.) (2001) Rationalised Economic Appraisal of Cultural Heritage (REACH): Management Tool Software. Contributing authors: Hamilton, R., Machin, N., Yates, T., Massey, S., Garrod, E., Henriksen, J.F., Kucera, V., Tidblad, J., Aires-Barros, L., Antonio, M., Navrud, S., Jensen, M., Knotkova, D., Kreislova, K. and Magnusson, J. Output from European Commission Project number ENV4-CT98-0708.

WHO (2000) Quantification of the health effects of exposure to air pollution. WHO, European Centre for Environment and Health, Bonn. http://www.euro.who.int/document/e74256.pdf.

WHO (2002) World health report 2002. Geneva, World Health Organization, 2002.

WHO (2004) Systematic Review of Health Aspects of Air Pollution in Europe. WHO Regional Office for Europe, Denmark. http://www.euro.who.int/document/e79097.pdf ; http://www.euro.who.int/document/e82790.pdf ; http://www.euro.who.int/document/e82792.pdf).

Woodruff TJ, Grillo J, Schoendorf KC: The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. Environ Health Perspect 1997, 105: 608-612. http://ehp.niehs.nih.gov/members/1997/105-6/woodruff.html

Working Group on Strategies and Review (2003) Valuation of ecosystem benefits from air pollution abatement. Summary report of the workshop by its chairman in collaboration with the secretariat. http://www.unece.org/env/documents/2003/eb/wg5/eb.air.wg.5.2003.1.e.pdf

Appendices

Appendix 1:

Abbreviations and Terminology

AA	Asthma attacks
$AF_{st}Y6$	Accumulated stomatal flux of ozone above a threshold of 6 $mmol.m^{-2}$
AOT40	Accumulated concentration of ozone over a threshold of 40 ppb
AOT60	Accumulated concentration of ozone over a threshold of 60 ppb
CAFE	Clean Air For Europe
CBA	Cost-benefit analysis
CCE	Coordinating Centre for Effects
CHF	Congestive Heart Failure
CO	Carbon monoxide
CO_2	Carbon dioxide
C-R	Concentration-response (function)
CV or CVM	Contingent valuation (method)
CVA	Cerebro-vascular conditions
EC	European Commission
EC DG ENV	European Commission Directorate General Environment
EMEP	The Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
EU	European Union
FAO	(UN) Food and Agriculture Organization
FGD	Flue gas desulphurisation
GBP	WHO Global Burden of Disease Project
GDP	Gross Domestic Product
GHG	Greenhouse gas
H^+	Hydrogen ion
HF	Hydrogen fluoride
IIASA	International Institute for Applied Systems Analysis
ICP	International Cooperative Programme
ICP/MM	International Cooperative Programme on Mapping and Modelling
IGCB	(UK) Inter-departmental Group on Costs and Benefits
IOM	Institute of Occupational Medicine
IPPC	Integrated Pollution Prevention and Control
LRTAP	Convention on Long Range Transboundary Air Pollution
MCA	Multi-criteria assessment
MFR	Maximum feasible reduction scenario
MRAD	Minor restricted activity day
NEBEI	Network of experts on benefit and economic instruments
NECD	National Emission Ceilings Directive
NH_3	Ammonia
NH_4^+	Ammonium ion
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NO_x	Oxides of nitrogen
O_3	Ozone

OECD	Organisation for Economic Cooperation and Development
PEC	Particulate elemental carbon
PM_{10}	Fine particles less than 10 µm in diameter
$PM_{2.5}$	Fine particles less than 2.5 µm in diameter
PVC	Poly-vinyl chloride
QWB	Quality of well being
RAD	Restricted Activity Day
RAINS	Regional Air Pollution Information and Simulation
REF	Reference scenario
RHA	Respiratory Hospital Admission
RY	Relative yield
SEI-York	Stockholm Environment Institute at York
SO_2	Sulphur dioxide
SO_4^{--}	Sulphate
TFEAAS	Task Force on Economic Aspects of Abatement Strategies
UNECE	United Nations Economic Commission for Europe
USEPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds
VOLY	Value of life year
VOSL	Value of statistical life
WTA	Willingness to accept
WTP	Willingness to pay
YOLL	Years of life lost

MATHEMATICAL NOTATION

The following prefixes and suffixes are used in this work;

E*x*, E-*x* as a suffix to a number, denotes that the number in question should be multiplied by 10 to the power *x* or -*x*. Hence 6.4E-3 is equal to 0.0064.

The following prefixes to units are also used;
n = nano = 10^{-9}
µ or u = micro = 10^{-6}
m = milli = 10^{-3}
k = kilo = 10^{3} = thousands
M = mega = 10^{6} = millions
G = giga = 10^{9} = billions

This system is standard notation in the sciences. Note that m and M are not equivalent (by a factor of 10^{9}) and hence should not be interchanged.

Appendix 2:

List of Stakeholders providing written comment after workshops, and the peer review team

Stakeholders providing written comment after the December workshop

Name	Organisation	Country
Baverstock, Suzie	BP/ UNICE	
Dunn, Helen	DEFRA	UK
Galland, JC	UNICE	
Hettelingh, Jean-Paul	RIVM/CCE	The Netherlands
Lemoine, Sylvie	ESIG	
Simonis, Dominique, Hager, Caroline	DG Enterprise	European Commission
Soleille, Sebastien	INERIS	France
Torfs, Rudi	VITO	Belgium
Vainio, Matti	DG Environment	European Commission
Walton, Heather	Department of Health	UK

Stakeholders providing written comment on the revised February Methodology Report

Name	Organisation	Country
Sébastien SOLEILLE	INERIS	France
Paul Ruyssenaars	Ministry of Housing, Spatial Planning and the Environment	Netherlands
Bernd Schärer	Umweltbundesamt - Federal Environmental Agency, Berlin	Germany
Bruno Celard	On behalf of EUROPIA / CONCAWE	
Pierre de Kettenis	ESIG (European Solvents Industry Group)	

Stakeholders providing written comment on the July 2004 release of the Methodology Report and workshop of July 16th 2004

Name	Organisation	Country, etc.
	DG Enterprise	European Commission
	DG Environment	European Commission
R.T van der Velde	Witteveen-en-Bos	The Netherlands
Mohammed Belhaj	IVL	Sweden
	CONCAWE	Oil industry
	Eurelectric	Electricity industry
	ESIG	European Solvents Industry
L. van Bree, E. Buringh	RIVM	The Netherlands
R. Swart	RIVM	The Netherlands
J. Burney	English Nature	UK
Mikael Skou Andersen	National Environmental Research Institute	Denmark
R. Torfs	VITO	Belgium

Peer Review Team

Alan Krupnick, PhD, Resources for the Future: Overall Coordination and Team Leader; Valuation of affected endpoints

Bart Ostro, PhD, California Office of Environmental Health Hazard Assessment: Health Effects estimation

Keith Bull, Ph.D., UNECE, Secretariat for the Convention for Long-Range Transboundary Air Pollution: Estimation of all non-health effects

Appendix 3
Consistency of the RAINS and CBA models

The following issues are of most interest with respect to consistency between the two models:

- Currency, currency year
- Variation in values between countries
- Taxation
- Discounting
- Quantification of impacts
- Basis for comparison of costs and benefits (e.g. total costs, marginal costs, costs and benefits accruing to each country)
- Treatment of uncertainty

The RAINS Review 2004 (Amann et al, 2004) has been used extensively in the assessment that follows.

Currency and currency year
Both RAINS and CAFE CBA use the EURO (€) in year 2000 as the basis for calculation.

Variation in values between countries
RAINS assumes that a free market exists for capital goods across Europe, and so does not vary capital costs by country. The labour element of operating costs is, however, costed at national rates. This may lead to some internal inconsistency in the RAINS model between the treatment of labour costs associated with the installation of equipment and those associated with operation and maintenance. However, the latter are presumably low as a fraction of total capital costs and so it would make little difference whether they were costed at local or European average prices. It may also be difficult to separate out such costs from the total with sufficient confidence to warrant doing so.

The default option for the benefits assessment is an assumption that values across the EU for the time horizon of interest are adequately represented by a standard set of values quantified for the EU at the present time. Given existing differences in income between the old and new member states this may seem surprising. However, it is hoped that the new countries will see a substantial increase in incomes as a result of their accession to the Union. On this basis the assumption of uniform values across the Union becomes more robust.

This of course means that there is some inconsistency between the assumption of European average values for the benefits analysis and the use of country specific labour prices for operation and maintenance in the RAINS model. The importance of this depends on factors such as:

- The contribution that these costs make to total costs,
- The extent of variation between countries at the present time,
- Assumptions on the way that labour costs change over time.

We conclude that whilst there are some dissimilarities between RAINS and the CBA on this issue, these arise from pragmatic responses to issues faced in the analysis and do not appear to be sufficient to have a significant effect on the analysis.

Taxation

Amann et al (The RAINS Review, 2004) state that:
The basic intention of a cost evaluation in the RAINS model is to identify the values to society of the resources diverted in order to reduce emissions in Europe. In practice, these values are approximated by estimating costs at the production level rather than prices to the consumers. Therefore, any mark-ups charged over production costs by manufacturers or dealers do not represent actual resource use and are ignored. Certainly, there will be transfers of money with impacts on the distribution of income or on the competitiveness of the market, but these should be removed from a consideration of the efficiency of a resource. Any taxes added to production costs are similarly ignored as transfers.

We have not identified any areas where this conflicts with the methodology for the CBA.

Discounting

The 2004 RAINS Review documents the RAINS approach to discounting:
Capital costs (Investments): Capital costs include the expenditures made until the start up of an abatement technology. These costs are annualized over the technological lifetime, using a discount rate of 4%.
Operating costs: A distinction is made between annual fixed expenditures and annual variable operating costs.

The expression of operating and capital costs on an annual basis then allows them to be converted to costs per unit of fuel input, which themselves are then converted to costs per tonne of pollutant removed.

It is important to ensure that capital costs are treated correctly in the context of a social – as opposed to private[15] - cost benefit analysis. In a social CBA, the usual procedure is to account for capital costs at the time when the resources are consumed by the project. In other words, the full cost of a capital asset is deducted from a project as it arises. In the context of CAFE, therefore, it is important to have an assumed profile of capital expenditures over the time period to which the CBA applies. In order to be consistent with the benefits assessment, the resulting profile of costs should be discounted by the common discount rate. The procedure of annualisation of capital costs adopted by RAINS is consistent with this requirement (see equation 4.2 of the RAINS Review).

The treatment of annual fixed and variable costs in RAINS as annual costs also appears consistent with the approach of the benefits assessment.

Quantification of impacts

Quantification of a selected effects is needed within RAINS for optimisation against environmental and health objectives. To the extent possible the CBA takes the RAINS generated estimates as inputs, but there are inevitably differences in general approach and

[15] Note that in a private CBA, capital costs are depreciated over the lifetime of the capital for accounting purposes so that the depreciation profile of costs is used in the analysis.

detail, reflecting the differing demands of integrated assessment modelling (IAM) and CBA. Differences include:

- The benefits quantification covers a much larger number of effects than RAINS (e.g. impacts on morbidity and materials damages). This is not important, as the impacts that are outside of the IAM analysis would make little or no difference to the RAINS optimisation, either because they are less significant, or because they bear a direct relation to those effects that are quantified.
- The treatment of uncertainty within the benefits assessment is far more extensive than within RAINS. Of importance here is the relationship between those parts of the analysis that can be quantified with confidence and those that are more uncertain – RAINS stops the analysis at a point where change in objectives should bear a close relationship with change in exposure. This is particularly the case for health impacts given the assumption of linear response functions applied with no threshold. This is appropriate for IAM, but not for CBA, which clearly needs to go further.
- Constraints imposed by optimisation procedures affect the way that some parts of the RAINS analysis are carried out. The same constraints do not apply to the CBA.

Differences that do exist between RAINS and the CBA are not considered significant, but are simply a pragmatic response to differences in the purpose of the two analyses. What is important is that the core elements of the analysis are identical and in line with what is currently considered best practice.

Basis for comparison of costs and benefits

The RAINS model has generally been used to quantify total costs accruing to each country from the set of options identified as necessary for pre-defined environmental targets to be met through the optimisation process.

Following on from scenarios developed under RAINS, the CBA carried out for the NEC Directive (AEA Technology, 1998) and the Gothenburg Protocol (Holland et al, 1999) quantified total benefits from air quality accruing to each country. However, this is only one of a series of valid comparisons that could be made. Instead of comparing total costs, it would be possible to compare marginal costs and benefits, though the format of modelling required for this assessment would differ in some respects to that presented here.

There are two options for aggregation of benefits for each country:

- Quantification of the total benefits accrued by each country from pan-European emission controls irrespective of where emissions have been reduced. This option was followed in the already-mentioned CBAs of the NEC Directive and Gothenburg Protocol. To illustrate, consider a reduction in emission of SO_2 in Germany. Under this option the benefit counted for Germany would include only benefits to health, etc. arising in Germany itself. Transboundary effects of the reduction in German emissions would be counted for each country in which they occur, even for countries that make no reduction in emissions.
- Quantification of the benefits arising from control in each country across the whole of Europe. Under this option, the benefits of a reduction in German SO_2 emissions would be attributed to Germany irrespective of whether they occur within Germany or in another country. Any country not making emission reductions would have no benefit recorded against it.

The former provides for an assessment where each country gains an idea of how it stands with respect to the costs and benefits of any proposals made. The latter, however, perhaps makes for a truer cost-benefit analysis. It would also require a more complex modelling framework with the assessment for each country being undertaken separately. With this in mind, such an assessment will not be carried out for all scenarios to be investigated, but lessons will be drawn from a limited assessment of marginal impacts for each country.

Treatment of uncertainty

Amann et al (RAINS Review, 2004, Section 9) demonstrate that uncertainty in integrated assessment models associated with individual parameters (emission scenarios, cost data, critical loads modelling, etc.) can be characterised relatively easily. This has, indeed, been done by a number of authors (Alcamo and Bartnicki, 1990; Bak and Tybirk, 1998; Duerinck, 2000; Syri et al, 2000 and others). However, such results do not answer the question of how uncertainty affects the *overall* results of the models, which is obviously the question of most policy relevance. The review of van Sluijs (1996) found that such an assessment is difficult, for a number of reasons, including that:

- Models did not fully address all relevant aspects within the whole spectrum of types and sources of uncertainty,
- They failed to provide unambiguous comprehensive insight to both the modeller and the user into the quality and limitations of models and their answers,
- They failed to address the subjective component in the appraisal of uncertainties.

Review made here suggests that uncertainties affecting the RAINS and CBA models used in CAFE are broadly similar in nature, though may have different effects so far as interpretation of results is concerned. The following table shows that problems of omission of options/impacts, uncertainties in input data, uncertainty in future scenario development, etc. are common to both IAM and CBA, though different elements of uncertainty can vary in both the direction and extent of errors.

Generic overview of uncertainties affecting RAINS and the CAFE-CBA

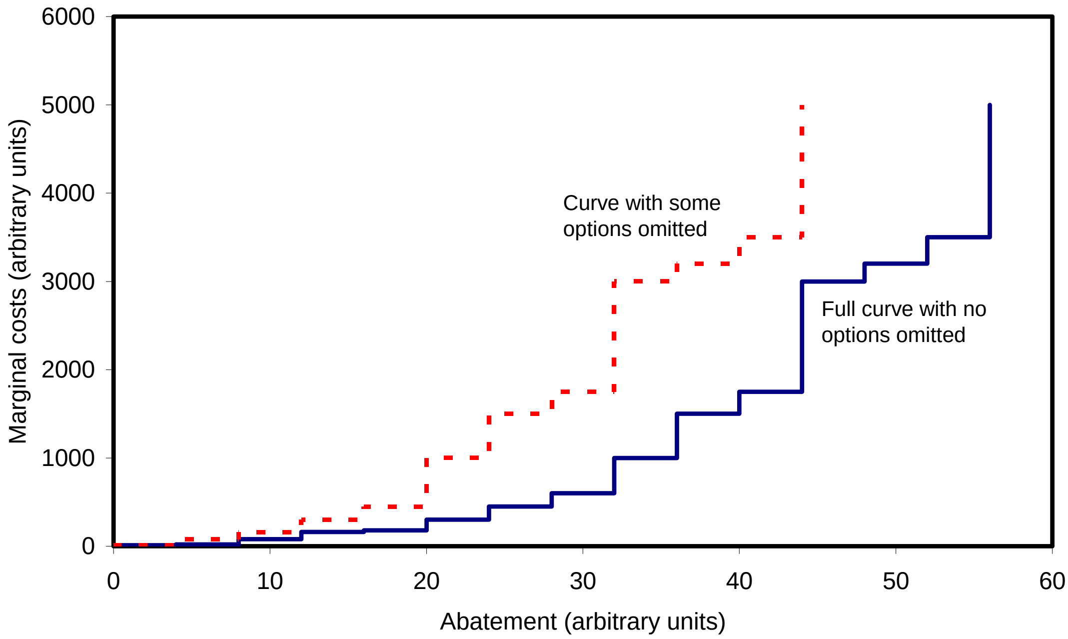
Source of uncertainty	RAINS	CBA
1. Omission of abatement options or impacts	××× biases to over-prediction of costs	×× biases to under-prediction of benefits
2. Uncertainty in existing input data on options and impacts	×× direction of bias unknown	××× direction of bias unknown
3. Knowledge of future technological / technical developments	× biases to over-prediction of costs	× e.g. advances in healthcare, biasing to over-prediction of benefits
4. Knowledge of future social developments	××× e.g. energy scenarios, direction of bias dependent on national energy systems	× e.g. economic growth, direction of bias unknown

Key: ××× Significant uncertainty. ×× Potentially significant uncertainty. × Source of uncertainty likely to have a limited impact on the balance of costs and benefits

The wording used in the table has been chosen carefully. We refer to ‘bias to’ over- or under-prediction rather than ‘will cause’ over- or under-prediction’ as uncertainty clearly needs to be viewed holistically, and some uncertainties will tend to cancel each other out.

Some of the conclusions raised in this table need further discussion. It is likely that RAINS will under-predict the maximum feasible reduction in emissions if it omits abatement options unless options that are included cancel the need for a particular measure. Similarly it is likely that omission of measures would lead to over-prediction of costs for reaching any level of control for which the marginal cost of abatement is higher than that of the measures that have been left out of the analysis. It is of course useful to ask what sort of measures may be omitted and how important they are. In the past RAINS has omitted fuel switching, which may have a large effect on emissions of several pollutants (as seen in the UK given the construction of several gas-fired power stations following liberalisation of the energy sector). It is believed that this will be accounted for in future model runs through sensitivity analysis on the energy scenarios considered.

Another group of measures that may be omitted are those that are likely to be considered at a local level, such as the use of congestion charging, low emission zones or driver training. Whilst all of these measures will benefit air quality only the use of low emission zones would be introduced solely for air quality improvement. The scale at which these local measures may be introduced is much finer than that which can be considered using a model like RAINS, unless results of case studies can be integrated with the model for extrapolation. In terms of national emissions, individual schemes like these are likely to have a small effect on any pollutant, but may have a major benefit locally.



Demonstration of the effect of omitting options from cost curves in terms of raising costs for achieving a given reduction in emissions and limiting the overall potential for abatement.

Options can be omitted for a variety of reasons, of which the following are particularly important.

1. **Improvements from measures that do not have a clear link to the problem under investigation.** As an example, energy market liberalisation in the UK appears responsible for much of the UK's reduction in sulphur emissions.
2. **Boundaries being drawn too tightly around the analysis.** In the past it seems that too much emphasis has been placed on 'end-of-pipe' solutions, and too little on measures that control demand or behaviour whilst maintaining access to energy and transport services. A good example would be driver training schemes that have been shown to offer a 10% and more reductions in emissions with significant cost savings after payback periods of only a few months.
3. **A failure to account for innovation.**

In contrast, the omission of most types of impact from the CBA would clearly bias to under-prediction of benefits.

It seems likely that, in general, technical input data for the measures included in RAINS are more robust than the input data for the benefits analysis. Information will be most robust for well-tested techniques, though these of course are likely to be already in place. Information is, however, less robust for new abatement methods. Experience suggests that the costs of these methods is likely to be overestimated per unit abatement, as efficiencies in production and operation are typically made as manufacturing experience grows. As an example, CONCAWE (1999) reported that their own earlier estimates of costs of reducing sulphur in oil-based fuels had been exaggerated for the following reason:

> *"…not enough allowance was made for emerging new advances of gas oil hydrodesulphurisation (HDS) technology (new catalysts, etc.). Following reviews with the catalyst manufacturers and oil company project experts, the cost of a high pressure (up to 60 bar) HDS unit, for example, has been revised downwards to M$75 for a 1.3 Mt/a unit from M$90 for a 0.73 Mt/a unit. At the same time, the desulphurisation rate achievable by such a unit has been increased to 99.5% from 97%."*

These changes appear to combine to improve the cost-effectiveness of the measure in question by a factor of 2.2.

It is, incidentally, noted that the factor of around 2 calculated by CONCAWE (1999) seems to have gained some acceptance as an indicator of the scale of uncertainty within the RAINS model. It should be recognized that this represents only one component of uncertainty within the RAINS model, other sources of error, for example associated with assumed future emissions of each pollutant, also need to be taken into account and are additional to the errors surrounding unit cost-effectiveness.

The principal approach to uncertainty assessment in RAINS is the use of sensitivity analysis, varying certain inputs (e.g. energy scenarios) to investigate their effect on emissions, costs, etc. However, time and other constraints limit the ability of the model to take account of uncertainty using sensitivity analysis. The effects of combined uncertainties are particularly difficult to forecast. In contrast, the CBA modelling under CAFE is more flexible in its treatment of uncertainty largely because it is not tied into optimisation procedures.

Conclusions

In general, the analysis carried out by the RAINS and CBA models is consistent. The most important area where inconsistency is present concerns the characterisation of uncertainty. The difficulties of uncertainty analysis within integrated assessment modelling are well known. Some additional work may be done (e.g. a bias analysis, similar to that to be carried out for the benefits analysis and described in brief elsewhere in this report), together with some sensitivity analysis, but stakeholders need to take time to consider the quality of the model output cost data from the perspective of those issues that may not be fully accounted for.

Appendix 4
Worked examples of impact assessment

Two worked examples are provided, both concerning health impact assessment. The first deals with effects of $PM_{2.5}$ on the development of chronic bronchitis and the second, effects of ozone on respiratory hospital admissions. Both cases quantify for a hypothetical grid cell containing 100,000 people subject to an exposure of 10 µg.m^{-3}.

Effect: Development of chronic bronchitis in adults aged >27
Original function: 7.0% change in baseline attack rates, per 10 µg/m^3 PM_{10}

		Quantity	Units
Step 1: Quantify total population exposure in grid cell x, y			
A	Population in grid cell x, y	100,000	people
B	PM2.5 concentration in grid cell x, y	10	µg.m^{-3}
C	Exposure in grid cell x, y (A × B)	1,000,000	person.µg.m^{-3}
Step 2: Adjust exposure for adult population aged >27			
D	Fraction of total population aged over 27	0.66	no units
E	Adjusted exposure (C × D)	660,000	person (aged>27).µg.m^{-3}
Step 3: Adjust concentration-response function to account for differences in pollution metrics			
F	Original function	7%	change in baseline attack rates, per 10 µg.m^{-3} PM_{10}
G	Factor to convert from PM_{10} to $PM_{2.5}$	1.54	no units
H	Factor to convert from 10µg.m^{-3} to 1µg.m^{-3}	0.1	no units
J	Revised function (F × G × H)	1.08%	change in baseline attack rates, per 1 µg.m^{-3} $PM_{2.5}$
Step 4: Quantify relevant incidence rates			
K	Incidence rate of chronic bronchitis	0.707%	%
L	Non-remission rate	53.40%	%
M	Adjusted incidence rate	0.378%	%
Step 5: Quantify impacts			
N	Increase in incidence in grid cell x, y (E × J × M)	26.9	New cases of chronic bronchitis in grid cell x, y
Step 6: Value impacts			
O	Value per case of chronic bronchitis	€ 190,000	€
P	Economic value in grid cell x, y (N × O)	€ 5,100,000	€
Step 7: Aggregate across other grid cells			
	Calculate national totals		
	Calculate regional (EU15, EU25, etc.) totals		

Effect: Respiratory hospital admissions (RHAs) in the general population
Original function: 0.3% change in admissions per 10 μg/m^3 O_3 (8-hr daily average)

		Quantity	Units
Step 1: Quantify total population exposure in grid cell x, y			
A	Population in grid cell x, y	100,000	people
B	O_3 concentration in grid cell x, y	10	μg.m^{-3}
C	Exposure in grid cell x, y (A × B)	1,000,000	person.μg.m^{-3}
Step 2: Adjust concentration-response function to account for differences in pollution metrics			
D	Original function	0.3%	change in baseline admissions per 10 μg.m^{-3} O_3
E	Factor to convert from 10 μg.m^{-3} to 1 μg.m^{-3}	0.1	no units
F	Revised function (D × E)	0.03%	change in baseline admissions, per 1 μg.m^{-3} O_3
Step 3: Quantify relevant incidence rates			
G	Incidence rate for RHAs in the general population	0.617%	%
Step 4: Quantify impacts			
H	Increase in incidence in grid cell x, y (C × F × G)	1.9	Additional respiratory hospital admissions in grid cell x, y
Step 5: Value impacts			
J	Value per respiratory hospital admission	€ 2,141	€
K	Economic value in grid cell x, y (H × J)	€ 3,700	€
Step 6: Aggregate across other grid cells			
	Calculate national totals		
	Calculate regional (EU15, EU25, etc.) totals		

Appendix 5
Example datasheets for the extended CBA

This appendix provides 2 datasheets from the extended CBA:

1. Visible injury to crops caused by exposure to ozone – an effect that will not be quantified in the benefits analysis in economic terms, because of a lack of data to indicate the severity of response.
2. Development of chronic bronchitis in adults in response to exposure to fine particles – an effect that will be quantified in terms of new incidence and monetary equivalent..

These datasheets have been selected to illustrate the type of information being brought together in the extended CBA. The first datasheet demonstrates the process by which it was concluded that visible injury to crops from ozone exposure would not be economically significant at the European level, but can be significant locally.

Further datasheets are currently in preparation covering the other impacts of concern to the CAFE programme.

EXAMPLE DATASHEET 1: VISIBLE INJURY TO CROPS FROM EPISODIC EXPOSURE TO HIGH LEVELS OF OZONE

Impact: Loss of value through visible injury to crops following exposure to high levels of ozone. The crops affected include spinach, lettuce, endive, spring (salad) onion, mainly those for which the saleable parts are sensitive to ozone. Crops affected by such damage are unlikely to be saleable. If injury is severe the damage may extend to reduced production of fruit and seed, for example, for melon. Alternatively, fruit and seed may not be of sufficient quality for sale (e.g. through poor sugar content in melon). The photos below show examples recorded in the field.

Ozone injury to spring onion, parsley, lettuce and water melon, from exposure in the ambient air (reproduced by permission of D. Velissariou)

Related impacts: Effect of cumulative ozone exposure over the growing season on yield of agricultural and horticultural crops.

Attribution of effect to ozone exposure: Attribution of injury to ozone is difficult because symptoms are often similar to those induced through mineral deficiencies or pest attack. As a result, and due to its somewhat infrequent appearance, it does not seem to be well recognised by farmers. Experts can eliminate other stresses as the cause of damage through inspection of crops for pests and knowledge of the local history of mineral deficiency.

Distribution of impact: Records of visible injury to many types of vegetation have been made in many parts of Europe, though there appears to be no systematic search for such damage. It is known that in recent years injury has been observed throughout Greece, in areas including the Athens basin which is known to experience high ozone episodes, and others far distant from it.

Map showing exceedence of critical level for visible injury to be added here if available

Quantification of damage: There are currently insufficient data available to permit predictive modelling of the economic damage caused by ozone injury. Estimates could be available for individual case studies.

Economic importance at the European scale: Given the limited number of crops that would seem to be at risk of visible injury to saleable parts, and the episodic nature of ozone injury, it seems unlikely that damage will be significant in the overall context of European agriculture. The total contribution of potentially sensitive crops to the overall value of European production is here estimated to be less than 5%. Of this, only a fraction will be affected in any year.

Economic importance at national and local scales: Although there is limited information available, it seems clear that this effect can be serious for individual farmers. One episode is reported to have cost €15,000 in lost lettuce production for one farmer alone. In another case an entire melon crop was lost. As noted above, there is a lack of systematic recording of such events, but they do not appear to be uncommon in some parts of Europe. A further economic impact may arise if farmers grow less valuable crops or cultivars to avoid ozone injury. Further research in this area certainly seems appropriate.

Acknowledgement: Data, photographs and maps presented here were provided by Prof. Dimitris Velissariou of the Technological Educational Institute of Kalamata, and presented at the February 2004 meeting of the ICP Vegetation in Kalamata, Greece.

EXAMPLE DATASHEET 2: CHRONIC BRONCHITIS and PM_{10}

Impact: Chronic bronchitis associated with PM_{10} exposure

Definition of impact: Bronchitis is an inflammation of the air passages connecting the windpipe with the sacs of the lung where oxygen is taken up by the blood. This inflammation causes excessive phlegm (or mucus) production and swelling of the bronchial walls, resulting in cough and the expectoration of phlegm. Chronic bronchitis is defined to be the occurrence of chronic cough or chronic phlegm for at least three months of the year, for at least two years.

Strength of association with pollution: The SALPADIA study carried out at eight study sites in Switzerland found a statistically significant association between chronic cough or phlegm production and exposure to PM_{10} among non-smokers (OR: 1.27 per 10 $\mu g.m^{-3}$ increase in annual concentration ; 95%CI: 1.08, 1.50), with similar results for current and former smokers. In the USA a series of studies by Abbey et al (1993, 1995a,b) have also shown significant associations.

Treatment of impact: There is no cure for chronic bronchitis, and treatment is primarily aimed at reducing irritation in the bronchial tubes. Chest infections are common in those with chronic bronchitis, and these can be treated with antibiotics. In addition, bronchodilator drugs may be prescribed to help relax and open up air passages in the lungs.

Related effects: The blocking of the airways can cause symptoms of breathlessness and wheezing. Once the bronchial tubes have been irritated over a long period of time, they become more susceptible to infections. At its most extreme, chronic bronchitis can cause serious injury to the lungs leading to serious respiratory problems or heart failure.

Frequency of occurrence of impact: Information from the 'Global Burdens of Disease' study estimates an annual incidence of chronic obstructive pulmonary disease (approximately equivalent to chronic bronchitis) in the WHO Europe sub-region of 770,000 in a population of 877,866,000; which is a rate of 88 per 100,000.

Estimate share of total impact attributable in some way to air pollution: To be added following initial quantifications.

Appendix 6
Further information on the Treatment of Effects on Agriculture and Horticulture

Introduction

Ozone is recognised as the most serious regional air pollutant problem for the agriculture and horticulture sectors in Europe at the present time. The effects of air pollution, particularly ozone, on crop yield have been quantified in a number of papers over the years in Europe (van der Eerden et al, 1988; AEA Technology, 1999; Holland et al, 2002) and in the USA (e.g. Adams et al, 1985; Shortle et al, 1986; Olszyk et al, 1988). Interestingly there was little or no cross-over in the functions used between the American and European studies, reflecting the existence of a substantial effects literature on both sides of the Atlantic in this field. However, Hornung and Jones (1999) used American data to modify a European function developed for spring wheat according to the relative sensitivity of a number of crops for which there is little or no European data.

European experimental work has generated a number of response functions based around the AOT40 metric ozone (AOT40 being the sum of hourly concentrations in excess of 40 ppb during the day [‘day’ defined as those hours with a clear sky global radiation of 50 Wm^{-2} or more] over the 3 month period with the highest running sum ozone concentration). Despite this, quantification remains controversial (Karenlampi and Skarby, 1996, and others since, have stated that AOT40 can be used to set a critical level, but not be taken further to quantification). The reason for this is that the AOT40 functions do not take account of the potential for plant response to a given level of pollution to change in response to other factors, such as the age of plants, the presence of other pollutants, time of day, temperature, water status and humidity, soil and plant nutrient status, species and cultivar, presence of pests and pathogens, and possibly other factors (ExternE, 1995a). This is partly due to the fact that AOT40 is not a direct estimate of ozone actually absorbed by the plant. Accounting for this requires use of a simple resistance model simulating ozone absorption by a vegetation canopy. Scientists working in this area have for some time been developing flux-based approaches that seek to account for some of these interactions, and these functions are beginning to emerge. An important issue for the CAFE CBA is to consider how best to use the information from both the flux based functions and the concentration (AOT40) functions in order to gain an informed view on the likely magnitude of damages across most agricultural and horticultural production.

Types of impact

This impact category is referred to here as ‘agricultural and horticultural production’ to recognise that, potentially, there could be effects on livestock production as well as crop production, even though there has been little attempt in the past to quantify the former. Impacts mapped out by pollutant are identified below. Some air pollutants other than those listed have been linked in the literature to crop damages, particularly HF, though this is outside the remit of the CAFE programme. In any event, modern industrial pollution controls should have reduced emissions of HF on agriculture to a point where they are now negligible.

Impacts of the principal CAFE air pollutants on agricultural and horticultural production

Pollutant	Effect
SO_2	• Increase in yield at low exposure, decrease in yield at high exposure • Visible injury at high concentrations (would make some leaf crops such as spinach or lettuce un-saleable) • Enhanced performance of pests and pathogens • Acidification of agricultural soils
NOx	• Enhanced performance of pests and pathogens • Reduced tolerance of other stresses (e.g. drought, cold) • Acidification of agricultural soils • Fertilisation of agricultural systems with nitrogen • Increased nitrogen run-off from agricultural systems
NH_3	• Enhanced performance of pests and pathogens • Reduced tolerance of other stresses (e.g. drought, cold) • Acidification of agricultural soils • Fertilisation with nitrogen • Increased nitrogen run-off from agricultural systems
Ozone	• Visible injury to crops • Reduction in crop yield • Enhanced performance of pests and pathogens • Interaction with climate
Particles	• Some discussion in the literature of impacts through shading effects of particles deposited on leaf surfaces • Decrease in photosynthetically active radiation reaching plants

Past analysis (e.g. the ExternE national implementation reports summarised in ExternE, 1999c) suggests that a number of these effects are now likely to be unimportant. A major reason for this is that the past few years have seen significant falls in emissions of SO_2 and other pollutants, such that in most agricultural areas concentrations are now well below those observed to cause damage. Largely in view of this the following will not be considered in detail in the CAFE process, though they will be considered, albeit briefly, in the MCA:

- Direct effects of SO_2, NOx, NH_3 and particles on yield;
- Visible injury caused by SO_2;
- Acidification of agricultural soils (which could be quantified through consideration of additional liming requirements for soils, noting that farmers routinely apply lime to counteract acidification linked to harvest);
- Fertilisational effects of deposited sulphur and nitrogen (which for nitrogen could be quantified in terms of the cost equivalent of N-fertiliser);
- Effects of nitrogen run-off.

The previous draft of this report invited stakeholders to comment on the exclusion of these effects, noting that the list contains some balance between potentially positive impacts (e.g. associated with nutrient inputs to agricultural land) and negative impacts (e.g. soil acidification and nutrient runoff). No comments were received, from which it is concluded that there is general agreement with this position.

The following effects will, however, be considered further in the CBA:

Impacts for detailed quantitative or qualitative consideration in the CAFE CBA, extent of analysis depending on the availability of data

Ozone only • Visible injury to crops • Reduction in crop yield • Interaction with climate • Reduction in livestock production	 • Qualitative discussion, possible inclusion in MCA • Quantitative assessment • Included in Level II modelling of effects on crop yield • Qualitative discussion, possible inclusion in MCA
All pollutants	• Qualitative discussion of interactions with pests and pathogens, possible inclusion in MCA

Stock at risk data

The following describes the information on crop production currently held by the CBA team, and generated at SEI-York. SEI are currently reviewing these data and assessing the potential for further improvements. These include a move to a common set of European land cover maps across those groups most active in this area. Updated maps of crop production will thus be used by the CAFE CBA team in the event that they are made available on a timescale that fits with the CAFE analysis.

The SEI-York land cover map is made up of discrete data layers (forests, semi-natural vegetation, urban, water bodies etc.) with each data layer being created by combining various existing land cover data sets. For the delimitation of agricultural areas and their linkage to the crop production statistics, the following data layers were combined: IGBP Global Land Cover (GLC) agricultural information; SEI Land Cover agricultural information and the Bartholomew Country and NUTS region boundaries

The GLC classification of agricultural classes was the dominant data source used to spatially delimit the distribution and type of crop lands across Europe. Firstly, the areas which were purely agricultural were identified, for example, "Cropland (Winter Wheat, Small Grains)". Next, the areas that were of mixed classes combined with forestry were delimited, for example, "Cropland (Rice, Wheat) with Woodland". Thirdly, areas that were mixed classes of agriculture, forestry and grassland were identified, for example, "Cropland and Pasture (Wheat, Orchards, Vineyards) with Woodland". The SEI agriculture map was then used to differentiate the extent of cropland from pasture and the distribution and classification of horticultural areas. The reclassified land use map contained approximately 250 discrete classes.

In order to combine the spatial database with statistical crop information, the agricultural map was overlaid with data sets showing the distribution of country boundaries, distribution of European NUTS level II areas and the EMEP 50km grid using unique condition modelling. This produced a database onto which country and NUTS specific information on yield and crop coverage could be appended and the results analysed by EMEP grid square. This data was then combined with statistical information from the EUROSTAT Agricultural Statistics for EU NUTS Level II and the FAO AGROSTAT Agricultural Statistics for the remaining European Countries.

For each country a specific database of the percentage coverage of crops and yields linked to the agricultural map was produced using the FAO agrostat data. For example, the grain class from the FAO map was defined as wheat, barley, rye, oats and millet with small grains being the subset of wheat, barley, rye and oats. The breakdown of the split of crop types by country in each polygon of the agricultural map was then used to calculate the area and yield of crops in each EMEP 50km grid square. A similar activity was performed for NUTS Level II regions for those countries that had reported yields and crop areas for 1999. The countries included in this more detailed disaggregation were the UK, Italy, France, Germany, Finland, Belgium and Luxembourg. The final stage of the mapping exercise required correction of estimated total yields for each country against total annual yields as reported to FAO.

Exposure-response functions

The precise approach to be used for assessment of crop damage will be developed over the coming months as part of a separate project funded by UK DEFRA that will involve assessment of the reliability of the different approaches that are outlined here. Readers should consult chapter 3 of the ICP/MM (Mapping and Modelling) report (2004) for more complete details of the functions and other information provided here. The caveats given in that report have been noted by the authors of this paper, though are not reproduced here. Information on derivation of ozone exposure data is also omitted, as this is generated by the EMEP and RAINS models, rather than within the CBA.

ICP/MM (2004) Mapping Manual provides a method for calculation of actual crop losses for wheat and potato based on flux modelling. This provides the following functions:

$RY_{wheat} = 1.00 – (0.048*AF_{st}6)$ [wheat, based on data from Finland, Belgium, Sweden and Italy, see Figure 1]

$RY_{potato} = 1.01 – (0.013*AF_{st}6)$ [potato, based on data from Finland, Sweden, Belgium and Germany, see Figure 2]

RY = Relative yield
$AF_{st}6$ = Accumulated stomatal flux of ozone over a threshold of 6 $mmol.m^{-2}$.

There is currently some debate as to what ‘threshold’ figure should be used to provide the most reliable relationship between exposure and impact on yield.

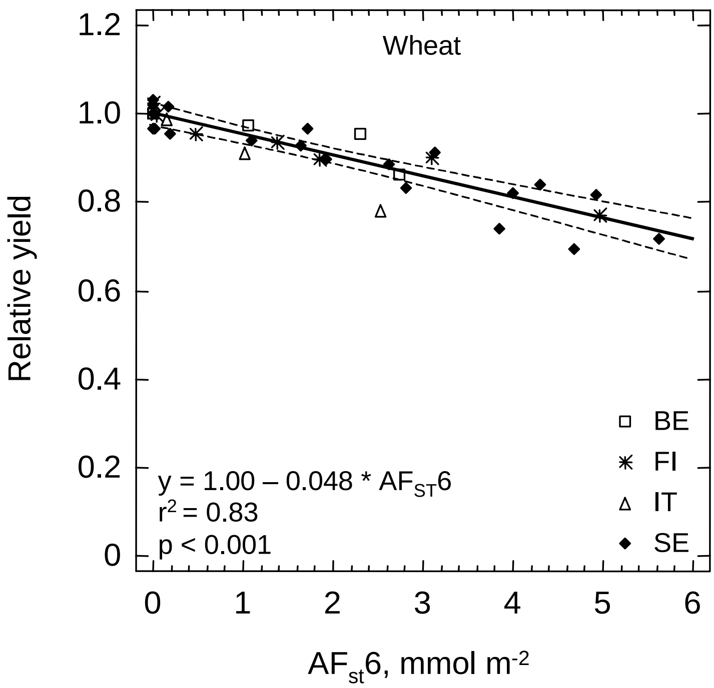


Figure 1. The relationship between the relative yield of wheat and $AF_{st}6$ for sunlit leaves in wheat based on five wheat cultivars from four European countries using effective temperature sum to describe phenology.

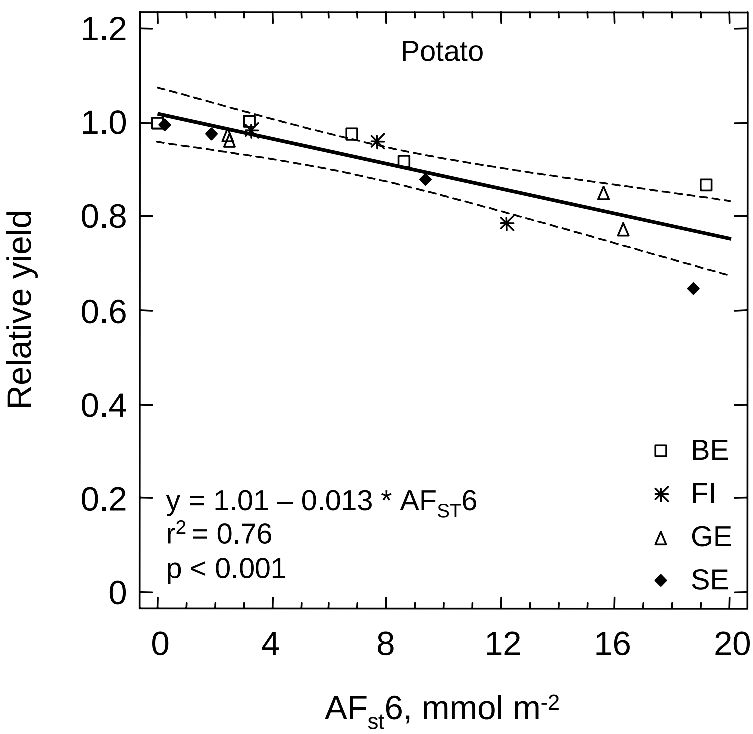


Figure 2. The relationship between the relative yield of potato and the $AF_{st}6$ for sunlit leaves based on data from four European countries and using effective temperature sum to describe phenology.

Although wheat and potato are very important crops, together they comprise only about 10% of European agricultural production. It is thus clearly desirable that a more comprehensive analysis is undertaken. There are two ways o doing this, drawing on the Level II modelling that is currently possible:

1. Adaptation of the flux based functions for wheat and potato based on relative sensitivity of other crops according to available AOT40 data. The table below reproduces one view of relative sensitivity, taken from Mills et al (2003) and cited in the mapping manual (ICP/MM, 2004).
2. Quantify using AOT40 functions modified between European regions in line with variation seen in flux-based assessments for wheat and potato.

These approaches are currently being explored in a research contract for DEFRA in the UK. Given limited availability of flux data is likely that the second option will be used.

The range of sensitivity of agricultural and horticultural crops to ozone with reference to AOT40 data (see Mills et al, 2003 for response functions and definition of sensitivities)

Sensitive (Critical Level ≤ 5 ppm.h)	**Moderately sensitive (Critical Level of 5 – 10 ppm.h)**	**Moderately resistant (Critical Level of 10 - 20 ppm.h)**	**Insensitive (Critical Level >20 ppm.h)**
Cotton, Lettuce, Pulses, Soybean, Salad Onion, Tomato, Turnip, Water melon, Wheat	Potato, Rapeseed, Sugarbeet, Tobacco	Broccoli, Grape, Maize, Rice	Barley, Fruit (plum & strawberry)

Valuation data

The valuation of impacts on agricultural production is reasonably straightforward, with estimated yield loss being multiplied by world market prices as published by the UN's Food and Agriculture Organization. World market prices are used as a proxy for shadow price on the grounds that they are less influenced by subsidies than local European prices (in other words, they are closer to the 'real' price of production).

In the event that impacts were large enough to change decisions that farmers take regarding the types of crop under production it would be desirable to perform analysis of the agricultural sector *per se*, rather than just production of a series of individual crops. However, we have no evidence that this is currently the case.

Valuation data for agricultural crops. All data taken from the FAO website, 2000.

	€/tonne		€/tonne
Barley	120	Pulses	320
Carrots	340	Rape	240
Cotton	1350	Rice	280
Fresh vegetables	340	Rye	80
Fruit	680	Soya	230
Grape	360	Sugar beet	60
Hops	4100	Sunflower	240
Maize	100	Tobacco	4000
Millet	90	Tomato	800
Oats	110	Water melon	140
Olives	530	Wheat	120
Potatoes	250		

Approach to non-quantified impacts

Referring back to the list of impacts to agriculture from air pollution exposure given above, it is apparent that the analysis defined above omits a number of potentially important impacts on agricultural production:

1. Visible injury from ozone exposure;
2. Effects of ozone on livestock productivity, and associated products such as milk;
3. The consequences for crop yield of interactions between various pollutants and pests and pathogens.

These three issues have been taken forward to the extended CBA (the datasheet for visible injury was shown in Appendix 5). Irrespective of whether experts are willing to make a quantitative judgement or a purely qualitative one, the results of the extended CBA discussion should be kept distinct from the results of the full quantitative assessment in the interests of transparency.

Possible future changes to the methodology for agriculture

Some refinement of methods will be made when the results of another contract funded by UK DEFRA become available in early 2005. This will consider the uncertainties in flux based modelling and AOT40 type modelling, and thus the reliability of methods for extrapolating from one to the other.

Appendix 7
Further information on the Treatment of Effects on Materials

Types of impact

Air pollution is associated with a number of impacts on materials:

- Acid corrosion of stone, metals and paints in ‘utilitarian’ applications;
- Acid impacts on materials of cultural merit (including stone, fine art, and medieval stained glass, etc.);
- Ozone damage to polymeric materials, particularly natural rubbers;
- Soiling of buildings and materials used in other applications.

Of these, monetary quantification has been carried out for all groups in previous studies, though not necessarily at the European scale, and economic assessments of impacts on cultural heritage are very limited. An alternative approach developed by ICP Materials for informing decision makers is based on assessment of ‘acceptable rates’ of deterioration, on the basis that materials left in the open air will be damaged even in the absence of air pollution. This approach is discussed in more detail below, though of course the concept of an ‘acceptable rate’ begs the question of what is acceptable.

Acid damage to materials in ‘utilitarian’ applications

This section deals with damages to materials in utilitarian applications, in other words, those used in buildings, etc., of no special cultural merit. This would include most modern houses, factories, railway buildings, etc.

The following text is taken from the website of ICP Materials and describes trends in damage, which clearly show benefits of existing action on air pollution in Europe. The trend exposure consisted of repeated 1-year exposures of steel and zinc on 39 test sites during the period 1987-1995. Of the environmental parameters investigated only concentrations of SO_2, NO_2 and H^+ (acidity) exhibit trends. All of these are decreasing with SO_2 having the strongest trend and NO_2 the weakest. For O_3 no specific trends were observed. The decreasing trend in the concentration of acidifying air pollutants has resulted in decreasing corrosion rates of the exposed materials. Both carbon steel and zinc show reduced corrosion rates in unsheltered as well as in sheltered positions, with changes in SO_2 levels being the largest single contributing factor to the trends. The decreasing acidity of precipitation is a contributing factor, though its effect is much smaller than that of dry deposition. The decrease in corrosivity is generally larger than expected from the drop of SO_2 and H^+ concentrations (reflecting uncertainty in exposure-response relationships). This part cannot be directly related to a specific pollutant and reflects the multi-pollutant character of process of material degradation.

Framework for assessment

Assessment of acid damage to building materials in everyday applications uses the following framework, which is broadly similar to that described elsewhere in this paper:

1. Describe the stock-at-risk in terms of the exposed area of sensitive materials on buildings and other structures within each country;

2. Describe background pollution levels (important because of non-linearities in exposure-response);
3. Describe climatic variables relevant to the response functions;
4. Apply material-specific response functions that provide estimates of the rate of corrosion, etc.;
5. Assess rate of deterioration against a critical loss of material to define change in maintenance or replacement frequency;
6. Value using standard maintenance cost data from reference sources used by builders and architects.

Stock at risk data
The stock at risk is derived from data on building numbers and construction materials taken from building survey information. The information listed here was collated for the EC ExternE Project (European Commission, 1995a, 1999a). Inventories are generally developed for individual cities; these can then be extrapolated to provide inventories at the national level (accepting the uncertainties inherent in the extrapolation). For countries for which data are not available, values must be extrapolated from elsewhere, though this inevitably results in lower accuracy. In general it is assumed that the distribution of building materials (m^2) follows the distribution of population (i.e. m^2/person). Sources of data are as follows:

Eastern Europe (including the eastern Lander of Germany):
Kucera *et al* (1993a,b), Tolstoy *et al* (1990) - data for Prague

Scandinavia:
Kucera *et al* (1993 a,b), Tolstoy *et al* (1990) - data for Stockholm and Sarpsborg

UK, Ireland:
Ecotec (1996), data for UK extrapolated to Ireland

Western Lander of Germany:
Hoos *et al* (1987) - data for Dortmund and Köln

Other western Europe:
Average of material use per person from Hoos *et al*, Kucera *et al* and Tolstoy *et al* (excluding Prague), and Ecotec.

For galvanised steel in structural (non-building) applications an average of material data was derived from European Commission (1995a) and Kucera *et al* (1993 a,b).

Exposure-response functions
The following series of exposure-response functions is taken from the ICP Materials (2003) website. Functions are based on exposures over an 8 year period (1987 to 1995). The most important for the CAFE assessment are likely to be those relating to steel, zinc and stone (limestone and sandstone), and application for mortar and rendering. The ICP has generated other functions, for example for copper, cast bronze some types of glass and some electric contact materials. These are not reproduced here as they are of limited relevance to utilitarian material applications, though they are of course important for consideration of effects on cultural heritage. Finally, there are also functions for paint damage, though previous work (e.g. in ExternE) has found the use of these functions difficult.

Key:
ML = Mass loss (g/m^2)
SO_2, NO_2, O_3 = concentration in $\mu g.m^{-3}$
T = temperature (C)
Rain = precipitation (mm/year)
H^+, Cl^- = hydrogen and chloride ion concentration in rainfall (mg/l)
R = surface recession (µm)
Rh = relative humidity (%)
t = time in years
ASTM is the degradation of coatings measured according to ASTM D 1150-55, 1987, giving a range between 1 and 10 where 10 corresponds to an unexposed sample.

Unsheltered Exposure

Weathering steel (N=148, R^2=0.68)
$$\mathbf{ML = 34[SO_2]^{0.33}exp\{0.020Rh + f(T)\}t^{0.33}}$$
f(T) = 0.059(T-10) when T<10°C, otherwise -0.036(T-10)

Zinc (N=98, R^2=0.84)
$$\mathbf{ML = 1.4[SO_2]^{0.22}exp\{0.018Rh + f(T)\}t^{0.85} + 0.029Rain[H^+]t}$$
f(T) = 0.062(T-10) when T<10°C, otherwise -0.021(T-10)

Aluminium (N=106, R^2=0.74)
$$\mathbf{ML = 0.0021[SO_2]^{0.23}Rh\cdot exp\{f(T)\}t^{1.2} + 0.000023Rain[Cl^-]t}$$
f(T) = 0.031(T-10) when T<10°C, otherwise -0.061(T-10)

Portland limestone (N=100, R^2=0.88)
$$\mathbf{R = 2.7[SO_2]^{0.48}exp\{f(T)\}t^{0.96} + 0.019Rain[H^+]t^{0.96}}$$
f(T) = -0.018T

White Mansfield sandstone (N=101, R^2=0.86)
$$\mathbf{R = 2.0[SO_2]^{0.52}exp\{f(T)\}t^{0.91} + 0.028Rain[H^+]t^{0.91}}$$
f(T) = 0 when T<10°C, otherwise -0.013(T-10)

Coil coated galvanised steel with alkyd melamine (N=138, R^2=0.73)
$$\mathbf{(10\text{-}ASTM) = (0.0084[SO_2] + 0.015Rh + f(T))t^{0.43} + 0.00082Rain\cdot t^{0.43}}$$
f(T) = 0.040(T-10) when T<10°C, otherwise -0.064(T-10)

Steel panels with alkyd (N=139, R^2=0.68)
$$\mathbf{(10\text{-}ASTM) = (0.033[SO_2] + 0.013Rh + f(T))t^{0.41} + 0.0013Rain\cdot t^{0.41}}$$
f(T) = 0.015(T-11) when T<11°C, otherwise -0.15(T-11)

Exposure under a sheltering roof

Weathering steel (N=148, R^2=0.76)
$$\mathbf{ML = 8.2[SO_2]^{0.24}exp\{0.025Rh + f(T)\}t^{0.66}}$$
f(T) = 0.048(T-10) when T<10°C, otherwise -0.047(T-10)

Zinc (N=91, R^2=0.80)
$$\mathbf{ML = 0.058[SO_2]^{0.16}Rh\cdot exp\{f(T)\}t^{0.49}}$$
f(T) = 0.039(T-10) when T<10°C, otherwise -0.034(T-10)

The exposure-response functions require data on meteorological conditions. Of these, the most important are precipitation and humidity. Data have previously been taken from the information collated from the ICP Materials sites, and used in the ExternE project. Further data from EMEP will be used in CAFE.

To convert mass loss (ML) for metals into an erosion rate in terms of material thickness, simply requires knowledge of the density of the materials concerned (e.g. for zinc a density of 7.14 tonnes/m^3 can be assumed).

A few issues are relevant for implementation:

- Dose-response functions for stone materials are based on a combination of functions from sheltered and unsheltered conditions. These reflect different deterioration mechanisms. We only apply dose-response functions for unsheltered conditions. For sheltered conditions the possibility of including soiling effects is investigated in a later section. The inventory therefore needs to make an estimate of the proportion of unsheltered material.
- Based on observation it is assumed that some common building materials are unlikely to be affected by air pollution, these being brick and aluminium. The reference to brick does not include surrounding mortar, which is considered sensitive.
- ICP Materials functions only exist for limestone, sandstone and zinc. Other materials (mortar, rendering, and galvanised steel) are expected to behave similarly to sandstone or zinc.

Given rather limited European data on the response of paints to acid deposition, past work on the NEC Directive used functions from a US source (Haynie, 1986) to assess damage to carbonate- and silicate-based paints. Given the age of these functions, and the rate at which paint technology has developed in the last 20 years, it is not clear how useful they would be in a current European assessment. It may be worth discussing their possible use in sensitivity analysis. The ICP analysis also includes two functions for paint (Coil coated galv. steel with alkyd melamine). The critical point for the paint coating material is when ASTM=5. However, in order to implement these function, an estimate is needed of the baseline status of material. Previous implementations (e.g. in ExternE) have therefore not progressed to quantification.

Consideration is being given to the updating of this inventory considering more recent sources of data, for example as presented at Modern Methods Of Corrosion Monitoring For Estimation Of Substantial Losses And Costs.19-21 May 2003, Jurata, Poland (http://www.imp.edu.pl/corprot), and the City of Tomorrow Workshop that took place in London in June 2004.

Valuation

Valuation of the loss of material requires some assumption to be made about human behaviour in relation to maintenance. In past work (e.g. European Commission, 1995a, 1999a; AEA Technology, 1999) it has been assumed that the owners of buildings and other structures are perfectly rational and undertake maintenance once a ‘critical thickness’ of material has been lost (corresponding to the time when it is most economically appropriate to undertake repair or maintenance), and prior to secondary damage (e.g. wood rot in window frames) becomes a problem. Assumptions on the critical thickness loss for maintenance and repair of different materials are as follows:

Assumed critical thickness for maintenance or repair measures for building materials.

Material	Critical thickness loss
Natural stone	3-5 mm
Rendering	3-5 mm
Mortar	3-5 mm
Zinc:	
Construction - sheet and strip	25 µm
Other construction, agriculture and street furniture	50 µm
Pylons, other transport	100 µm
Galvanised steel	15 - 120 µm
Paint	20 - 100 µm

Critical thicknesses were quantified as follows:

- For zinc, galvanised steel and paint, from information on the thickness of the coating.
- For stone and stone-based materials, from consideration of the average amount of degradation across a surface that would necessitate repairs being made. On any surface of any significant size it is likely that some areas suffer much heavier damage than others, so implicit within the 3-5 mm average is an assumption of degradation by 1 cm or more in some parts. This is sufficient to prompt most home-owners to undertake repairs, such as repointing the mortar-work between bricks.

Valuation data, derived using reference materials used by the building trade, are given below:

Repair and maintenance costs [€/m^2] proposed for this analysis.

Material	€/m^2
Zinc	21
Galvanised steel	25
Natural stone	235
Rendering, mortar	25
Paint	11

Uncertainties in the quantification

A series of uncertainties are present in the proposed analysis, of which the following appear likely to be the most important:

1. Development of the inventory of stock-at-risk, involving extrapolation of data from a number of studies in specific cities;
2. Application of a limited number of response functions to materials that will vary in some ways from the experimentally exposed samples;
3. Extrapolation of response data from small samples to materials used on buildings which will differ in their exposure characteristics;
4. Determination of the critical thickness for the different materials;
5. Assumption that building (etc.) owners react to material damage in a purely rational manner.

Further useful information for the CAFE work was also presented at the City of Tomorrow workshop, held in London in June 2004. There is also a benefit study on materials and cultural heritage that has been commissioned by the Ministry of Housing, Spatial Planning and the Environment in the Netherlands. The results of these will be used to update the analysis presented here ready for the final methodology.

Acid damage to cultural heritage

Introduction

Corrosion of cultural heritage from acid rain leads to irreversible damage, as restoration will never be able to return the undamaged originals. Against this, materials exposed to even an unpolluted atmosphere will degrade over time, but at a much slower rate.

Quantification based on the impact pathway approach as used for acid damage to utilitarian buildings is not possible for cultural heritage for the following reasons:

- An appropriate stock-at-risk does not exist for European cultural heritage;
- Critical thickness for damage will vary considerably;
- Valuation will also vary considerably.

In this CBA a better way to value damages to cultural heritage would be to elicit the willingness-to-pay (WTP) of European households for a reduction in damages through the CAFE programme; either by way of a new valuation study or in a benefit transfer (BT) exercise. Due to the scarcity of time and resources to do a new European-wide valuation study, an evaluation of the potential for BT from the current stock of CV studies of cultural heritage has been undertaken. This analysis relies heavily on the work by Navrud and Ready (2002); which was conducted as part of the REACH project.

Lessons learned from valuation studies of cultural heritage

Navrud and Ready (2002, chapter 15) review 27 studies valuing different types of cultural heritage, ranging from rock carvings and cathedrals to historical cities, from local to global goods such as the UNESCO World Heritage site at Stonehenge. The review considered data from developing and developed countries and transition economies. The table below lists all 27 studies and provides a summary of their results. While the conclusions of each study are different, some consistent findings emerge from the studies:

a) Few economic valuation studies have been undertaken in the area of cultural heritage (either built or movable heritage). All studies reviewed here use stated preference methods, mainly contingent valuation. There exist very few applications of revealed preference methods (and these are travel cost studies of performing arts).
b) The existing studies vary widely both in terms of the type of good or activity being analysed and the type of benefit being evaluated. There are some instances where similar goods were evaluated. However, the type of benefit estimated is usually different as is the sample frame used, making it difficult to make meaningful comparisons between studies.
c) Generally, the findings suggest that people attribute a significantly positive value to the conservation or restoration of cultural assets. The implication is that damages to cultural goods are undesirable and that the public would be willing to pay positive amounts to avoid them or to slow the rate at which they occur.

d) Several of the studies show a relatively large proportion of respondents stating a zero WTP (up to 89%). Some of these responses can be considered protests against some aspect of the survey instrument (i.e. a dislike of paying taxes or a rejection of the contingent scenario) and thus are not a reflection of people's true preferences. Others, however, are 'genuine' zero values arising from budget constraints, lack of interest in cultural issues and from the fact that cultural heritage preservation is typically ranked low amongst competing public issues, as is shown consistently by attitudinal questions. Hence, the welfare of a significant proportion of the population seems to be unaffected by changes in cultural goods/activities.
e) Values for users (visitors or residents) are invariably higher than for non-users. This indicates that there can be significant values from recreation and education visits. A number of issues should be taken into account when designing pricing mechanisms: the implications of the current focus on making heritage available to the general public; and the possible trade-off between access and conservation that suggests the importance of calculating congestion costs and tourist 'carrying capacity' of a site. However, user values alone may not be enough to deliver sustainability for the large majority of cultural goods and services;
f) Non-visitor benefits are positive. In cases where the relevant population benefiting from improvement or maintenance of the cultural good is thought to be very large, possibly crossing national borders, the total aggregated benefit can be very large. This is the case when unique and charismatic cultural heritage goods are at stake. However, the available evidence also suggests that the proportion of those stating zero WTP is largest amongst non-users;
g) The issue of competing cultural goods and of part-whole bias (when the value of a group of cultural goods is not significantly different from a smaller subset of those goods) has been insufficiently addressed by the existing studies. This issue may be less of a problem for flagship cultural goods with no substitutes (e.g. the Pyramids in Egypt), but may be very severe when cultural goods perceived as being non-unique are being evaluated (e.g. historical buildings, castles, churches and cathedrals). If this bias exists, the estimated values for a particular cultural good may reflect a desire to preserve all similar goods, and thus overstate the value of the good;
h) Little attention has been given to the periodicity of the elicited WTP values. While it is difficult to compare values across studies of different goods, there appears to be a pattern where less periodic payments result in lower WTP amounts. This could be an indication of temporal embedding, where respondents may give lump-sum amounts that are lower than the present value of periodic WTP values using market discount rates. Tests for this kind of bias should be incorporated in studies using one-off or very periodic payments.
i) Finally, we see authors dedicating a great deal of attention to presenting an accurate description of the good to be valued, presented in a form that meaningful to the respondent. This has two components. First, it is of critical importance that the level of provision of the good match expert assessments of the with-project situation. For example, when valuing impacts from air pollution, it is necessary to match up the valuation scenarios with projections made by atmospheric and materials scientists. Second, these differing levels of quality must be presented in a way that respondents can understand. Several of the studies included photographs and maps to help in this regard.

It is striking to note that all of these conclusions apply equally to studies that value environmental goods. There, we have an equally diverse set of goods that can have values that are highly site-specific, though far more environmental valuation studies have been conducted to date than cultural heritage valuation studies. There too we often see a combination of large use values per person held by a few visitors and small non-use values per household held by a large population of non-visitors. Likewise, in environmental valuation, we face part-whole and embedding issues requiring careful construction and pre-testing of the survey instrument. Finally, presenting an accurate and meaningful description of the good to be valued is equally important when valuing environmental goods, and we see many of the same types of visual aids in use.

While the valuation of cultural heritage goods is certainly challenging, it is no more challenging, or fundamentally different, from the valuation of an environmental good that has a significant non-use component. We expect non-market valuation techniques to perform equally well for cultural heritage goods as they have for environmental goods, where literally thousands of studies of have been conducted.

Review of cultural heritage valuation studies. Studies presented in Navrud & Ready (2002) are numbered according to their chapter number. Other studies are assigned a letter, for use in Table 2. Source: Navrud & Ready, table 15.1

Study and nature of the asset	WTP (US$) [1]	WTP definition[2]	Annuity (US$)[3]	% zero WTP	% of stated income [4]
Valuing the impacts of road improvements upon Stonehenge, UK. Contingent valuation * (Chapter 7)	20-23: on-site, nationals 6-11: off-site, nationals 0.3-2: on-site, foreigners	Household, annual, 2 years, PC/CA, tax, (entry fee for foreigners)	2.3-2.7 0.7-1.3 0.02-0.1	55% 65%	0.08-0.09 0.03-0.06 0.0001-0.0004
Valuing aesthetic changes in the Lincoln Cathedral due to air pollution, UK. Contingent valuation. (Chapter 5)	1-2 per year of soiling, residents of Lincolnshire	Household, annual, DB DC, tax	1-2	<19%	0.005-0.01
Non-Moroccan values for rehabilitating the Fes Medina, Morocco *. Contingent valuation. (Chapter 9)	38-70: Fes visitors 22-31: Morocco visitors 6-17: European non-visitors	Individual, per trip, SB DC tax Household One-time Payment, OE	2.4-4.4 1.4-2.0	Approx. 17% Approx. 19%	n.a.
Non-Moroccan values for rehabilitating the Fes Medina, Morocco *. Carson et al 2001 - M Delphi - Contingent Valuation Survey of 30 European environmental economists		none	0.4-1.1	> 15 %	n.a.
Valuing access to Durham Cathedral, UK *. Contingent valuation. (Chapter 4)	1.4	Individual, per visit, OE, fee	56 (average no.visits = 41)	36%	0.2
Valuing the preservation of Bulgarian monasteries, Bulgaria *. Contingent valuation (Chapter 6).	0.6-1	Household, annual, OE, tax	0.6-1	39%	0.1-0.2
Valuing acid deposition injuries to marble monuments in Washington, DC, USA Contingent valuation. (Chapter 11)	16: low impact 23: medium impact 33: high impact	Household, one-time only, CA, none	1.0 1.5 2.1	8% (approx.)	0.003-0.006

Study and nature of the asset	WTP (US$) [1]	WTP definition[2]	Annuity (US$)[3]	% zero WTP	% of stated income [4]
Valuing the conservation of Campi Flegrei archaeological park in Napoli, Italy. Contingent valuation. (Chapter 10)	216	Individual, Annual, 5 years, SB DC, donation	58	18% (approx.)	0.5
Renovation of historical buildings in Grainger City, Newcastle, UK. Contingent valuation. (Chapter 4)	16-22	Household, annual, OE, tax	16-22	47%	n.a.
Recreational value of aboriginal rock paintings, Nopiming Park, Canada. Contingent valuation (Chapter 8)	134	Individual, annual, CB, travel cost	134	n.a.	n.a.
Valuing the right to access two Italian art museums at present charges. Contingent valuation. (Chapter 12)	28-33	Individual, annual, SB DC, donation	28-33	18% (approx.)	n.a.
Valuing visitor benefits to Warkworth Castle. UK. Contingent valuation. (Chapter 4)	4	Individual, per visit, OE, fee	4 (average no. of visits = 1)	n.a.	0.01
Value of continuing current activities of the Royal Theatre in Copenhagen. Contingent valuation. (Chapter 13)	9-24	Individual, annual, OE, tax	9-24	18%	n.a.
Maintaining the Napoli Musei Aperti. Contingent Valuation (Chapter 14)	11 (users) 4 (non users)	Household, annual OE donation	11 4	34% (users) 67% (non-users)	n.a.
Damages from air pollution on the Nidaros Cathedral, Norway. Contingent valuation. (Chapter 3)	51: originality preserved 45: restoration - losing originality	Individual, annual, OE, tax and donation	51 45	9-20 % (domestic visitors) 38-49 % (foreign visitors)	n.a.
Damages from traffic-caused air pollution on historical buildings in Neuchatel, Switzerland. Contingent valuation. Grosclaude and Soguel, 1994 - A	77-86	Individual, annual, BG, donation	77-86	43%	n.a.
Arts support (theatre, opera, ballet, music, visual arts, crafts), Sydney, Australia. Contingent valuation. Throsby and Withers, 1986 -B	18-111	Individual, annual, OE, tax	18-111	n.a.	n.a.
Prehistoric cave paintings preservation programs (two hypothetical new caves discovery in Peak District, U.K). Contingent Valuation Coulton 1999- C	1 (two caves open to public, none exist in 50 years) 14 (one cave open to public, one cave protected and exist in 50 years)	Individual, One time, OE tax	0-1	85 % 29 %	0-0.00003
Restoring historic core of the city of Split, Croatia, Contingent Valuation Pagiola 1999 - D	44 (domestic and foreign tourists) 168 (local residents)	Individual, per visit Individual, annual DB DC, tax	n.a. 168	n.a. n.a.	n.a

Study and nature of the asset	WTP (US$) [1]	WTP definition[2]	Annuity (US$)[3]	% zero WTP	% of stated income [4]
Machu Picchu, * Peru. Contingent valuation. Hett and Mourato, 2000 - E	47 (foreign tourists) 26 (Peruvians)	Individual, per visit, PC entry fee	47 26	n.a	0.07 0.26
Picture library, UK. Contingent valuation. EFTEC, 2000 - F	12	Individual, annual PC	12	10%	n.a
History (recorded heritage) centre. .Contingent Valuation, EFTEC, 2000 - G	34 (users, loss of access, but collection protected) 48 (users, loss of access and collection) 18 (non-users, loss of access and loss of collection)	Individual, annual PC	34 48 18	n.a	n.a
Preservation of the St. Genevieve Academy. Contingent Valuation Whitehead et al, 1998 - H	5-6	Household, one-time PC donation	0.3-0.36	61%	0.001
Preservation of the Northern Hotel in Fort Collins Contingent Valuation. Kling et al, 2000 – I	86 (tax, low information) 126 (tax, high information) 195 (foregone rebate, low information) 434 (foregone rebate, low information)	Household, one-time DC	5 8 12 26	n.a.	n.a.
Congestion in the British Museum., Conjoint Analysis Maddison and Foster, 2001 - J	9 (marginal congestion cost per visitor)	Individual Per visit CA entry fee	n.a.	n.a.	0.01
Restoring Stone Town *, Zanzibar Contingent Valuation. Bølling and Iversen, 1999 – K	20 (tourists)	Individual Per visit OE / SB DC arrival fee	n.a.	n.a.	n.a.
Rehabilitating Colon Theatre, Buenos Aires, Argentina Conjoint Analysis Roche Rivera (1998) - L	58 (Local residents)	Individual, Annual SB DC tax	58	n.a.	n.a.

Source: Based partly on Pearce and Mourato (1999) and Pearce, Maddison and Pollicino (2001)

Notes: * Is or includes a site listed in UNESCO's World Heritage List; n.a. = data not available 1 Using average exchange rates for the year of the study; 2 Individual or household; periodicity; elicitation format (OE: open-ended; PC: payment card; BG: bidding game; SB DC: single-bounded dichotomous choice; DB DC: double-bounded dichotomous choice; CA: conjoint analysis; CB: contingent behaviour); payment vehicle (tax, donation, entry fee, arrival fee, travel cost); 3 Estimated annuities were calculated for a time horizon of 50 years using a discount rate of 6%; 4 Gross annual household returns

Potential for benefit transfer of cultural heritage values

One lesson we can take from the environmental valuation literature is that benefit transfer, that is the application of values estimated at one site to policy issues at a geographically different but similar type of site, is often unreliable. Environmental values and cultural heritage values are naturally highly site- and good-specific.

It may turn out that groups of cultural heritage goods have similar values. To date, there are too few studies to judge the extent to which values for cultural heritage vary. The table below attempts to classify the valuation studies of cultural heritage by type of object and policy question addressed. Whether value estimates will vary much from site to site and good to good is still an open question. We can state, however, that for benefit transfer to work at all, it must be between sites that are very similar, both in the physical good being valued, the change in the good and the population holding the values. Very few studies address damages to cultural heritage from air pollution, and it is not advisable to generalize values from these studies to all cultural heritage damaged by air pollution in Europe. Meanwhile, impacts on cultural heritage could be addressed by expert assessment in e.g. a multi-criteria analysis framework.

Inclusion of effects on cultural heritage within the CAFE CBA

There are a number of reasons preventing the economic evaluation of damage to cultural heritage within the CAFE-CBA, as outlined in this section. For these reasons it is considered more appropriate to consider cultural heritage within the framework of the extended CBA. This should, as a minimum, highlight the risks faced by cultural heritage across Europe in a manner that provides decision makers with a better understanding of the current and future situations.

Ozone damage to polymeric materials

Although ozone is a major determinant of the lifetime of many rubber materials exposed to the ambient air, we know of only two studies in Europe that have investigated the problem from an environmental perspective. Lee et al (1996) estimated annual damages to the UK of £170 to £345 million for impacts on surface coatings (paints) and elastomers and the cost of anti-ozonant protection used in rubber goods. These estimates were based on US data from the late 1960s, demonstrating the dearth of information in this area. Lee’s work served as a scoping study for a larger project (Holland et al, 1998) that undertook experimental assessments of a range of paints (96 in all, selected to be representative of the UK market) and rubber formulations.

Various effects from ozone exposure were noted on the paint samples, including colour change, change in flexibility, resistance to petrol and water, and changes in gloss. There was no clear relationship between these changes – for example, the fact that a sample showed one effect did not mean that it would be more likely to show any of the other changes. A dose-response function was developed for colour change, which was the most common effect. Application of this function gave the result that on average most paints that were sensitive would not change colour noticeably (when compared to original samples) until about 12 years had passed. As this is longer than the service lifetime of most paints it was concluded that the direct effects of total ozone exposure on paints had no significant economic cost in the UK. The effects on paints of a marginal change in ozone levels would thus also be negligible. The possible effects of interactions of ozone with other environmental stresses in damaging paints were not addressed.

Cultural heritage studies classification. Studies that fit in two categories are listed in both. The number or letter assigned to each study refers to table.1. Studies marked with * is or includes a site listed in the UNESCO's World Heritage List. Source: Navrud and Ready (2002, table 15.2)

Type of Benefit	Type of Good				
	Single building	Group of buildings	Monuments	Archaeological areas and artefacts	Other
Protect from air pollution damages	5 - Lincoln Cathedral 3 - Nidaros Cathedral	A – Historical buildings in Neuchatel	11 - Washington D.C Monumenents		
Restore or preserve from degradation	3 - Nidaros Cathedral 5 - Lincoln Cathedral H – Northern Hotel, Fort Collins	6 - Bulgarian Monastries* 9, M - Fes Medina* 4 - Grainger City D - Historic Core of Split E- Machu Picchu* K – Stone Town of Zanizibar*		C – Prehistoric cave paintings in UK	L- Colon Theatre
Protect from urban development/ infrastructure				7 – Stonehenge 10 – Campi Flegrei Archaeological Park	
Gain access	4 – Warkworth Castle 4- Durham Cathedral			8 –Rock Paintings, Nopiming Park C – Prehistoric cave paintings in UK	12 – Art galleries in Turin
Maintain at present level	I – St. Genevieve Academy				13- Royal Theatre, Copenhagen 14 – Napoli Museui Aperti B –Performing and visual arts in Sydney F- Picture library, UK G-History (recorded heritage) Centre, UK
Reduction of congestion					J - British Museum

The work on rubber goods required development of an extensive inventory of rubber products and use for the UK. The inventory was divided into those products that would be ozone-sensitive and those that would not be (e.g. products likely to be made from some synthetic rubbers). A dose-response function was generated for crack growth in sensitive materials, allowing assessment of the lifetime of products. These data were used to estimate total annual damages to rubber goods in the UK of £35 to 189 million, with a best estimate of £85 million/year. The effect of a 1 ppb change in ozone was estimated at £4 million/year.

This latter estimate could be used to make a rough estimate of ozone damage to rubber products for the CAFE CBA work. Whilst it would not be possible to develop inventories for the whole of Europe under this project, it may be appropriate to extrapolate the UK result based on the size of each country's vehicle fleet (the motor industry dominates rubber product utilisation) using the following expression:

$$Damage / ppb\_change\_in\_O_3 = £4million \times \frac{vehicles\_in\_country\_x}{vehicles\_in\_the\_UK}$$

Soiling of buildings

Soiling of buildings by particles is one of the most obvious signs of pollution in urban areas. Soiling affects both 'utilitarian' and historic buildings and causes economic damages through cleaning and amenity costs. Particles may also be involved in damage to building fabric directly[16].

Soiling is an optical effect (a darkening of reflectance), caused primarily by the deposition of airborne particulate matter onto external building surfaces. The factors which can affect the degree of soiling include (QUARG, 1996): the blackness per unit mass of smoke; the particle size distribution; the chemical nature of the particles; substrate-particle interfacial binding; surface orientation; and micro-meteorological conditions. Similarly, different types of particulate emission have different soiling characteristics, shown in the table below. They can be differentiated by fuel type with the use of dark smoke emission factors (Newby *et al*, 1991; Mansfield *et al*, 1991). For example, diesel emissions have a much higher soiling factor relative to petrol or domestic coal emissions. This is due to their particulate elemental carbon (PEC) content (QUARG, 1993). PECs have a high optical absorption coefficient and their hydrocarbon content means they are very sticky and much less water soluble than suspended soil particles (which are readily removed by rain washing; Mansfield, 1992). Therefore, a PEC particle landing on a surface is more likely to strongly adhere than other particulate matter. Diesel emissions are the main source of atmospheric PEC in Western Europe.

Smoke emissions and relative soiling factors

Fuel	smoke emission factor (% by mass)	dark smoke emissions factor (by mass)	Soiling factor relative to coal
Coal (domestic)	3.5	3.5	1.0
Diesel	0.6	1.8	3.0
Petrol	0.15	0.065	0.43

Source: Mansfield, 1992.

16 carbon particles may play a role as a catalyst for stone erosion, particularly in the conversion of SO_2 and NO_x into sulphuric and nitric acids

Quantifying and valuing building soiling

Although soiling damage has an obvious cause and effect, the quantification of soiling damage is not straightforward. Soiling can impact on a number of different materials, including natural stone, paint, concrete, rendering and also potentially glass. The latter effect is potentially important, though there are limited studies investigating the potential effects[17]. Most analysis to date has been undertaken on stone buildings. These studies show through measurement data on reflectance (and industry experience) that soiling appears to be very rapid on clean surfaces, following initial exposure. The effect is therefore strongly non-linear. Moreover, evidence shows that reflectance measurements oscillate, indicating a cleansing and re-soiling process. This may occur as soil derived particles may be deposited on materials but are more likely to be removed by rainfall than a deposited diesel particle.

There are a number of dose-response functions in the literature for soiling. It is possible to proceed to valuation, based on cleaning due to a loss of reflectance (e.g. a 30% loss of reflectance is quoted as a trigger for repainting). A review in ExternE (Friedrich and Bickel, 2001) looked at the functions relating to an exponential and a square root model, and reviewed critical levels and repair action. The most promising function was that of Pio et al. (1998): however, this function has proved difficult to implement in practice.

As a result, a simplified approach is often used that quantifies soiling damage based on cleaning costs (in the absence of WTP data). However, as this approach does not include amenity costs, it is therefore clear that cleaning cost estimates will be lower than total damage costs resulting from the soiling of buildings. There is one study that has incorporated an amenity component, described below. This provides a function which links population weighted particle concentrations to cleaning and amenity costs.

Rabl et al (1998) looked at total soiling costs (i.e. the sum of repair cost and amenity loss). The study showed that for a typical situation where the damage is repaired by cleaning, the amenity loss was equal to the cleaning cost (for zero discount rate); thus the total damage costs are twice the cleaning costs. The study recommended the following function:

$S_i = a * P_i * \Delta TSP_i$ (where $a = b * 2$)

S_i = Annual soiling damage at receptor location i.
P_i = Number of people in location i.
ΔTSP_i = Change in annual average TSP (Total Suspended Particles) $\mu g/m^3$.
a = WTP per person per year to avoid soiling damage of $1 \mu g/m^3$ particles.
b = Cleaning costs per person per year from a concentration of $1 \mu g/m^3$ of TSP.

This function allows a site-specific assessment, linking reductions in particle concentrations with population. A value of €0.5 for cleaning costs has been used previously, based on Paris cleaning costs data**.** In applying this function, a number of considerations are important:

- PM_{10} may not be the most relevant functional unit for analysis. Instead black smoke or TSP (total suspended particulates) is a better metrics for assessing damages.

[17] Jeanrenaud *et al* (1993) looked at the social costs of transport in Switzerland. Although this study adopted a top-down methodology, it did provide estimates for window cleaning costs. The study considered commercial buildings, assuming a average unitary cost of window cleaning of $6SF/m^2$ (roughly equivalent to £3.75). The results indicate that window cleaning costs could be significant.

- Knowledge of the characteristics of different types of particulates suggests that only primary particles have soiling effects. We assume that that secondary particles formed from SO_2 (e.g. sulphate aerosol and ammonium sulphate) and from nitrates (e.g. ammonium nitrate and nitrate aerosol) are very different in nature (they do not contain PEC) and do not lead to a loss of reflectance. Note, for national or city wide measurement data, the use of measured PM_{10} would therefore need adjustment for the proportion of primary and secondary particulates in the original air pollution mixture. In the Rabl study, this implied an increase for PM_{10} to $PM_{10\ (primary)}$ of a factor of three.
- There is also a real question of a threshold for soiling. The loss of reflectance needed to trigger action, i.e. cleaning, will only occur when there is a certain build-up of particles. For this reason, observation shows that soiling is only associated with urban emissions of particles – there is no rural effect from low levels of building exposure. It is even likely that the effect is constrained to certain road types, notably street canyons, where buildings are extremely close to the roadside.

We will therefore apply the function for Rabl for quantification and valuation of soiling for urban emissions only.

Future improvements to the methods presented here

3. The most immediate improvement is likely to concern the response functions used here, as these are being reviewed under the EC's Multi-Assess Project. This is expected to report by April 2005. Any changes suggested at that time will be incorporated into the CAFE Methodology immediately.
4. Improvement of methods for quantification of damages to cultural heritage will not be made sufficiently quickly for inclusion in the CAFE programme. However, new data emerging from Multi-Assess and other projects will be reviewed for inclusion in the framework of the extended CBA.

Appendix 8
Valuation of Effects on Ecosystems

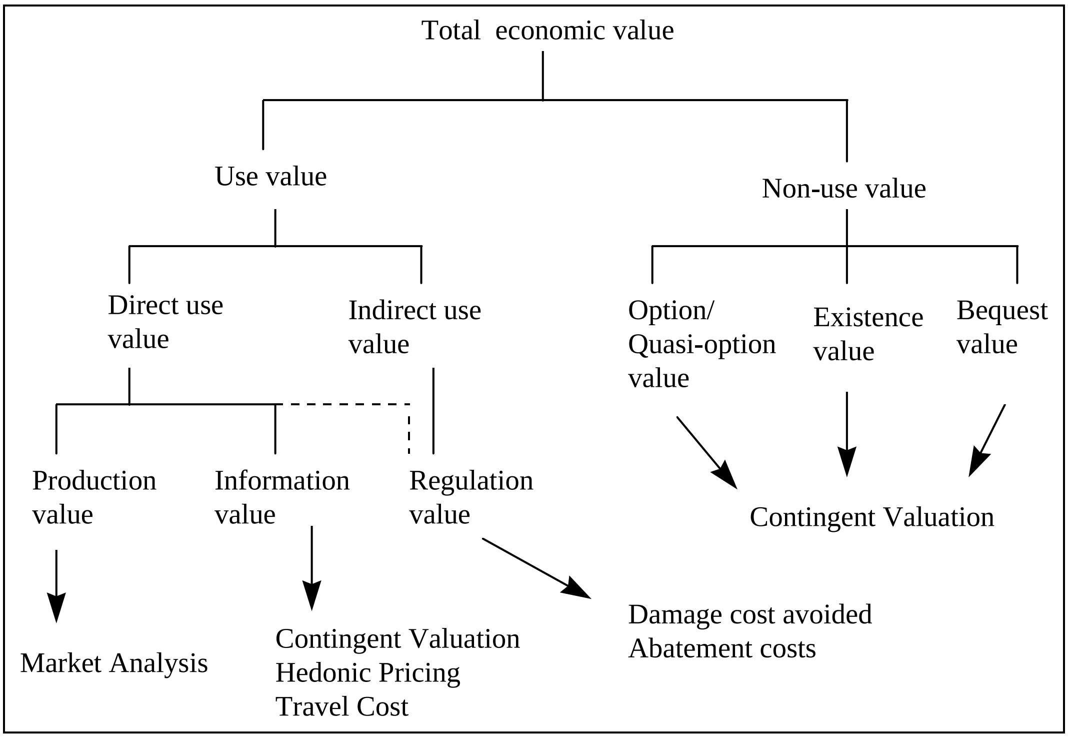
The fact that ecosystem acidification has been a key driving force behind much European legislation on trans-boundary air pollution demonstrates that it is widely recognised as an important problem. Indeed, given that air pollution impacts of trans-boundary air pollution policy on health were not considered in the development of the original UNECE Protocols on SO_2 and NOx, the estimated costs of those actions could be inferred to represent willingness to pay to protect natural ecosystems and cultural heritage. Continued omission of monetised ecosystem damage from CBA means that there appears to be a significant bias towards underestimation of total damage. [Note that this does not necessarily lead to underestimation of the total damages, as that depends on the overall balance of uncertainties across all relevant impacts.]

NEBEI (Network of Experts on Benefits and Economic Instruments) convened a workshop in October 2002 to discuss issues of ecosystem valuation, largely (though not exclusively) in the context of air pollution. A summary of the workshop is presented in a report from the Working Group on Strategies and Review (2003). Whilst recognising the role that benefits estimation might play in the assessment of legislation on air pollution, the Working Group stated that the benefits estimation should complement, rather than replace, other techniques for reporting ecological risks. This position is supported by the CBA team.

Under the EC DG Research NewExt project an attempt has been made to infer the value placed on ecosystem protection by looking at how far decision makers were prepared to go in restricting emissions under the National Emission Ceilings Directive and the Gothenburg Protocol. This ‘standard price’ or ‘control cost’ approach permits calculation of a cost per hectare no longer subject to critical loads exceedance. Problems with this technique have been widely reviewed before (e.g. ExternE, 1995a), and it is not recommended where other techniques are practicable. Even where it is the only technique available the NewExt researchers recommend that its application is limited, for example for ranking technologies. They explicitly do not recommend its use for cost-benefit analysis largely because it is self-referencing.

Ruijgrok (2003) illustrates the overall problem of ecosystem valuation using the following diagram. It demonstrates that there are a variety of aspects to the valuation of ecosystems, and that a number of different techniques are required in order to fully capture ecological value. Explanation of the different elements is given below the figure, taken directly from the Ruijgrok report.

The total economic value of nature consists of several components (Pearce and Moran, 1994; Hanley and Spash, 1997). Direct use values pertain to tradable goods such as fish and wood (production values) and to services such as the possibilities for recreators to enjoy natural beauty (information values). Indirect use values refer to supportive features of ecosystems for direct use, such as climate regulation (regulation values). Option values are values that people attach to keeping the possibility of a particular type of use open for the future, whereas quasi-option values concern unknown future use. Bequest values pertain to the value people attach to preserve natural assets for future generations. Existence values refer to the fact that people simply want certain functions or species to exist, regardless of whether or not they will ever use them. The following figure shows that only the non-use function and the information function (read: the recreational perception function) can be valued by means of CVM – other components need to be described using other techniques.



The components of the total economic value of nature

Ruijgrok (2003) provides the results of an analysis for the Netherlands, suggesting that the elements in the diagram that can be valued using contingent valuation indicate a figure for ecosystem damage from acidification in the Netherlands of €200 million per year. Whilst this indicates that some degree of valuation is possible, it still leaves elements unquantified. However, along with data from other studies, it does provide the basis for development of a position on the economic importance of ecosystem damages relative to other effects considered in the CAFE programme. These data will, therefore, be used in the extended-CBA.

Appendix 9
The GEM-E3 Model

Model and impacts for macroeconomic assessment

The workplan will use an existing macroeconomic general equilibrium model – GEM-E3 – to develop estimates of the macroeconomic impacts of improved air quality. GEM-E3 has been selected as it has been widely applied in past assessments, with the result that there is an existing awareness of its strengths and limitations.

The model and its database were updated in 2004 and extended to 8 New Member States (Hungary, Poland, Slovenia, Estonia, Latvia, Lithuania, Czech Republic and Slovakia). To ensure an overall consistency with the other models used in the project (e.g. RAINS), other updates (e.g. of the cost functions) have been undertaken for the CAFE analysis.

Using a general equilibrium model such as GEM-E3 allows to evaluate the macroeconomic impact of the environmental policies foreseen in the CAFE project and their distributional effects across countries, economic sectors and agents. The assessment will relate to the following aspects:

- the impact on employment and domestic production in the different EU countries,
- the competitiveness and terms of trade impact between EU countries and relative to the Rest of the World, both overall and at sectoral level
- the impact on GDP and welfare, inclusive the environmental benefits
- the impact on emissions and air quality, inclusive its transboundary aspects.

Results can be reported for each EU country separately and for the EU as whole.

The model allows the evaluation of policies using command and control instruments and economic instruments such as taxes or permits. As a result, the cost of the different policies in terms of the elements cited above can be compared. One other important element is that interactions in terms of both economic and the environmental aspects of different policies can be evaluated. These can be important as the air pollutant abatement possibilities are largely linked to energy consumption. The model integrates also the impact such policies can have on the world energy markets and hence their feedback on the EU economy.

The model will need as input a precise definition of the policies to be evaluated, in terms of the policy instrument to be used, the target for air quality translated into EU or country emission level, the revenue recycling strategy if the policy generates new income for the public sector.

Integration of GEM-E3 outputs with other CBA results

The main questions to be addressed through the use of the GEM-E3 model concern:

1. Will the air quality improvement policies investigated in CAFE lead to reduced competitiveness for European economies?
2. Are these policies likely to have a significant effect on employment across Europe?

It is not intended to convert results on either into a metric that could be combined directly with quantified impacts on health, agriculture, etc, to give a total for comparison with the RAINS-generated cost information. Instead, the GEM-E3 results will be used to provide an indication of the likely direction and magnitude of effects of air quality improvement policies in these areas. If macro-economic effects appear to be significant it could be appropriate to adjust policies or to investigate further before finalising recommendations.

Examples of applications of GEM-E3

- The ex-post evaluation of the impact of the Single Market Programme (Capros et al, 1997a).
- The study of the revision of the minimum excise taxation for energy products for the European Union Member States (Capros et al, 1997b and Kouvaritakis et al 2003).
- The study of the possibility for a "double dividend" for environment and employment (Capros et al, 1996).
- The evaluation of the macroeconomic implications of the European Union's targets for the Kyoto negotiations for greenhouse gas mitigation, inclusive the local benefits through the improved air quality.
- The examination of the impact of creating a market of tradable pollution permits.

Description of GEM-E3

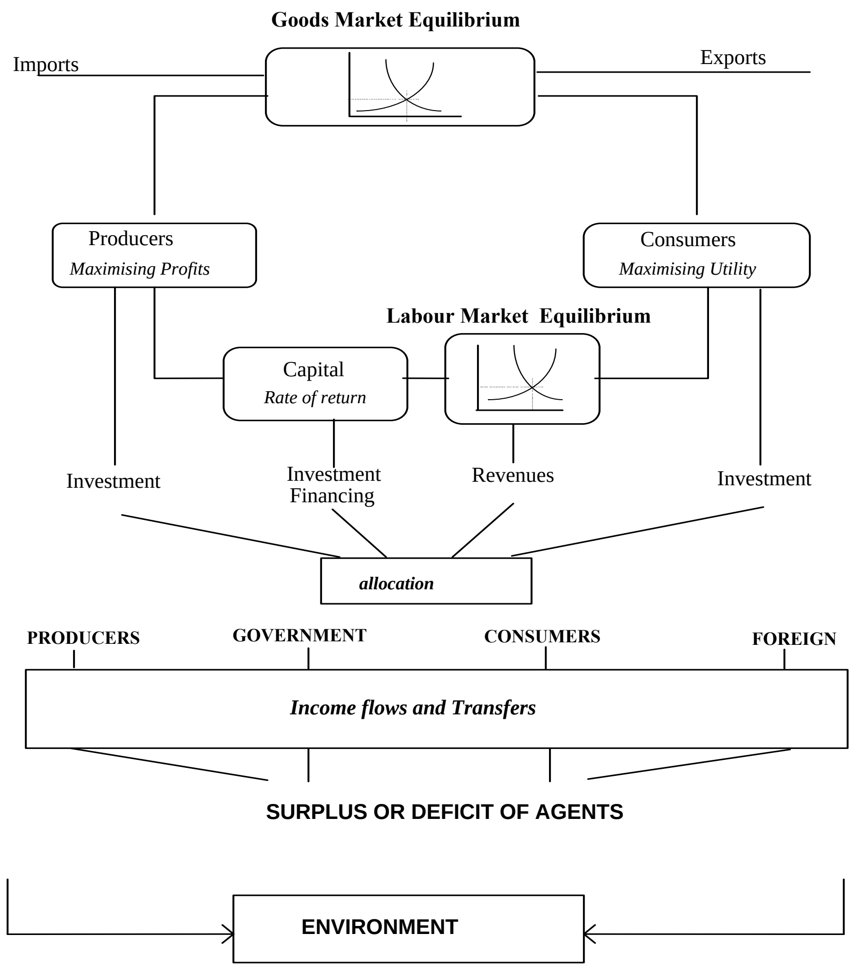
Overall description of the model

The GEM-E3 model is an applied general equilibrium model, simultaneously representing World regions or EU countries, linked through endogenous bilateral trade. It aims at covering the interactions between the economy, the energy system and the environment. The model computes simultaneously the competitive market equilibrium under the Walras law and determines the optimum balance for energy demand/supply and emission/abatement. A major aim of GEM-E3 in supporting policy analysis is the consistent evaluation of distributional effects, across countries, economic sectors and agents. The burden sharing aspects of policy, such as for example energy supply and environmental protection constraints are fully analysed, while ensuring that the European/World economy remains at a general equilibrium condition.

The model (see Figure) has the following general features:

1. It scope is general in two terms: it includes all simultaneously interrelated markets and represents the system at the appropriate level with respect to geography, the sub-system (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.
2. It formulates separately the supply or demand behaviour of the economic agents which are considered to optimise individually their objective while market derived prices guarantee global equilibrium
3. It considers explicitly the market clearing mechanism and the related price formation in the energy, environment and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed

4. The model is simultaneously multinational (for the EU or the World) and specific for each country/region; appropriate markets clear European/World wide, while country/region-specific policies and distributional analysis are supported
5. Although global, the model exhibits a sufficient degree of disaggregation concerning sectors, structural features of energy/environment and policy-oriented instruments (e.g. taxation). The model formulates production technologies in an endogenous manner allowing for price-driven derivation of all intermediate consumptions and the services from capital and labour. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services. The model is dynamic driven by accumulation of capital and equipment. Technology progress is explicitly represented in the production functions and for each production factor.
6. The model formulates pollution permits for atmospheric pollutants and flexibility instruments allowing for a variety options, including: allocation (grandfathering, auctioneering, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc.



Basic structure of GEM-E3

The Current Operational Versions of the Model

There are two versions of GEM-E3, GEM-E3 EUROPE and GEM-WORLD. They differ in their geographical and sectoral coverage, but the model specification is the same. They use the GAMS software and are written as a mixed non-linear complementarity problem solved by using the PATH algorithm.

Geographical Aggregation

The World version of GEM-E3

The model uses the GTAP-4 database and the IEA energy statistics. The base year is 1995. The GTAP database includes more than 50 world regions, which have been aggregated into 21 regions. The model code allows however for a user-defined aggregation of regions and definition of the regional coverage of the model. The 21 regions are:

Australia and New Zealand, Japan, China, India, Rapid growing Asian countries, Rest of Asia, USA, Canada, Mexico and Brazil, Rest of Latin America, Northern EU countries, Germany, UK, Rest of European Union, Other European countries, Central European Associates, Former Soviet Union, Mediterranean countries, Middle East, Africa, Rest of the World.

The European version of GEM-E3

The European version covers 22 EU countries and the ROW (in a reduced form) and is based on the EUROSTAT database (IO tables and National Accounts data). The base year is also 1995.

Sectoral disaggregation

The model distinguishes 18 productive branches:

Agriculture	
Energy	solid fuels, crude oil & refined oil products, gas, electricity
Manufactured goods	ferrous and non ferrous ore/metals, chemical products, other energy intensive goods, electric goods, transport equipment, other equipment goods, consumer goods, building and construction (in the World version, consumer goods are further disaggregated into food, textile and other products)
Services	telecommunications, transport, credit and insurance, other market services, non market services (the World version has only two market services, trade & transport and other market services)

The data base of the World model includes more than 50 production branches. The model code allows for a user-defined aggregation of branches and traded products.

The model specification

Domestic producer behaviour

Domestic production

For each branch, domestic production is represented through a nested separability scheme involving capital, labour, electricity, fuels and materials. Fuels are further divided in coal, gas and oil and materials in fourteen categories of inputs.

First, production is split into two aggregates, one consisting of capital stock and the other aggregating labour, materials, electricity and fuels. Further down, the aggregate is first split into electricity and the other inputs, then the other inputs into labour, materials and fuels, the ensuing production functions are further divided in their components parts. The CES

(Constant Elasticity of Substitution) specification, with factor augmenting technical change, is used throughout. It allows also a coherent representation of the branch reaction (e.g. production factor switching or emission abatement) towards the use of environmental instruments, such as tradable permits, environmental taxation or standards. The model uses dual unit cost functions to represent the supply behaviour of the producers and derives factor demand by means of the Shephard lemma.

Investment demand
The desired demand for capital, which fixes the investment demand of the firms, is determined through their optimal decision on factor inputs. The assumptions regarding the expectations of producers on future prices, interest rate and growth of the economy are important for the dynamic characteristics of the model. As the stock of capital is fixed within the year in GEM-E3, the investment decision of the firms affects their production frontier only the next year.

Consumer behaviour
Consumption
The household behaviour is represented by an inter-temporal model of the household sector. In a first stage the household decides each year on the allocation of its resources between present and future consumption of goods and leisure. This decision is modelled as the maximisation of an inter-temporal utility function under a life-time resource constraint, using a LES formulation. It derives the saving and consumption by households and their labour supply.

In a second step, the household allocates its consumption between durable goods and non-durables, again through a LES scheme. The categories of goods considered in the model are :

non durables	food, beverages & tobacco, fuel and power, housing, house furniture, purchased transport, operation of transport, clothing, medical and health expenditure, communication, recreation, entertainment, other services
durables	cars, heating systems, electric appliances

Special care is given to the treatment of durable goods by explicitly linking the consumption of specific non durables to the stock of durable. The price of the durable used in the consumption decision thus reflects not only the market price of the durable but also the price of the non durables linked to the durable. It can also incorporate the cost for the consumer of environmental policies.

The government
Government final demand by product is obtained by applying fixed coefficients to the exogenous volume of government consumption and investment.

The model distinguishes 9 categories of receipts: indirect taxes (mainly excises), value added taxes, production subsidies, environmental taxes, social security contributions and transfers, import duties, foreign transfers and revenue from government firms.

The rest of the world (ROW)
As the European model does not cover the whole planet, the behaviour of the rest of the world is exogenous : imports demanded by the ROW depend on the price offered by the exporters

from the European Union and exports from the ROW to the European Union, i.e. the supply of the ROW, occur at a fix price. For the World model, all behaviour are endogenous.

Aggregate domestic demand
The specification of the model assumes further that the total domestic demand by branch (from household, producers and government) can be satisfied either by domestically produced goods either by imported goods, though they are not considered perfect substitutes. This allocation occurs through the minimisation of the buyer's total cost, following the Armington type formulation. The price used in the demand function is the 'composite' good price, a function of the supply price of the domestically produced goods and the price of the imported goods.

The total imports by branch are, at a second level, allocated over the countries of origin according to the relative import prices. The EU countries/World regions buy imports at the prices set by the supplying countries following their export supply behaviour.

The model computes, for each branch and for each EU country/World region, the imports from and the exports to each EU country/World region and to the ROW in the form of a trade matrix.

Equilibrium on the goods and labour markets
In the goods market a distinction is made between tradable and non tradable goods. For the tradable goods the equilibrium condition refers to the equality between the supply of the composite good, related to the Armington equation, and the domestic demand for the composite good. The equilibrium condition assumes at this stage perfect competition on the good markets.

For the non tradable, there is no Armington assumption and so the good is homogenous. The equilibrium condition serves then to determine domestic production, the supply behaviour being modelled through the supply price equation.

For the labour market, at this stage it is assumed that wages are flexible such as to ensure full employment. On the demand side we have the labour demand by firms (derived from their production behaviour) and on the supply side we have the total available time resources of the households minus their desire for leisure (derived from the maximisation of their utility function). The equilibrium condition serves to compute the wage rate. Another version of GEM-E3 allows wage-rigidity and hence the possibility of unemployment.

The income account
The income flows in the real sector of the model are grouped within the framework of a Social Accounting Matrix, which ensures consistency and equilibrium of flows from production to the agents and back to consumption.
Equilibrium, in quantity and in value, on the good and labour market is guaranteed by the price formation mechanism on these markets.

Evaluation of externalities
The model evaluates the energy-related emissions of CO_2, NOx, SO_2, VOC and PM as a function of the energy consumption and the abatement level per branch and per pollutant. These emissions are then translated into concentration/deposition of pollutants, taking into account the transportation (between countries) and transformation mechanism of pollutants. In

a final step, the damage generated by these concentration/deposition of pollutants are computed in physical units and valued through valuation function.

There clearly needs to be a check on the consistency of treatment of these pollutants between GEM-E3 and the wider CAFE process.

Three types of environmental policy instruments are formulated: taxes, tradable pollution permits, and emission standards (upper bounds on sectors and/or countries). A variety of policy institutional regimes associated to these instruments are considered (burden sharing rules, limits on trade, recycling mechanism). The possibility for market power in permit markets is also modelled.

Appendix 10
Analysis of impacts on visibility

Functions

The following is based on work carried out during development of the National Emission Ceilings Directive (AEA Technology, 1999). The core reference used was the review by Landrieu (1997), prepared for a meeting of the TFEAAS (Task Force on Economic Aspects of Air Pollution) in June 1997.

Light extinction (the cause of reductions in visibility) results from two phenomena, scattering and absorption. It would seem that the most appropriate function adds together extinction from various fractions of ambient air;

$$b = b_{air} + e_S(SO_4^{--})f(RH) + e_N(NO_3^{-})f(RH) + e_O(organics)g(RH) + e_C(elementalcarbon) + e_D(otherfineparticles) + e_G(NO_2)$$

b = light extinction coefficient of the atmosphere
b_{air} = scattering of light by molecules in unpolluted air = 0.011 km^{-1} (average value)
SO_4^{--}, NO_3^{-}, etc. are air concentrations of the pollutants of concern
$e_{subscript}$ defines the scattering efficiencies of each fraction. The units given in the Landrieu paper are $m^2\ mg^{-1}$, except for NO_2, for which e_G is expressed in $km^{-1}ppm^{-1}$). Values for each are as follows, noting in most cases that there is an absence of specific field data;

e_S	=	0.003	e_N	=	0.003
e_O	=	0.003	e_C	=	0.012
e_D	=	0.001	e_G	=	0.33

f(RH) and g(RH) are ratios of the scattering due to hygroscopic aerosols at a given relative humidity RH to the scattering at 0% RH

Ammonium is not specifically accounted for in the function proposed by Landrieu.

Landrieu describes the complex interaction between humidity and scattering efficiency. Following Sisler *et al* (1994) the following is adopted for the average annual scattering effect of humidity on nitrates and sulphates;

$$f(RH) = 4.6 - 15(RH) + 19(RH)^2$$

and for the average annual scattering effect of humidity on organics;

$$g(RH) = 2.5 - 6(RH) + 5(RH)^2$$

A problem arises here because the calculation demands knowledge of all pollutants that affect visible range. It is not sufficient to base calculations on the level of one pollutant, because of non-linearities in the calculations (see below). A further problem may arise in the temporal averaging of data.

Valuation

The ‘haziness index’ (dv) suggested by Pitchford (1994), can be combined with a value of €8/dv to quantify value (in €) per person;

$$valueperperson = 8dv = 80\ln\left(\frac{b}{0.01}\right)$$

Maddison (1997) reviewed a number of different studies to produce an alternative estimate of WTP. One of the purposes of the analysis was to test whether the results of certain studies were statistically different from the rest of the literature. The function derived by Maddison, converted to give WTP in €[1990], and omitting terms that covered studies that Maddison concluded were flawed, was:

$$WTP = 125\ln\left(\frac{V_2}{V_1}\right)$$

V_1 = initial visual range
V_2 = final visual range

There are clear uncertainties in this analysis, particularly relating to the transfer of data from the USA to Europe.

Consideration of visibility in the CAFE CBA

Given the lack of concern about air pollution effects on visibility in Europe it is concluded here that it would be inappropriate to quantify changes in visibility as part of the main CBA work, based on extrapolation of data from the USA, where this issue is seen as a significant problem. The peer reviewers agreed that the lack of a European literature in this area made it unwise to proceed with quantification. It will, however, be considered within the framework of the extended CBA.