UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

EB.AIR/WG.5/1998/4/Add.1
12 January 1999

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

EXECUTIVE BODY FOR THE CONVENTION ON
LONG-RANGE TRANSBOUNDARY AIR POLLUTION

Working Group on Strategies
(Twenty-eighth session, 25 - 29 January 1999)
Item 3 of the provisional agenda

ECONOMIC ASPECTS OF ABATEMENT STRATEGIES

Addendum

II. BENEFIT ESTIMATES FOR MULTI-POLLUTANT, MULTI-EFFECT SCENARIOS

1. This chapter summarizes the findings of a study on the benefits of integrated assessment modelling scenarios prepared for the multi-effect, multi-pollutant protocol negotiations. The study was prepared by AEA Technology for the Task Force funded by the European Commission (DG XI). It was presented to the Task Force by Mr. Mike HOLLAND (United Kingdom). Its specific objectives were to quantify, in economic terms so far as possible, the environmental and health effects of reducing emissions of nitrogen oxides, SO_2, ammonia and VOCs, and to compare these effects to the associated costs of emission abatement. The integrated assessment modelling work and the modelling results used as a basis for the study are those presented to the Working Group on Strategies by the Task Force on Integrated Assessment Modelling in documents EB.AIR/WG.5/1998/3 and Add.1.

2. The report on the study and other material presented to the Task Force and available to the secretariat in electronic form have been made available on the Internet at: www.unece.org/env/tfeaas.

3. The report follows two earlier studies and one that is ongoing. The first was prepared for the Task Force and funded by the United Kingdom Department of the Environment, Transport and the Regions (summarized in EB.AIR/WG.5/R.97). It addressed the benefits of some preliminary scenarios considered in the context of the multi-effect and multi-pollutant protocol. The second was funded by the European Commission (DG XI) and was mainly concerned with the development of a directive on ozone limits. The ongoing study, also for the EC, is related to the EC national emission ceilings directive.

4. Other national activities on benefit estimation are also ongoing. An expert from the Czech Republic informed the Task Force about a project on the economic assessment of damage caused by air pollution to materials and buildings in the Czech Republic. Preliminary results include a rough estimation of annual damage caused by air pollution to residential buildings in areas (two in Prague and one in Ostrava) of the Czech Republic. The Task Force expressed its interest in the progress of this project, which may provide a more realistic account of damage costs in central and eastern Europe compared to previous studies.

A. Methodology and data

5. The methodology adopted in the study was presented in previous reports by the Task Force (EB.AIR/WG.5/R.97 and EB.AIR/WG.5/R.70, chapter I). It largely follows the methods developed under the European Commission DG XII ExternE Project. Model calculations follow a stepwise progression through emission, change in exposure, quantification of impacts using exposure-response functions, to valuation based on willingness-to-pay (see EB.AIR/WG.5/R.97, paras. 11-12). A key feature of the model is the way in which the major sensitivities have been assessed. This is reflected in the extensive sensitivity analysis presented in section 4 below.

1. Effects included

6. Table 1 lists the effects that would be influenced by the emission changes defined by the integrated assessment modelling scenarios. It also shows which effects have been included in the analysis and which excluded.

Table 1. Effects quantified and not quantified in the course of this study

Effect	**Quantified?**	**Comments**
Health		
NO_3, SO_4, NH_4 aerosols		
acute - mortality	Yes	
chronic - mortality	Yes	Limited availability of work in the research literature
acute - morbidity	Yes	
chronic - morbidity	Yes	

Effect	**Quantified?**	**Comments**
Ozone		
acute - mortality	Yes	Less clear linkage between O_3 and mortality than for PM_{10}
acute - morbidity	Yes	
chronic effects	No	No data for assessment of chronic effects
SO_2		
acute - mortality	Yes	
acute - morbidity	Yes	
chronic effects	No	No data for assessment of chronic effects
Direct effects of VOCs	No	Lack of data on speciation, etc.
Direct effects of NO_2	No	Lack of reasonable evidence for effects at current ambient levels
"Altruistic" effects	No	Reliable valuation data not available
Materials		
SO_2 / acid effects on utilitarian buildings	Yes	
Effects on cultural assets, steel in re-inforced concrete	No	Likely to be of limited importance in scenarios that do not consider SO_2 effects
Effects of O_3 on paint, rubber	No	Lack of European inventory on stock at risk
Macroeconomic effects	No	Unknown reliability of data extrapolation
Crops		
Direct effects of SO_2 and O_3 on crop yield	Yes	
Indirect SO_2 and O_3 effects on livestock	Yes	
N deposition as fertilizer	Yes	
Interactions between pollutants, with pests and pathogens, climate, etc.	No	Exposure/response data unavailable
Acidification/liming	Yes	Effect of atmospheric deposition likely to be negligible
Macroeconomic effects	No	Unknown reliability of data extrapolation
Forests		
O_3 effects on timber production	Yes	Valuation subject to very high uncertainty
Non-O_3 effects	No	No data available

Effect	**Quantified?**	**Comments**
Non-timber benefits of forests	No	No data available
Exceedance of critical load for eutrophication	No	Exceedance reported, but no data available for valuation
Exceedance of critical load for acidification	No	Exceedance reported, but very limited data available for valuation
Other ecosystems		
Exceedance of O_3 critical level	No	No data available for valuation
Exceedance of critical load for eutrophication	No	Exceedance reported, but no data available for valuation
Exceedance of critical load for acidification	No	Exceedance reported, but very limited data available for valuation
Visibility Change in amenity	Yes	Extremely uncertain against background of little apparent concern in Europe. Valuation based on US data

7. The effects of short-term pollution exposures on health appear to be reasonably comprehensively covered, in contrast perhaps to those of long-term exposures, through a lack of data. Effects are classified as being ‘acute’ or ‘chronic’. Acute effects are those arising from short-term exposure to air pollution. Chronic effects arise from exposure over several years (rather than days). The most significant effects relate to the concentration of fine particles (PM_{10}). For the scenario analysis, the most relevant particles are so-called secondary particles, such as ammonium sulphate or ammonium nitrate. These particles are not released directly from combustion sources or other activities. They are formed as a consequence of the effects of atmospheric chemistry on precursor pollutants (SO_2, NO_x and NH_3). There is also good evidence that ozone has health effects and that these effects are additive to those of particulates.

8. Similarly, the effects of pollution on agriculture are reasonably comprehensively covered, though again subject to uncertainty. Possible sources of error are discussed below. Some are likely to lead to an overestimation of damage, others to an underestimation.

9. The assessment of material damage concentrates on the effects of acidic deposition. Associated damage is small compared to that on health and agriculture. The effects on buildings of cultural merit and the effects of ozone on polymers have not been included in this study because of a lack of data on effect and valuation.

10. Forest damage from ozone is included, though the approach used is far from satisfactory. Particularly the exposure-response functions used and the necessarily simplistic valuation function are open to criticism. A more sophisticated approach to forest valuation is not currently possible given the lack of appropriate forest growth models. In view of the deficiencies in impact assessment, a scenario-based approach to valuation is not warranted. Results suggest that reduced forest output is likely to be much less important

than the effects on agriculture.

11. The loss of amenity owing to the effects of emissions on visibility was quantified using valuation data from the United States literature, suggesting that significant benefits could be attained. However, given the high degree of uncertainty regarding the transferability of the United States data, it was not thought to be appropriate to include these results to justify emissions abatement in Europe.

12. This report does not consider a number of effects of the pollutants of interest here because of a lack of data at some point in the analytical chain (see table 1). Effects that may be important from an economic point of view include those on ecosystems, secondary economic implications of changed agricultural yield and damage to materials, and possible chronic effects of ozone on health. Such omissions lead to an overall underestimation of benefits.

2. Data sources

13. Data on the stock at risk have been taken from various sources. The main source is the land-use database held by the Netherlands National Institute of Public Health and the Environment (RIVM). The categories contained within the database are, however, typically too broad for direct application to the study and additional data were necessary. An overview of the data on stock at risk is given below:

RIVM data set	Used for:	Additional data
Population	Health effects	Population of Bosnia and Herzegovina Age structure of population Frequency of asthma Death rates
	Materials damage	Inventories of buildings and material use
	Changes in visibility	None
Land use	Crop damage	Crop production data by species
	Forest damage	Forest production data for coniferous and deciduous woods
	Ecosystem damage	None needed

14. The model used for benefit estimation is based on the EMEP 150 km x 150 km grid and makes it possible to analyse the effects of sulphur/nitrogenous pollutants and ozone on public health, materials, crops, forests, ecosystems and visibility. Air quality data are calculated from emissions estimates generated for each scenario by the IIASA Regional Acidification Information and Simulation (RAINS) model, combined with country-to-grid cell factors calculated from EMEP model runs for all pollutants except ozone. For ozone, data are generated externally using the EMEP model run by the Meteorological Synthesizing Centre-West (MSC-W).

15. The main source of exposure-response functions is the ExternE project. For material damage, these functions are based on work under the International Cooperative Programme on effects of air pollution on materials (ICP Materials), from which most of the specific stock-at-risk data also originate.

The functions applied to estimate crop damage use the critical level but follow a crude procedure that is not fully compatible with the recommendations made by the International Cooperative Programme on effects of air pollution and other stresses on crops and non-wood plants (ICP Crops).

16. Valuation data are taken from ExternE and from some other sources that were not available in time to be included in the latest report on the ExternE methodology. World market prices rather than national cost data have been used to calculate the effects on crop production to avoid, so far as possible, the distortions that arise through market intervention. Timber production is also valued at international market prices. In both cases the same set of values are used in all countries.

17. Damage to other receptors - health, materials and amenity (for reductions in visual range) - has been valued in two ways in an attempt to take account of variations in income across Europe. One set of calculations, not presented here but shown in the study, is based on a European average, adjusted for purchasing power parity (PPP) and weighted by the population in each country. For reasons of consistency, the average is limited to countries within the geographical domain used by the EMEP and RAINS models. It excludes countries such as Armenia, Canada, Cyprus, Iceland and the United States. The other set of calculations, presented in this report, uses the ExternE figures for member States of the European Community (EC), but adjust costs in other countries individually on the basis of PPP. Unit valuations in most countries are lower than the EC average, though higher in Norway and Switzerland. In the context of the Convention on Long-range Transboundary Air Pollution, this approach seems not to be controversial, because there is not such a clear relationship between wealth, the level of emissions and likely levels of impact. For pollutants that act on a regional scale, rather than globally, countries with high emissions are more likely to experience a significant part of the damage attributable to those emissions.

3. Scenarios

18. Six joint scenarios have been presented in the report by the Task Force on Integrated Assessment Modelling (EB.AIR/WG.5/1998/3 and Add.1) based on modelling work conducted at IIASA. For three of these (G5/1 G5/2 and G5/3, excluding those with mixed ambition levels), economic benefits are estimated. The results are compared to the reference (REF) scenario, which accounts for existing legislation and planned emission reductions up to the year 2010. The benefits of the incremental change from 1990 to REF are also quantified. The environmental targets set in the optimization conducted by IIASA for the three scenarios assessed here were as follows:

	Lower ambition (G5/1)	Medium ambition (G5/2)	Higher ambition (G5/3)
Acidification			
Gap closure on accumulated excess acidity	90%	95%	95%
Gap closure on accumulated excess acidity for Norway	80%	85%	90%
Maximum excess deposition for the most sensitive 2% of ecosystems	(900 eq/ha)	(850 eq/ha)	800 eq/ha
Health-related ozone			
Gap closure on AOT60	60%	67%	70%
Maximum AOT60, to be achieved in 4 out of 5 years	3.0 ppm.h	2.9 ppm.h	2.7 ppm.h
Vegetation-related ozone			
Gap closure on AOT40	30%	33%	35%
Maximum excess AOT40, mean over five years	10.5 ppm.h	10 ppm.h	9.5 ppm.h
Eutrophication			
Gap closure on accumulated excess nitrogen deposition	55%	60%	67%

4. <u>Uncertainties and sensitivity analysis</u>

19. There are clearly numerous uncertainties in the analysis. From a review of the potential for error in the analysis, the key sensitivities were identified as:

- Issues relating to the assessment of mortality generally;

- Prediction of changes in exposure using the EMEP model;

- Influence of meteorological and other factors on estimates of changes in crop yield; and

- Omission of effects on ecosystems, possible chronic effects of ozone exposure on morbidity, indirect economic effects arising from reduced agricultural yield, etc.

20. The existence of significant uncertainty makes it difficult to interpret the study's results. A variety of techniques has been used to try to resolve the issue in a transparent manner. The discussion here is limited to the factors that could introduce some systematic error into the analysis. Details on the statistical techniques used in the study are not presented.

21. The EMEP atmospheric model is designed to estimate deposition rates on rural receptors. Although the 150 km grid size is coarser than desirable, the inaccuracy introduced by this resolution is limited because these receptors are generally remote from the largest sources of pollution. Even for urban receptors, the problems may not be too big. Where point sources emit high above the ground and outside the urban area (typical of some large electricity generating power stations), the modelling approximations may be fairly accurate. And for some secondary pollutants (e.g. acid aerosols), the rate of formation is slow, so that short-range impacts can be small compared to the

long-range effects, even if the precursor is emitted in areas of high receptor density.

22. However, the EMEP model does not reproduce the urban ground-level concentrations of primary pollutants. The actual relationship between the concentrations of these pollutants due to emissions close to the ground in the urban area is significantly underestimated, both because the horizontal averaging is so coarse that the urban area is not well resolved and because the modelling assumption about immediate vertical mixing through the whole boundary layer is inaccurate in this instance. The result of the approximations is therefore that impacts of primary pollutants emitted close to the ground in urban areas on urban receptors will be underestimated by a significant factor. As people are concentrated in urban areas, the effect will be most pronounced for human health impacts. However, most of the health impacts discussed in this paper are due to secondary pollutants (mainly acid aerosols) and therefore the overall results might not deviate too much. Direct effects of SO_2 on health and materials are likely to be underestimated.

23. Similar problems result from the use of the EMEP model for the estimation of urban ozone levels. Validation of model predictions against ozone monitoring data shows that there is reasonable agreement for rural sites, but that for sites in urban areas there can be a significant “over-prediction” of ozone concentrations. The reason for this is well understood. Most NO_x is emitted as nitric oxide, NO, which contributes to ozone reduction in the short range, forming NO_2. This ozone titration reaction is incorporated within the ozone chemistry scheme of the EMEP model. However, much of the process will occur at a sub-grid scale and before mixing through the full height of the boundary layer is achieved in areas where emission densities are very high. The scale of ozone reduction at the ground level in urban areas is therefore not adequately captured by modelling at the resolution of the EMEP grid. It is also clear that high-stack and ground-level emissions may have different effects. The problem is potentially significant for the assessment of impacts on urban-based receptors - notably human health. This error may, however, be counteracted by the presence of primary pollutants that are systematically underestimated in the EMEP model.

24. There is some evidence that the EMEP model may overestimate concentrations of secondary particles in central Europe, though they may to some degree be underestimated in other areas. Overall, there would appear to be a tendency to overestimate the effects due to this error. The extent to which different errors in the modelling of air quality will cancel one another out is unknown. It is clearly an area where a systematic error analysis would be advantageous, though this was beyond the scope of the present study.

25. There is debate about the inclusion of functions linking mortality with acute exposure to ozone and chronic exposure to fine particles. A statistical uncertainty rating of different health effects was presented in a previous report (EB.AIR/WG.5/R.97, para. 14). The most contentious issue regarding health effects relates to thresholds. For many pollutants there is clearly a threshold at the individual level, in the sense that most people are not realistically at risk of severe acute health effects at current background levels of air pollution. There is, however, no sound evidence of a threshold at the population level; i.e. it appears that, for a large population, even at low background concentrations, some vulnerable people are exposed some of the time to concentrations that do have an adverse effect. This understanding

first grew in the context of ambient particles, where the ‘no threshold’ concept is now quite well established. Similarly, evidence does not point to a threshold for the acute effects of ozone. There remains some risk that by not specifically accounting for thresholds, results could be overestimated.

26. There is also debate on the correct approach to valuing cases of premature mortality, given the fact that many, perhaps most, of those at increased risk of premature mortality linked to short-term exposure to air pollution may have only a very limited life expectancy in any case, and that air pollution will rarely be the most important determinant of age at death. Two approaches are being investigated, one where valuation is based on the value-of-statistical-life (VOSL) approach, and another based on the value-of-life-years (VOLY) concept. The Task Force, at its thirteenth meeting, had agreed to use the VOSL approach, as it saw the methodological basis for the VOLY approach as inadequate (EB.AIR/WG.5/1998/2). It will, however, keep the issue under review. The study uses a VOSL of about ECU 2 million. An alternative to the VOLY approach, may be the use of an adjusted and much reduced VOSL. This could give a result close to that of the application of the VOLY. A separate sensitivity analysis will have to be undertaken to examine this.

27. Also concerning the estimation of material damage, a number of uncertainties remain. The following are identified as research priorities:

(a) Improvement of inventories, in particular; the inclusion of country-specific data for all parts of Europe; disaggregation of the inventory for paint to describe the type of paint in use; disaggregation of the inventory for galvanized steel to reflect different uses (which has been partially attempted here, though somewhat indirectly); disaggregation of calcareous stone into sandstone, limestone, etc. In addition, alternatives to the use of population data for the extrapolation of building inventories should be investigated;

(b) Further development of dose-response functions, particularly for paints, mortar, cement rendering, and for ozone;

(c) Assessment of exposure dynamics of surfaces of differing aspect (horizontal, sloping or vertical), and identification of the extent to which different materials can be considered to be sheltered;

(d) Definition of service lifetimes for stone, concrete and galvanized steel;

(e) Integration of better information on repair techniques;

(f) Improving the knowledge about human response to the need for maintenance.

Although this list of uncertainties is extensive, it would be wrong to conclude that knowledge of the effects of air pollution on building materials is poor. Indeed, the opposite may be true; because a great deal is known about damage to materials, it is possible to specify uncertainties in more detail than for other types of damage about which less is known. Some of these uncertainties will lead to an underestimation of impacts; others to an overestimation. The factors affecting galvanized steel are of most concern given that damage to it makes up a high proportion of total material damage. However, a number of potentially important areas (table 1 lists the most important ones) are excluded from the analysis because no data are available. In general, inclusion of these effects would lead to greater estimates of impacts. Estimates of damage to galvanized steel are sometimes criticized for relying on inventories of stock at risk that do not distinguish galvanized steel from other materials such as plastic sheeting. The sources of information used here for galvanized steel assessment avoid this trap.

28. In the absence of definitive guidance, these issues have been assessed using sensitivity analysis. In presenting the overall results of the cost-benefit analysis below, a stratified sensitivity analysis is applied. Based on responses by United Kingdom experts to a questionnaire on the perceived uncertainty of different damage categories, these were ranked. In presenting results, the different categories are added sequentially, starting with those with the lowest perceived uncertainty, to give focus on these impacts and divert attention from extremely uncertain impacts. Given the potential significance of uncertainty in this area, the effect of excluding mortality altogether is also shown in the results.

B. Benefit estimates for different damage categories

29. The uncertainties presented above have to be kept in mind when interpreting the results of the study. The study presents a detailed list of uncertainties for each damage category that is not presented here. The results were calculated for the change from 1990 emission levels to those under the REF scenario. For the optimized scenarios (G5/1, G5/2, G5/3), REF is considered as the baseline. All the results given refer to annual benefits in the year 2010. Prices are given in 1990 ECU for reasons of consistency with the output of the RAINS model. The results presented here use a country-specific valuation and for mortality the VOSL approach. In the study, results are also given for valuation using an average for the whole region and valuing mortality following the VOLY approach.

30. Table 2 shows the mortality impacts in physical terms (cases of premature mortality) for short-term (acute) exposure to ozone and particles and for the life years lost due to chronic exposure to fine particles. Table 3 shows the same impacts after the valuation has been applied using the VOSL approach. Table 4 gives the benefits resulting from the estimated change in incidence of various morbidity conditions.

31. Table 5 presents the benefits resulting from reduced damage to materials and the estimated benefits to agriculture from reducing damage to crops. Finally, table 6 gives the estimated annual benefits in terms of timber and pulp production from reducing damage to forests and the estimated benefits from improvements in visibility.

C. Comparison of benefits and costs

32. The most important impacts in the benefits analysis are those on human health and crops. Effects on forest productivity and materials are negligible in comparison, whilst those on ecosystems were unquantified due to a lack of valuation data.

33. The benefits from reduced impacts on agriculture alone offset a

significant proportion of total costs. The effects on the agricultural sector are complicated, as sulphur and nitrogen depositions have the capacity to improve crop growth, whilst ozone will reduce it. Overall, the negative ozone effect substantially outweighs the benefits of sulphur and nitrogen fertilization.

34. Costs and benefits are compared in table 7 below. Table 7 (a) shows the results for mortality valuation based on the value of statistical life (VOSL), whilst table 7 (b) shows the results with mortality valuation based on value of life years (VOLY). Benefits are expressed cumulatively, sequentially adding together the results for groups of impact types, based on the results of a confidence ranking exercise conducted among United Kingdom experts in 1997. Group I contains those effects for which the respondents to a questionnaire had the most confidence in the results; group V those that the respondents had the least confidence in. The groupings were:

(a) Group I: material damage (excluding paint); N fertilization on crops; acute effects on mortality (VOLY approach); morbidity (excluding days of restricted activity and chronic bronchitis);

(b) Group II: days of restricted activity; paint damage; ozone and SO_2 effects on crops;

(c) Group III: acute effects on mortality (VOSL approach); chronic effects on bronchitis;

(d) Group IV: ozone effects on forests; chronic effects on mortality (VOLY approach);

(e) Group V: chronic effects on mortality (VOSL approach); changes in visibility.

Table 7 (a): Costs and benefits (in million ECU/year) for each scenario, with the mortality valuation using the VOSL approach

Scenario	Cumulative benefits					Costs
	Group I	+ Group II	+ Group III	+ Group IV	+ Group V	
REF	3740	14970	96270	96900	213050	64255
G5/1 */	340	3410	17530	17735	34465	4916
G5/2 */	620	4660	26540	26790	55745	9692
G5/3 */	720	6140	34490	34820	73940	17823

Table 7 (b): Costs and benefits (in million ECU/year) for each scenario, for the mortality valuation using the VOLY approach

Scenario	Cumulative benefits					Costs
	Group I	+ Group II	+ Group III	+ Group IV	+ Group V	
REF	5460	16690	29190	132000	137960	64255
G5/1 */	645	3720	5495	20205	21255	4916
G5/2 */	1090	5130	8200	33540	35390	9692
G5/3 */	1330	6745	10880	49010	47580	17823

*/ Benefits and costs above REF.

35. In each table the shading denotes the number of these groups required for benefits to exceed costs in each scenario. In all cases, the least certain of the quantified effects are not needed for benefits to exceed costs. The same information as presented in table 7 (a) is given for each country covered in the analysis in tables 8 (a) to (d) for the four scenarios. These tables are limited to showing results for mortality valuation based on VOSL and for country-specific valuations. The results were also calculated for mortality valuation based on VOLY and for average valuations; they can be found in the study.

36. By combining different assumptions about the individual elements in the list of uncertainties, it is possible to generate total benefit estimates that are smaller than the costs of the scenarios considered. The analysis does not therefore prove beyond all reasonable doubt that benefits would exceed costs. But it is important to remember that many effects have not been included in this assessment. In most cases these effects are cumulative to those shown in table 9. Most of the concern over transboundary air pollution in Europe originally concentrated on damage to ecosystems and cultural heritage, particularly, though not exclusively, stonework. This suggests that it is highly valued, at least at current levels of pollutant emission (and hence potential damage). Substantial reductions in ecosystem exceedance will be achieved with respect to acidification under REF, with the percentage of ecosystems at risk falling from about 16% to 3% across Europe as a whole. However, this still leaves significant levels of overall exceedance in several countries, particularly Belgium, Germany, the Netherlands and the United Kingdom (in all cases exceedance will affect more than 12% of ecosystems, see EB.AIR/WG.5/1998/3/Add.1, table 23 for details). Also, the uneven distribution of exceedance within countries will mean that some types of ecosystems are likely to remain at significant risk, even when the overall rate of exceedance within a country appears to be low. The situation with respect to eutrophication appears more severe. High rates of exceedance are observed in a number of countries even under the higher ambition scenario (see EB.AIR/WG.5/1998/3/Add.1, table 24).

37. The effect of other uncertainties, for example possible exaggeration of mortality benefits (lack of an ozone threshold in the core analysis, assumptions about the harmfulness of different particulate fractions, etc.) may, but need not, lead to an overestimation of benefits.

38. Finally, it should be noted that the cost estimates prepared by IIASA are also subject to uncertainties. There is a common view that the IIASA cost estimates are too high because of the exclusion from the RAINS model of structural measures, like energy-savings, that may be more cost-effective than the technology options included in the model. It is important to note that the IIASA cost curves were developed to enable a cost comparison between countries in order to find a cost-effective abatement strategy for Europe. They were not developed to be used in a benefit-cost comparison. An expert from Norway presented a note to the Task Force emphasizing that structural and technological change is not captured in an appropriate way in the RAINS cost curves to allow interpretations of the absolute cost levels calculated. In particular, any policy decision to strengthen abatement efforts for certain pollutants will induce both structural and technological changes which cannot be anticipated in the present model structure. Further sensitivity analysis would be useful to explore these effects.

39. While it is interesting to see whether benefits exceed costs, from an economic point of view the benefit-cost ratio is the most important result to consider. Table 9 shows these ratios for the four scenarios examined. The total benefits and costs are shown and used for the calculation of the ratio, while in tables 7 and 8 for scenarios G5/1 to 3 only incremental cost above the REF scenario are shown. Benefits include all damage categories. Table 9 (a) shows the results for mortality valuation based on VOSL, whilst table 9 (b) shows the results for mortality valuation based on VOLY.

Table 9 (a). Benefit/cost ratios for the four scenarios with benefit valuation based on VOSL approach.

Scenario	Total benefits (million ECU/yr)	Total costs	Benefit/cost ratio
REF	213050	64255	3.32
G5/1	247512	69171	3.58
G5/2	268795	73947	3.64
G5/3	286988	82078	3.50

Table 9 (b). Benefit/cost ratios for the four scenarios with benefit valuation based on VOLY approach.

Scenario	Total benefits (million ECU/yr)	Total costs	Benefit/cost ratio
REF	137961	64255	2.15
G5/1	159214	69171	2.30
G5/2	173348	73947	2.34
G5/3	185545	82078	2.26

40. Independent of the valuation approach chosen, the benefit-cost ratios peak for scenario G5/2. Given the uncertainties for the analysis discussed above, in particular the fact that the ecosystem protection, which has been the main target for the scenarios, is not included in the benefit assessment, while some other rather uncertain categories, like visibility, are included, this result should not be overemphasized. The comparison of costs and benefits, however, suggests that even without ecosystem damage included benefits are greater than costs by quite a large ratio, one that is higher than in most cost-benefit analyses. This supports the conclusion that investment in acidification/eutrophication/ozone control is very profitable from a social standpoint.

D. <u>Conclusions</u>

41. After a discussion of the results presented (the report on the study was not yet available at the time of the Task Force meeting), the Task Force reached the following conclusions:

(a) Given the central assumptions made in the study, total monetized benefits for all of Europe are likely to exceed total costs for the three scenarios, even when taking into account the uncertainties in the parameters. This does not mean that these scenarios are at an optimum;

(b) The first conclusion is more robust when estimating benefits for the whole of Europe, than when limiting the analysis to western Europe;

(c) There will, in most cases, be some countries where, either due to low benefits (at the margins of the modelling area) or due to high cost (in the centre of the modelling area), benefits are unlikely to exceed costs.

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Table 2. Reduction in premature mortality due to short-term (acute) exposure to ozone and secondary particles and in life years lost due to chronic effects of exposure to particles

Country	**Acute mortality cases**				**Chronic mortality (life yrs lost)**			
	Total	**Above REF**			**Total**	**Above REF**		
	REF	**G5/1**	**G5/2**	**G5/3**	**REF**	**G5/1**	**G5/2**	**G5/3**
Albania	140	31	59	77	6100	1300	2600	3100
Austria	1000	180	300	380	48000	7800	13000	17000
Belarus	480	92	140	200	22000	3700	6200	8400
Belgium	1000	210	300	360	53000	8600	14000	18000
Bosnia and Herzegovina	280	64	120	150	12000	2600	5100	6000
Bulgaria	480	130	230	310	23000	5600	11000	14000
Croatia	380	87	150	200	17000	3600	6400	7800
Czech Republic	690	110	180	230	34000	4500	8100	10000
Denmark	210	30	49	70	11000	1200	2300	3300
Estonia	44	7	10	14	1900	240	410	570
Finland	100	12	20	28	4100	400	700	1000
France	4400	950	1300	1600	200000	35000	55000	71000
Germany	8200	1200	1800	2300	410000	47000	87000	110000
Greece	260	57	110	150	11000	2300	5000	6200
Hungary	530	160	250	310	25000	6900	11000	13000
Ireland	89	13	16	26	4500	450	710	1300
Italy	3900	790	1400	1600	180000	33000	60000	69000
Latvia	80	13	20	28	3500	490	830	1100
Lithuania	130	25	38	51	6100	990	1600	2200
Luxembourg	250	48	67	84	12000	1800	3000	3800
Netherlands	2000	340	480	590	110000	14000	25000	33000
Norway	82	12	20	33	3700	400	780	1300
Poland	3300	670	1100	1400	170000	29000	50000	64000
Portugal	250	46	72	120	10000	1400	2300	4600
Republic of Moldova	130	33	52	70	6300	1500	2400	3100
Romania	1500	490	750	1000	73000	22000	35000	45000
Russian Federation	3000	300	510	740	140000	12000	22000	33000
Slovakia	360	87	130	180	18000	3800	6200	7700
Slovenia	160	31	52	66	7400	1300	2400	2800
Spain	1300	210	360	570	54000	7300	13000	23000
Sweden	340	51	84	120	16000	2000	3600	5300
Switzerland	440	72	110	140	20000	3000	5100	6300
The FYR of Macedonia	51	12	21	30	2500	530	1000	1300
Turkey	74	16	31	41	3400	680	1400	1800
Ukraine	2600	540	870	1200	130000	23000	39000	54000
United Kingdom	3400	620	770	1000	220000	22000	32000	58000
Yugoslavia	540	130	230	310	26000	5800	10000	13000
European Community	26000	4800	7200	9200	1300000	180000	320000	430000
Total	43000	7900	12000	16000	2100000	320000	550000	730000

Table 3. Benefits of reducing in mortality from short-term (acute) exposure to ozone and secondary particulates and long-term (chronic) exposure to secondary particulates (million ECU/yr)

Country	Acute mortality				Chronic mortality			
	Total	Above REF			Total	Above REF		
	REF	G5/1	G5/2	G5/3	REF	G5/1	G5/2	G5/3
Albania	36	8	15	20	79	17	33	41
Austria	2229	411	663	844	5279	854	1482	1860
Belarus	245	48	72	100	577	97	160	217
Belgium	2215	466	639	785	5802	943	1515	2002
Bosnia and Herzegovina	95	22	40	53	212	44	87	103
Bulgaria	249	66	119	164	615	148	285	363
Croatia	279	65	112	147	631	134	238	292
Czech Republic	730	113	186	242	1836	241	434	561
Denmark	475	66	109	153	1202	129	250	363
Estonia	24	4	6	8	51	6	11	16
Finland	224	28	42	60	446	44	77	112
France	9780	2105	2959	3652	21725	3878	6102	7815
Germany	17966	2566	4055	5185	45493	5142	9614	12624
Greece	590	126	244	326	1251	250	545	686
Hungary	385	118	177	226	921	254	392	479
Ireland	196	28	38	59	497	49	78	139
Italy	8781	1741	2991	3557	19360	3600	6597	7587
Latvia	31	5	8	11	68	9	16	22
Lithuania	51	10	15	20	120	20	33	44
Luxembourg	537	104	148	184	1266	196	325	416
Netherlands	4158	762	1042	1303	11663	1515	2700	3662
Norway	198	29	48	78	446	48	94	152
Poland	2211	443	701	906	5586	950	1645	2119
Portugal	557	100	158	255	1096	150	258	501
Republic of Moldova	46	12	18	24	109	25	41	54
Romania	734	239	367	510	1799	537	849	1095
Russian Federation	1622	164	278	410	3824	335	622	920
Slovakia	385	92	144	184	953	202	330	412
Slovenia	121	23	39	49	278	49	88	106
Spain	2935	466	788	1271	5914	800	1414	2494
Sweden	756	111	183	263	1798	215	401	582
Switzerland	1336	219	341	421	3038	449	771	957
The FYR of Macedonia	13	3	6	8	32	7	13	17
Turkey	42	9	17	24	96	19	39	50
Ukraine	851	168	273	383	2047	357	621	854
United Kingdom	7566	1366	1706	2247	23752	2372	3497	6411
Yugoslavia	148	36	62	86	355	80	142	182
European Community	58967	10445	15764	20144	146542	20137	34855	47255
Total	68798	12341	18807	24218	170217	24165	41801	56310

Table 4. Benefits of reducing morbidity (in million ECU/yr)

Country	Total REF	Above REF G5/1	G5/2	G5/3
Albania	9	2	4	5
Austria	629	97	170	210
Belarus	69	11	18	25
Belgium	655	109	173	225
Bosnia and Herzegovina	25	5	10	12
Bulgaria	78	17	36	43
Croatia	74	15	28	33
Czech Republic	230	27	50	64
Denmark	132	14	28	40
Estonia	6	1	1	2
Finland	52	5	9	13
France	2474	434	690	879
Germany	5524	589	1090	1417
Greece	140	28	61	76
Hungary	111	30	46	55
Ireland	55	6	9	15
Italy	2180	395	734	837
Latvia	8	1	2	2
Lithuania	14	2	4	5
Luxembourg	147	22	37	47
Netherlands	1327	177	304	406
Norway	50	6	11	17
Poland	693	112	199	250
Portugal	127	17	29	56
Republic of Moldova	13	3	5	6
Romania	219	63	101	127
Russian Federation	464	39	71	104
Slovakia	117	24	39	48
Slovenia	33	5	10	12
Spain	690	90	158	286
Sweden	201	24	45	64
Switzerland	344	50	86	106
The FYR of Macedonia	4	1	2	2
Turkey	11	2	4	6
Ukraine	249	41	72	98
United Kingdom	2684	290	410	716
Yugoslavia	43	9	17	21
European Community	17016	2297	3946	5286
Total	19881	2762	4761	6329

Table 5. Benefits of reducing damage to materials and agricultural crops (in million ECU/yr)

Country	Material damage				Crop damage			
	Total	Above REF			Total	Above REF		
	REF	G5/1	G5/2	G5/3	REF	G5/1	G5/2	G5/3
Albania	0	0	0	0	6	2	3	5
Austria	41	3	7	7	87	32	41	59
Belarus	5	0	1	1	27	9	10	18
Belgium	35	7	10	12	48	44	32	26
Bosnia and Herzegovina	2	0	1	0	2	0	0	1
Bulgaria	6	1	3	3	67	37	42	94
Croatia	4	0	1	1	3	0	0	1
Czech Republic	20	1	2	3	47	28	32	46
Denmark	6	0	1	1	53	17	20	28
Estonia	0	0	0	0	3	1	1	1
Finland	3	0	0	0	7	1	1	2
France	85	7	19	24	1829	653	722	832
Germany	386	20	39	47	867	268	284	375
Greece	4	0	2	2	134	37	51	87
Hungary	6	1	2	2	148	83	113	176
Ireland	3	0	0	1	16	6	6	7
Italy	79	5	21	17	1531	402	590	790
Latvia	0	0	0	0	4	1	1	2
Lithuania	1	0	0	0	6	1	1	2
Luxembourg	7	1	1	2	0	0	0	-1
Netherlands	85	12	17	20	45	83	46	32
Norway	2	0	0	1	2	1	1	1
Poland	71	7	17	18	342	161	161	252
Portugal	4	0	0	1	62	18	27	35
Republic of Moldova	1	0	0	0	-6	-2	-3	-2
Romania	14	3	5	5	68	41	51	114
Russian Federation	27	2	3	4	9	12	16	28
Slovakia	9	1	2	2	93	47	64	91
Slovenia	2	0	1	0	4	1	1	2
Spain	27	1	3	9	605	136	240	331
Sweden	10	1	2	2	13	3	4	5
Switzerland	14	1	2	3	109	23	30	38
The FYR of Macedonia	0	0	0	0	0	0	0	0
Turkey	0	0	0	0	199	68	91	162
Ukraine	19	2	3	4	-54	15	10	32
United Kingdom	267	34	39	56	-36	83	75	22
Yugoslavia	3	0	1	1	-1	0	-1	1
European Community	1043	92	161	200	5261	1783	2138	2630
Total	1251	113	207	249	6338	2312	2763	3694

Table 6. Benefits in terms of timber and pulp production of reducing ozone and of improving visibility (million ECU/yr)

Country	Forest damage				Visibility			
	Total	Above REF			Total	Above REF		
	REF	G5/1	G5/2	G5/3	REF	G5/1	G5/2	G5/3
Albania	3	1	1	2	3	1	1	1
Austria	56	15	20	27	188	39	69	89
Belarus	0	0	0	0	25	5	8	11
Belgium	10	6	5	5	181	38	63	85
Bosnia and Herzegovina	0	0	0	0	7	2	4	4
Bulgaria	4	2	2	5	20	6	11	15
Croatia	0	0	0	0	22	6	10	13
Czech Republic	8	4	5	6	54	9	17	23
Denmark	1	0	0	0	56	7	15	22
Estonia	0	0	0	0	3	0	1	1
Finland	19	3	4	5	31	3	6	9
France	171	56	64	75	788	174	279	364
Germany	146	45	50	63	1357	204	394	530
Greece	2	1	1	1	41	9	20	25
Hungary	13	7	9	13	30	10	16	20
Ireland	0	0	0	0	38	5	7	13
Italy	30	8	11	14	639	143	269	313
Latvia	0	0	0	0	4	1	1	1
Lithuania	0	0	0	0	6	1	2	2
Luxembourg	0	0	0	0	37	7	12	16
Netherlands	1	1	1	0	350	59	110	154
Norway	5	1	2	2	30	4	7	12
Poland	26	11	13	19	179	39	70	92
Portugal	15	4	6	8	45	7	12	23
Republic of Moldova	0	0	0	0	4	1	2	2
Romania	18	10	14	24	61	22	35	47
Russian Federation	0	0	0	0	181	17	32	48
Slovakia	27	13	17	24	28	8	13	16
Slovenia	0	0	0	0	9	2	4	5
Spain	29	6	10	14	245	37	66	118
Sweden	27	6	8	11	93	13	24	36
Switzerland	22	4	6	7	102	19	34	42
The FYR of Macedonia	0	0	0	0	1	0	1	1
Turkey	1	0	0	1	4	1	2	2
Ukraine	0	0	0	0	74	15	27	38
United Kingdom	2	2	2	1	1011	130	194	373
Yugoslavia	0	0	0	0	12	3	6	8
European Community	510	153	182	225	5100	874	1540	2170
Total	636	206	250	327	5959	1045	1843	2575

Table 8 (a). Costs and benefits of moving from 1990 emissions to the REF scenario (in million ECU/yr). Mortality valuation based on VOSL. Highlighted cells identify the benefits that need to be added together for overall benefit to exceed costs

Country	**Groups of benefit categories (see para. 34)**					**Costs**
	I	**I+II**	**I+II+III**	**I+II +III+IV**	**I+II+III +IV+V**	
Albania	1	10	52	54	108	0
Austria	126	370	2987	3043	6644	1061
Belarus	9	59	346	346	744	0
Belgium	103	313	2954	2964	6907	1596
Bosnia and Herzegovina	3	13	123	123	268	1
Bulgaria	20	106	400	404	820	157
Croatia	12	35	360	360	790	53
Czech Republic	62	162	1027	1035	2272	979
Denmark	11	103	666	667	1503	592
Estonia	0	6	34	34	70	0
Finland	9	29	287	306	626	832
France	349	2792	14168	14339	29220	8277
Germany	1286	3435	24742	24889	55621	12922
Greece	17	186	868	870	1724	1371
Hungary	21	197	649	662	1287	586
Ireland	6	37	270	270	631	582
Italy	297	2369	12572	12602	25807	9391
Latvia	0	8	44	44	92	0
Lithuania	1	12	72	72	156	0
Luxembourg	25	60	690	690	1547	94
Netherlands	229	601	5616	5616	13523	2220
Norway	6	22	253	257	577	586
Poland	179	695	3316	3343	7124	3299
Portugal	19	112	750	764	1520	1470
Republic of Moldova	2	2	54	54	128	0
Romania	47	169	1035	1053	2275	157
Russian Federation	67	220	2123	2123	4774	694
Slovakia	29	149	604	631	1274	423
Slovenia	7	19	161	161	350	126
Spain	116	888	4257	4286	8364	6320
Sweden	27	91	980	1007	2267	1524
Switzerland	50	243	1802	1824	3897	880
The FYR of Macedonia	1	2	17	17	39	1
Turkey	1	204	253	253	320	1
Ukraine	34	62	1063	1063	2460	328
United Kingdom	559	1171	10482	10484	26885	7643
Yugoslavia	8	19	193	193	435	92
Total	3744	14968	96268	96903	213050	64255

Table 8 (b). Costs and benefits of moving from the REF scenario to scenario G5/1 (in million ECU/yr). Mortality valuation based on VOSL. Highlighted cells identify the benefits that need to be added together for overall benefit to exceed costs

Country	Groups of benefit categories (see para. 34)					Costs
	I	I+II	I+II+III	I+II +III+IV	I+II+III +IV+V	
Albania	0	2	12	13	24	1
Austria	11	69	543	558	1151	60
Belarus	-1	14	69	69	137	12
Belgium	19	91	626	631	1281	520
Bosnia and Herzegovina	0	2	27	27	58	2
Bulgaria	0	44	120	122	224	14
Croatia	0	5	81	81	173	7
Czech Republic	3	39	170	173	339	80
Denmark	1	22	97	98	189	0
Estonia	0	1	5	5	10	0
Finland	1	3	34	37	69	0
France	38	809	3199	3254	5949	746
Germany	80	499	3443	3488	7028	689
Greece	2	47	191	192	363	1
Hungary	0	96	232	239	413	574
Ireland	0	8	40	40	77	114
Italy	32	538	2544	2551	5035	212
Latvia	0	1	7	7	14	0
Lithuania	0	2	13	13	27	3
Luxembourg	3	8	126	126	261	1
Netherlands	34	161	1035	1036	2077	349
Norway	1	3	35	36	71	1
Poland	12	210	723	734	1388	501
Portugal	2	24	134	138	242	28
Republic of Moldova	0	0	13	13	31	31
Romania	3	68	347	357	726	282
Russian Federation	1	27	216	216	450	36
Slovakia	3	57	164	176	315	30
Slovenia	1	3	30	30	63	2
Spain	9	168	694	700	1257	16
Sweden	3	12	139	145	298	21
Switzerland	5	41	293	298	609	3
The FYR of Macedonia	0	0	4	4	9	1
Turkey	0	69	80	80	93	1
Ukraine	-7	31	225	225	472	39
United Kingdom	82	233	1773	1775	3440	496
Yugoslavia	0	3	45	45	100	43
Total	337	3412	17528	17734	34462	4916

Table 8 (c). Costs and benefits of moving from the REF scenario to scenario G5/2 (in million ECU/yr). Mortality valuation based on VOSL. Highlighted cells identify the benefits that need to be added together for overall benefit to exceed costs

Country	**Groups of benefit categories (see para. 34)**					**Costs**
	I	**I+II**	**I+II+III**	**I+II +III+IV**	**I+II+III +IV+V**	
Albania	0	4	22	23	46	1
Austria	23	109	881	901	1931	84
Belarus	0	18	102	102	214	12
Belgium	28	104	854	859	1904	1055
Bosnia and Herzegovina	1	5	52	52	111	24
Bulgaria	7	60	200	202	398	82
Croatia	2	11	141	141	306	76
Czech Republic	8	53	271	276	574	205
Denmark	2	30	157	158	335	28
Estonia	0	1	8	8	16	0
Finland	1	5	52	56	112	0
France	78	982	4389	4453	8694	1140
Germany	144	707	5469	5519	12149	2182
Greece	7	74	357	358	732	2
Hungary	2	132	338	347	617	760
Ireland	1	10	53	53	111	168
Italy	84	860	4336	4347	8902	514
Latvia	0	2	11	11	22	0
Lithuania	0	3	20	20	43	4
Luxembourg	5	14	186	186	410	1
Netherlands	46	169	1409	1409	3270	931
Norway	1	5	60	61	130	17
Poland	34	256	1078	1091	2223	757
Portugal	3	38	214	220	400	71
Republic of Moldova	0	0	20	20	49	31
Romania	9	95	525	539	1123	537
Russian Federation	4	45	368	368	803	54
Slovakia	6	81	248	265	491	126
Slovenia	2	6	51	51	112	12
Spain	16	297	1188	1199	2184	54
Sweden	5	21	233	241	525	28
Switzerland	10	61	459	465	999	8
The FYR of Macedonia	0	1	7	7	16	1
Turkey	0	92	112	113	140	1
Ukraine	-4	39	358	358	787	109
United Kingdom	94	267	2230	2232	4691	531
Yugoslavia	1	6	78	78	176	86
Total	621	4660	26538	26788	55745	9692

Table 8 (d). Costs and benefits of moving from the REF scenario to scenario G5/3 (in million ECU/yr). Mortality valuation based on VOSL. Highlighted cells identify the benefits that need to be added together for overall benefit to exceed costs

Country	Groups of benefit categories (see para. 34)					Costs
	I	I+II	I+II+III	I+II +III+IV	I+II+III +IV+V	
Albania	0	6	30	32	59	1
Austria	24	139	1119	1146	2442	239
Belarus	0	27	143	143	296	18
Belgium	33	116	1048	1053	2437	979
Bosnia and Herzegovina	0	5	66	66	137	106
Bulgaria	5	114	304	309	558	154
Croatia	1	13	182	182	384	312
Czech Republic	8	71	354	361	747	545
Denmark	2	42	222	222	480	79
Estonia	0	2	11	11	22	0
Finland	1	7	75	81	162	0
France	97	1161	5387	5462	10900	2059
Germany	170	911	7023	7086	15808	3467
Greece	8	115	491	493	964	11
Hungary	2	199	459	472	803	832
Ireland	1	13	82	82	186	206
Italy	80	1086	5201	5215	10460	749
Latvia	0	3	15	15	31	0
Lithuania	-1	4	28	28	59	6
Luxembourg	6	18	233	233	519	10
Netherlands	55	189	1761	1761	4291	1491
Norway	2	7	96	98	209	67
Poland	32	365	1427	1445	2909	1355
Portugal	6	55	346	354	702	115
Republic of Moldova	0	1	29	29	66	33
Romania	5	166	756	780	1537	1444
Russian Federation	4	70	547	547	1191	78
Slovakia	6	111	325	349	632	383
Slovenia	1	7	64	64	137	53
Spain	40	442	1896	1911	3647	246
Sweden	7	29	335	346	759	42
Switzerland	11	76	568	575	1239	8
The FYR of Macedonia	0	1	10	10	21	0
Turkey	1	164	191	191	226	1
Ukraine	-8	71	517	517	1108	263
United Kingdom	122	323	3041	3042	7574	2251
Yugoslavia	0	8	108	108	234	220
Total	723	6137	34490	34818	73938	17823