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Assessment of environmental and health benefits from the implementation of the UN-ECE protocols on long range transboundary air pollution

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Abstract

Following a detailed bottom-up impact pathway approach, environmental and health benefits in Europe resulting from the reduction of SO_2 and NO_x emissions according to the current UN-ECE protocols are quantified. As far as possible, the physical impacts are transformed into monetary terms, thus, allowing a direct comparison of abatement costs and environmental benefits. Compared to 1990 emission levels, the reduction scenario results in avoided damage costs of about 100 billion ECU per year. The analysis of geographical variation of benefits shows however that benefits and emission reduction efforts are unevenly distributed across countries.

Keywords: UN-ECE protocol; Air pollution; SO_2; NO_x

1. Introduction

The Convention on Long-range Transboundary Air Pollution is one of the main means of protecting our environment in Europe. The history of the Convention dates back to the 1960s, when scientists demonstrated the link between sulphur emissions in continental Europe and the acidification of Scandinavian lakes. After a period of

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negotiating, in 1979, 34 governments and the European Community signed the Convention on Long Range Transboundary Air Pollution [1]. In the succeeding protocols, concrete reduction targets were specified. While in the first Sulphur Protocol signed in 1985, the signatories committed themselves to reduce their emissions of sulphur to the air by at least 30%, the latest protocol, which is the second Sulphur Protocol signed in 1994, shows a different approach by setting different requirements for each country. In the sense of cost-effectiveness, the new approach aims to attain the greatest effect for the environment at the least overall cost. Work within the Convention is now focused on negotiating a new nitrogen protocol on the same principles as the second one for sulphur.

While the introduction of cost-effectiveness analysis to identify least cost emission reduction strategies in the ‘second generation’ protocols is a significant improvement in the sense of optimising resource allocation, even more precise guidance for the efficient setting of emission levels can be gained from a systematic cost benefit analysis. Cost benefit analysis allows the returns in terms of environmental benefits to be expressed on the same basis as the costs of achieving them. In addition, actions against particular pollutants can easily be prioritised, allowing resources to be targeted at those pollutants found to be responsible for the most damage. While formal cost benefit analysis is a well accepted instrument for environmental policy making in the USA [2], it is far from being used as a standard procedure in Europe. The complexity of environmental impact assessment and the relatively large uncertainties in this field are likely to be main reasons for this attitude. However, over the last years, within the EU-funded ExternE Project on External Cost of Energy, a consistent framework for the quantification and monetisation of health and environmental impacts from airborne pollutants that is based on a detailed damage function approach has been established [3]. While originally developed to estimate externalities from electricity generation, in the present paper, we demonstrate the applicability of this framework within a broader context by calculating environmental benefits resulting from the implementation of the current nitrogen and sulphur protocols.

2. Scope of the analysis

2.1. Emission scenarios considered

The present paper focuses on the estimation of environmental benefits in Europe resulting from the implementation of the UN-ECE first Nitrogen Protocol (1988) and the second Sulphur Protocol (1994). Emission targets are compared against a ‘reference scenario’ that is defined by using CORINAIR 1990 emissions (Table 1). The ‘reduction scenario’ refers to the sulphur emission ceilings for the year 2000 fixed in the second Sulphur Protocol, and to the 1987 NO_x emission levels, which should not be exceeded after 1994 according to the first Nitrogen Protocol. In a number of countries, the 1990 NO_x emissions were already below the 1987 level, in these cases, we used the 1990 emissions for both scenarios.

Table 1
SO_2 and NO_x emissions in *kt* for the ‘reference’ and the ‘reduction’ scenario

	SO_2		NO_x	
	‘Reference scenario’ (CORINAIR 1990)	‘Reduction scenario’ (sulphur emission celing for year 2000)	‘Reference scenario’ (CORINAIR 1990)	‘Reduction scenario’ (1987 emission level)
Austria	93	78	227	227
Belgium	317	248	343	297
Denmark	198	90	273	(273)[a]
Finland	227	116	270	270
France	1300	868	1590	(1590)[a]
Germany	5257	1300	2980	(2980)[a]
Greece	641	595	544	(544)[a]
Ireland	178	155	116	115
Italy	2253	1330	2053	1700
Luxembourg	14	10	23	19
Netherlands	201	106	576	559
Portugal	283	304	221	116
Spain	2206	2143	1257	950
Sweden	105	100	345	(345)[a]
UK	3787	2449	2773	2480
Total EU-15	17060	9892	13591	12465
Non EU-15	10815	6677	4203	3865
Total Europe	27875	16569	17794	16330

[a] 1990 emissions already below the 1987 level, 1990 emissions used for analysis.

Although only a change in SO_2 and NO_x emissions is considered, the analysis needs to account for chemical conversion and formation of secondary particles. Secondary particles considered are sulphate and nitrate aerosols which are treated as fine particles for the assessment of health effects. Note that, within this paper, we have not estimated the effect of reduced NO_x emissions on ground level ozone concentration.

2.2. Impacts considered

In ExternE, estimates of damages from airborne pollution have been made for a wide variety of receptors, including human health, materials, crops, forests, fisheries and natural ecosystems. In this paper, we concentrate on impacts to the first three categories, which have shown to result in major damage costs. Health effects include increased mortality and a wide range of morbidity endpoints, e.g., respiratory symptom days, asthma attacks, or respiratory hospital admissions. Impacts on crop production are estimated for wheat, barley, potato, rye, oats, and sugar beets. To quantify material impacts, the replacement frequency of zinc, galvanised steel, limestone, mortar, sandstone, paint, and rendering for utilitarian buildings is estimated.

3. Methodology

The methodology follows the detailed bottom-up impact pathway approach developed in the ExternE project [3], in which we try to model the causal relationships from the release of pollutants through their interactions with the environment to a physical measure of impact and, where possible, a monetary valuation of the resulting welfare losses. Based on the concepts of welfare economics, monetary valuation follows the approach of 'willingness-to-pay' for improved environmental quality. While in the following sections, we briefly summarise some of the basic assumptions underlying the impact assessment, a more detailed discussion of the approach is provided in Ref. [3].

To quantify environmental benefits according to the detailed impact pathway approach, we use the integrated assessment model EcoSense that has been developed within the ExternE project [4]. EcoSense provides a comprehensive set of air quality and impact assessment models together with relevant input data, including population distribution, land use, material inventory and meteorological data for the whole of Europe. The change in concentration and deposition of acid species is calculated using the Windrose Trajectory Model, a Lagrangian trajectory model included in the EcoSense package.

3.1. Human health effects

There are now numerous studies linking fine particulate air pollution with a wide range of both acute and chronic health effects, and there is a growing tendency to treat the associations as causal. Incremental particulate air pollution may arise due to the direct emissions of particulates, but also due to the subsequent formation of sulphate and nitrate aerosols from gaseous SO_2 and NO_x emissions, which is of primary relevance for our study. From recent epidemiological studies (e.g. Ref. [5]), there is an increasing evidence of chronic mortality effects from ambient particulates. In contrast to the time series studies on acute mortality (e.g. Ref. [6]), which show a correlation between day-to-day changes in ambient air particulate concentration and daily death rates, studies on chronic mortality give a change in age-dependent mortality rate within the total population resulting from long term exposure to an increased level of air pollution. Using this measure, we can quantify the cumulated loss of life expectancy within the population rather than the number of 'additional' deaths [7]. (Taking into account the fact that everyone is going to die only once, the quantification of 'Years of Life Lost' due to air pollution seems to be more appropriate than counting 'additional' deaths.) The exposure–response function used here was derived by applying the change in age-dependent mortality rate as a function of ambient particulate concentration from Ref. [5] to a European population, resulting in a relation between a change in ambient concentration and reduced life expectancy, measured as 'Years of Life Lost'. [1]

[1] F. Hurley et al., Mortality estimation and valuation, ExternE working paper, unpublished, 1997.

The valuation of mortality is based on the *Value of Statistical Life* (VSL), a measure commonly used in environmental economics, indicating the *Willingness-to-Pay* for a reduction of (a small) risk. A meta-analysis of valuation studies from Europe and North America undertaken in ExternE suggests a mean VSL of 3.1 million ECU. Taking into account the new concept of quantifying a loss of life expectancy rather than the number of deaths, there is an ongoing debate on how to derive a *Value of Life Year Lost* (VLYL) from the VSL estimate. Based on a given time distribution of impacts from air pollution in a European reference population, we have used the VSL of 3.1 million ECU to calculate a Value of Life Year Lost as a function of discount rate, which is used to express individuals' time preference, resulting in 98 000 ECU, 84 330 ECU, and 60 340 ECU for discount rates of 0%, 3%, and 10%, respectively. While the approach of putting a value on a life year lost seems to be plausible for many people, in particular, as it better takes into account the specific context of premature death than the VSL based valuation, to date there is only limited empirical evidence supporting this approach, so that uncertainty remains large. In our case, a valuation using the VSL approach would result in much higher benefits, so that the present results might be considered as a lower estimate.

Morbidity costs that are calculated taking into account both willingness-to-pay and cost of illness result in a minor fraction of the overall health related damage costs.

3.2. Effects on agriculture

We have assessed direct effects of SO_2 on crop yield. Exposure–response functions used for impact assessment have been derived from field exposure or open-top chamber experiments, they are given in Ref. [3]. Furthermore, the costs of changing the amount of lime needed to deal with acidification of agricultural soils, and the benefits of N deposition acting as fertiliser has been estimated following an approach described in Ref. [8]. The estimated yield loss is valued with world market prices to obtain resulting damage costs. Costs of liming and benefits of oxidised N deposition are calculated from market prices for lime and fertiliser.

3.3. Effects on building materials

The dose–response functions for the effects of SO_2 and wet acid deposition on corrosion are mainly taken from the work of the UN-ECE ICP on materials [9]. The thickness or mass loss calculated by using these dose–response functions leads to an estimate of changes in the maintenance and replacement effort, which are valued using market prices. The material inventories are quantified in terms of the exposed material area from estimates of 'building identikits' (representative buildings). Surveys of materials used in the buildings in some European cities (Birmingham, Cologne, Dortmund, Sarpsborg, Stockholm, and Prague) were used to take into account the use of different types of building materials around Europe. As no such data were available for Southern Europe, data collected in northern Europe had to be extrapolated.

4. Results and discussion

Taking into account impacts on human health, crops and materials, the reduction of SO_2 and NO_x emissions from 1990 levels to the emission targets specified in the current UN-ECE protocols is estimated to result in avoided damage costs of about 100 billion ECU per year (Table 2), which is about 1% of the gross domestic product of the EU-15 countries in the 1990 reference year. Nearly 90% of these benefits are due to avoided mortality impacts. According to our estimates, the reduction in emission levels leads to an additional life expectancy of 90 000 life years per year within a population of about 530 million people covered in this study. This positive effect is mainly caused by a significant reduction of ambient sulphate concentrations.

The impacts on crop production show a net damage in spite of reduced SO_2 concentration levels. As demonstrated in a large number of experiments, low levels of SO_2 are capable of stimulating growth, so that—depending on background conditions—a reduction of SO_2 concentration might result in yield loss. There is some uncertainty involved in describing this effects by using a quadratic exposure–response function at low level SO_2 concentrations as suggested in Ref. [3], but due to the relatively small overall impact we do not expect results to be significantly influenced.

The largest damages for materials are associated with paint and galvanised steel, which are materials with relatively short maintenance cycles. Effects on stone are negligible, though we have omitted the assessment of damage to buildings of cultural value.

The spatial distribution of benefits is indicated in Fig. 1. Not surprisingly, the largest reductions in damage are observed in the countries with the largest populations, Germany, France, UK, and Italy. Avoided damage tend to be larger also in the central European countries because of emission reduction in the surrounding countries.

Although we have made no attempt to perform a full cost–benefit analysis in this study, in Fig. 1, we compare each country's contribution to the overall emission reduction targets against the share of benefits for each country. More than 20% of the total benefits are expected to occur within Germany, where at the same time the highest SO_2 emission reductions are required. Countries like France, Austria, and the Netherlands seem to be among the winners, as the share of benefits clearly exceeds the contribution to the overall emission reduction. However, as discussed before, the costs

Table 2
Benefits from avoided environmental damage in Europe

Impact category	Avoided damage in million ECU/year
Human health impacts	
Mortality	88 374
Morbidity	9395
Crop losses	−66
Material damage	2512
Total	100 215

European currency unit (ECU) = US$1.25.

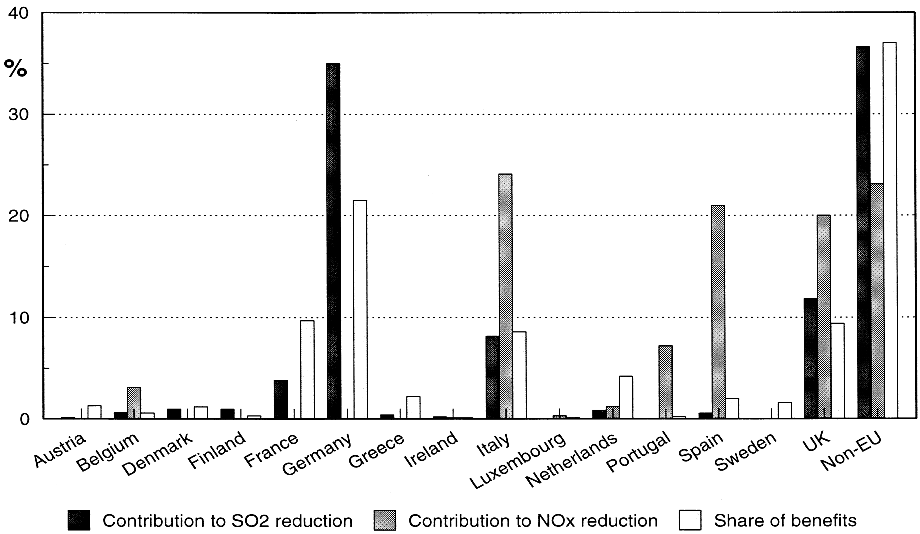

Fig. 1. Emission reduction efforts and environmental benefits.

of emission reduction, which have not been addressed in this paper, should be used for a direct comparison.

The results presented above are very much dominated by mortality impacts, so that we briefly discuss some of the most important assumptions and related uncertainties. While the mechanism of action of particulate air pollution is not yet well understood, a large number of epidemiological studies show a significant statistical association between air pollution and health effects. Uncertainties in these studies are commonly addressed by reporting confidence intervals derived from statistical analysis. However, the 'statistical' uncertainty is assumed to be relatively small compared to some 'strategic judgements' which are required to apply exposure–response functions within our context. One of the most important assumption is that there is no threshold at the population level. Although there clearly is a threshold at the individual level in the sense that most people are not realistically at risk of severe effects at current background levels, it appears that for a large population even at low background concentrations some vulnerable people are exposed, which are likely to experience an adverse effect. [2] This 'no-threshold' assumption is now quite well established (see, for e.g. Ref. [10]).

As discussed above, the second major source of uncertainty is the valuation of mortality impacts. We have used the Value of Life Years Lost derived from the VSL using a 0% discount rate as a best estimate. The use of higher discount rates leads to a reduction of mortality damage costs of 14% or 40% in the case of a 3% or 10% discount

[2] F. Hurley, P. Donnan, An update of exposure–response functions for the acute and chronic public health effects of air pollution, Unpublished ExternE working paper, Institute of Occupational Medicine, Edinburgh, 6 February 1997.

rate, respectively. The valuation of mortality impacts using the VSL approach would increase the benefits from avoided mortality damage by a factor of 3.

5. Conclusions

The present paper provides a detailed bottom-up assessment of monetised damages to health, materials and crops from the reduction of SO_2 and NO_x emissions according to the current UN-ECE agreements. We have used detailed models, which have been reviewed by experts from Europe and the USA, for tracing pollutants from the source to the effect on receptors, thus, taking into account site specific conditions which we found to be important in previous ExternE work. Benefits resulting from avoided environmental and health damage amount to about 100 billion ECU per year, which in our case practically is an effect of SO_2 reduction, as the reduction of NO_x required to comply with the current Nitrogen Protocol is very small. Benefits from future NO_x and NH_3 emission reduction, which are expected from the implementation of the second Nitrogen Protocol or a European acidification strategy can easily be assessed following the same approach. Taking into account the uncertainties discussed, such information can be used for the identification of cost-optimal emission reduction strategies. The presentation of geographical variation in damage and benefits is of particular policy interest, as it provides helpful information for the negotiation process of national and international emission targets.

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