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The revision of the air quality legislation in the European Union related to ground-level ozone ☆

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Abstract

Complying with the obligation in the current ozone directive, the European Commission came forward in 1999 with a strategy to combat tropospheric ozone together with a proposed revision of the air quality legislation for this pollutant. As a daughter legislation under the 1996 Framework Directive on Air Quality, the proposed ozone daughter directive defines for the first time (interim) air quality targets for ozone to be attained by 2010, complemented by long-term objectives for ozone based on the guideline values of the World Health Organisation. It also sets out enhanced requirements for monitoring and assessment of ozone concentrations, as well as minimum criteria for appropriate information of the public about the measured air pollution.

In the past, abatement strategies against air pollution consisted of concrete obligations for controlling emissions derived solely on the basis of technical and economic aspects, covering specific types of installations or activities, thus with no direct quantitative relationship to the level of air pollution let alone to its effects.

In compensating this deficit, the Commission presented, as a complement to the existing sectoral legislation, a proposal for a directive on national emission ceilings (NEC) which quantifies emission targets for every Member State to bring its total precursor emissions by 2010 down to levels being considered as necessary to achieve everywhere on a regional scale the air quality targets set in the ozone daughter directive.

As the core element of the ozone abatement strategy, the national ceilings for emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOC) were derived from a cost-effectiveness analysis integrating information on economic, technical, physical and biological aspects of ozone pollution and abatement. This integrated assessment considers the potential and costs for further emission control in the various economic sectors in the Member States and combines this with information on ozone formation and

☆ Views expressed in this paper do not necessarily reflect the views of the European Commission.

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transport processes in the atmosphere and with indicators for the impact of ozone on human health and environmental.

Reflecting the discussions with Member States and stakeholders, a number of decisive steps in the process of deriving the national emission ceilings are presented here: the way of framing interim objectives, how to choose an appropriate ambition level, aspects of how to cope with uncertainties in the model and the input data and how to treat extreme meteorological situations and resolve problems in the spatial distribution of the interim objectives given the different size of countries. Finally, the paper explains the scenario underpinning the proposed national emission ceilings, its environmental gains and the distribution of cost incurring for emission control measures in Member States.

Keywords: Ground-level ozone; European Union Environmental Policy; Air Quality Framework Directive; National Emission Ceilings Directive; Integrated assessment model

1. Introduction

Increasing levels of photochemical pollution (the 'summer smog') are recognized as a widespread air quality problem in the European Union since more than a decade. The first EU directive on ground-level ozone (Council Directive 92/72/EEC) established in 1992 a common framework for the assessment of the summer smog problem in the Community with specific obligations to monitor ozone and to report regularly about the pollution load.

Since then, widespread violation of the ozone protection thresholds specified in this directive was reported all over Europe, and it is estimated that more than 330 million people in the Community are exposed to harmful ozone levels [1]. These exceedances and growing evidence about the transboundary nature of the ozone problem [2] underlined the urgency for a Community-wide strategy to reduce ground-level ozone. Between 1997 and 1999, the European Commission developed a package of policy proposals to revise the Community legislation related to ground-level ozone and to devise a comprehensive and efficient emission control strategy (COM(99)125 final, see http://europa.eu.int/comm/environment/docum/99125sm.htm).

This article reviews the history of ozone-related legislation of the European Union and describes the process leading to the recent air quality daughter directive on ground-level ozone. Section 2 discusses the basic concept for air quality management in the EU. Section 3 summarizes the main aspects discussed in the course of the recent revision process of the ozone-related EU legislation. Section 4 introduces the cost-minimized emission control scenario underpinning the Commission's proposal on the directive on national emission ceilings. Conclusions are drawn in Section 5.

2. The legislative approach to control air pollution in the EU

2.1. The concept

The Treaty establishing the European Community, as amended by the Amsterdam Treaty of 1997, explicitly provides for the development and implementation of a

Community policy on the environment. The general objectives formulated in the Treaty (Art. 174 (1)) are to

(i) preserve, protect and improve the quality of the environment,
(ii) to protect human health, and
(iii) to utilize natural resources in a prudent and rational way.

For achieving these environmental objectives, the Treaty explicitly lists in Article 174(2) the precautionary principle, the principle of preventive action, the principle of rectifying damage at the source and the polluter pays principles. At the same time the principle of subsidiarity applies, meaning that action on EU level ought to confine itself to the extent that measures can be taken more effectively on Member States level (Art. 5).

A more specific interpretation of the environmental objectives is provided in the Fifth European Environment Action Programme for the years 1992–2000 [3]. In particular, achieving sustainability is established as the central target. For ecosystems, sustainability is interpreted as the 'non-exceedance of critical loads and critical levels', i.e., of the 'no-damage' exposure thresholds for acid deposition and ozone levels for vegetation as developed within the scientific work of the UN/ECE Convention on Long-range Transboundary Air Pollution [4]. In addition, the Fifth Environment Action Programme calls for the effective protection of all people against recognized health risks and demands that the guideline values of the Word Health Organization [5] should become mandatory at EU level.

Thereby, the EU Treaty and the Fifth Environment Action Programme set out the overall objectives and principles for EU environmental policy. A wide body of legislation translates the general policy objectives into specific air quality criteria and concrete instructions for assessing and managing air quality. Traditionally, this legislation follows a two-track approach. Air quality criteria, common monitoring strategies and information requirements are defined in air quality directives, while for the individual emission sources the required control measures and their technical details are specified in a variety of emission-related directives.

2.2. Air quality related directives

2.2.1. The 1992 directive on air pollution by ozone

In the early 1990s, increasing concentrations of ground-level ozone were recognized as a matter of concern to many European countries. Responding to domestic legislation, rather dense monitoring networks were established, particularly in Germany and in the Benelux countries. These monitoring activities improved the information of the public about pollution levels, generated increased public concern about the summer smog problem and resulted in a strong public demand for control measures. The first synoptic assessment of the measured ozone pollution in Germany [6] demonstrated a significant transboundary dimension of the problem. A joint Benelux–German initiative in 1990 established common thresholds for informing and warning the population.

This initiative also pushed action at EU level to come forward with a Community-wide regulation. In 1992, the first EU ozone directive (92/72/EEC) introduced Community-wide health and vegetation protection thresholds for ozone based on the WHO guidelines valid at that time and obliged the Member States to monitor ozone pollution and to report regularly to the Commission.

In contrast to the United States, where the ozone standards represent policy targets that are connected to the implementation schedules of emission control measures, the thresholds specified in the EU 92/72 directive served merely as indicators for air quality monitoring and assessment. Only Article 7(2) of the directive requested the Commission to come forward with a strategy to combat ozone within 4 years, if the assessment of the ozone load reported by Member States indicated a need for it.

The 92/72 directive also introduced information and warning levels to trigger timely information to the public about high ozone levels in the ambient air and to advise about recommended health measures. This innovative provision led to a significant raise in public awareness on air pollution, which eventually surged the pressure on Member States and the Commission to take action.

2.2.2. The 1996 air quality framework directive

The adoption of the "framework" directive on assessment and management of air quality (96/62/EC) in 1996 can be considered as a culmination of this development. This directive introduces a general framework, designed to deal with a larger list of air pollutants in a common way. It retains the idea of the 92/72 ozone directive of obliging authorities to provide adequate information on pollution levels to the public and even to "alert" people in the event of pollution exceeding certain short-term thresholds. In addition, the directive sets out the common scheme of monitoring and assessment requirements and introduces air quality standards in form of limit- (and for ozone also target-) values, which will serve as quantitative benchmarks for air pollution abatement polices in the future. Member States must develop and regularly review abatement plans and programs to ensure compliance with these limit values.

Details of the air quality standards and specific monitoring strategies for the various pollutants are subjects of a series of 'daughter directives'. The first of the new daughter directives (99/30/EC) with revised limit values for SO_2, fine particulate matter, NO_2 and lead came into force in 1999. At the moment of writing this article, Council and the European Parliament are discussing the Commission's proposal for a new daughter directive on ozone.

2.3. Emission-related directives

2.3.1. Uniform emission limit values and quality standards for fuel and products

The traditional approach in Community legislation to the control of polluting emissions consists of a number of directives regulating the release of emissions from a wide range of sources by setting uniform limit values for emissions in industrial key sectors and imposing quality criteria on certain fuels and products. Examples are the 'large combustion plant' directive (88/609/EEC), the vehicle-related directives up to 94/12/EC and 96/69/EC, the Directive on Volatile Organic Compounds Emissions from Storage and Distribution of Petrol (94/63/EC), and the Directive on Solvents Use in Industry (99/13/EC). Driven by the precautionary principle, these limit values were decided on the basis of the 'best available technique' (BAT) concept, in most cases by taking the more stringent of existing national emission standards as a starting point for EU legislation.

2.3.2. The Integrated Pollution Prevention and Control (IPPC) Directive

Since 1996, the IPPC directive (96/61/EC) extends the implementation of the BAT concept to a large number of industrial activities (energy industries, production and processing of metals, mineral and chemical industries, waste management, etc.), for which it lays down general rules for the national permitting systems.

The basic concept is that operators should go as far as they reasonably can to optimize their environmental performance by applying the best available techniques. Environmental performance is eventually to be measured against meeting the existing environmental quality standards, e.g., for air pollution to comply with the air quality standards of Community legislation.

The practical implementation of the IPPC approach requires that both operators and permitting authorities are aware of the BATs in the relevant industrial sector. To ensure the exchange of relevant information on BAT, the European IPPC Bureau was established within the Institute of Prospective Technological Studies (IPTS) in Seville, which is part of the Commission's Joint Research Centre. The IPPC Bureau is currently drafting jointly with experts from industry and Member States more than 30 so-called "BAT Reference Documents" (BREFs) covering all IPPC sectors.

The emission limits listed in the BREFS are judged to represent reasonable (longer term) targets for an industrial sector as a whole, and they do not imply that all existing installations would have to meet those standards by a certain date. Regulators are requested to take the information contained in the BREFs into account when setting permit conditions, but the emission limit values contained in these documents are not considered as binding for the whole industry.

Therefore, the IPPC approach cannot be regarded as a means to substitute the legislation on emission limit values (ELVs) mentioned above. It was even the Council who inserted Article 18 of the IPPC directive into the original Commission's proposal to underline that IPPC should not lead to abandoning legislation containing binding Community-wide ELVs.

2.4. Consolidation of the community's air pollution control approach

It is important to highlight the different but complementary functions of the air quality directives on the one side and the emission-related directives on the other. The air quality directives define air quality criteria for the various pollutants, common methodologies for monitoring air quality and procedures for reporting, but do not address concrete action to achieve the criteria set out. Thereby the air quality directives translate the general objectives of Community environmental policy as contained in the EU Treaty into concrete and measurable air quality criteria. The emission-related directives address the requirements for controls at specific sources. Thus they embody the key principles of environmental policy mentioned in the EU Treaty, i.e., the precautionary principle, preventive action, rectifying damage at the source and the polluter pays principles. However, in quantifying the required degree of emission controls, these directives, while taking into account the costs for control, usually do not establish formal links to the air quality criteria. The two-way interactions between the two elements are illustrated by Fig. 1.

In principle, the IPPC directive can be considered as a first step towards a consolidated approach towards air quality management, integrating air quality related legislation with concrete regulations on emission control. However, as discussed above, the IPPC directive falls short of specifying quantitative obligations to industrial sectors and Member States.

2.5. The acidification strategy and the directive on national emission ceilings

A further step towards an integration of environmental policy objectives and emission control measures was undertaken by the European Commission in its Acidification Strategy (COM97(88)final) proposed in 1997. Based on the environmental (long-term) objectives laid down in the Fifth Environment Action Programme (the full achievements of critical loads) and facing the practical difficulties of achieving these targets within the medium-term, the Commission proposed environmental interim targets for the protection against acidification, to be achieved by the year 2010. A cost-effectiveness analysis, taking into account the differences in costs of the remaining emission control options and in the dispersion characteristics of the various pollutants in the atmosphere,

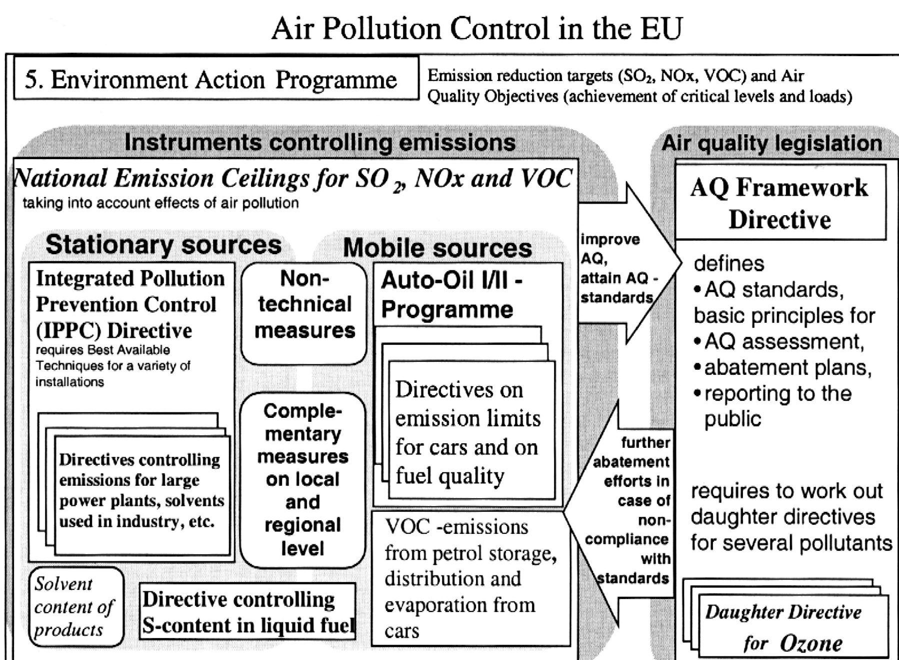

Fig. 1. The conceptual structure of air quality management legislation in the European Union.

identified the least-cost distribution of additional emission control measures across the various economic sectors in the Member States. Such ‘national emission ceilings’, to be laid down in a future directive, should eventually guarantee the achievement of the environmental objectives.

Limiting the volume of total national emissions responds to the transboundary character of acidifying pollution. Due to the long-range transport of emissions in the atmosphere, acid deposition at a given site originates from a large variety of emission sources, usually from a large number of countries. In most parts of Europe, local deposition is heavily dominated by transboundary contributions, so that domestic emission control measures can have only limited environmental effects near the sources. National emission ceilings imposed on all Member States address the transboundary component of pollution, so that there is a realistic chance that local measures can lead to effective environmental improvements.

While acknowledging internationally uniform source-specific minimum requirements laid out in the various emission-related directives, obligations in the form of national emission ceilings leave maximum flexibility to the Member States on how certain emission reduction targets could be best implemented. This opens the door for economic instruments (fuel taxes, road pricing, fiscal incentives, etc.) and for complementary measures on a local scale.

3. The revision of the ozone legislation

3.1. Introduction

After the acceptance of the air quality framework directive in 1996, work started on the daughter directive addressing ground-level ozone. This revision of the 92/72 ozone directive aimed at a more rational approach for determining obligations to European industry and Member States for controlling ozone precursor emissions.

The 1990s saw growing scientific understanding that, similar to acid deposition, ozone and its precursor emissions may also reside for a significant time in the atmosphere and may be transported over several hundreds of kilometers [7]. Similar to acid deposition, the control of ground-level ozone was recognized as a transboundary task, and the general model of the daughter directives developed for ‘local’ pollutants was not considered to be fully appropriate for ozone.

The revision process had to address the following issues:

- Establish for ground level ozone the environmental policy objectives, i.e., define for ozone the ‘no-damage levels’ compatible with the long-term targets of the Fifth Environment Action Programme, and decide upon appropriate environmental interim targets with a well defined time-scale for attainment;
- Specify in more detail the monitoring requirements for ground-level ozone;
- Propose rules for reporting to the Commission and for informing the public;
- Propose concrete measures for reducing precursor emissions to control ground-level ozone; and
- Identify appropriate policy instruments for implementing emission controls.

While in reality these aspects are strongly interconnected with each other, for formal reasons they had to be decomposed into three legal elements: (i) the daughter directive on ground-level ozone, (ii) a new ozone strategy and (iii) the directive on national emission ceilings.

Under the guidance of the Air Quality Steering Group composed of members from the Commission services, Member States and representatives of industry and non-governmental organizations, three expert groups were formed. The 'Ad-hoc' Working Group on Ozone focused on the development of the daughter directive and the ozone reduction strategy; the 'Risk Assessment' subgroup collected and reviewed scientific information about the impacts of ozone on human health and vegetation, and the 'Monitoring' subgroup, with technical support of the Environment Institute of the EU Joint Research Center in Ispra, prepared the guidelines for the monitoring strategy. The synthesis results of these expert groups were condensed into the 'ozone position paper' edited by the Commission Services staff [8]. This position paper reviews the legal basis for ozone control, discusses the long-term and medium term environmental objectives, describes the monitoring and assessment strategy and introduces the reporting guidelines.

3.2. The selection of the environmental objectives for ozone

In the overall framework of the air quality directive, the ozone daughter directive had to specify the environmental objective for ozone. The context is given in the general objectives for EU environmental policy as stipulated in the EU Treaty (protection of human health and of vegetation) and by the provisions of the Fifth Environment Action Programme, i.e., the full achievement of no-damage levels such as critical loads and levels to protect vegetation and to guarantee levels of air quality that are not detrimental to health.

In practical terms, the Risk Assessment Subgroup referred, for vegetation protection, to the work of the UN/ECE Working Group on Effects, where no-damage thresholds of ozone exposure are determined for natural vegetation, agricultural crops and forest ecosystems. These 'critical levels' are expressed in terms of 'AOT40', i.e., the accumulated hourly excess ozone over a threshold of 40 ppb. For natural vegetation and agricultural crops, the AOT40 calculated for daylight hours over a 3-month vegetation period should not exceed 3000 ppb h. For trees, a critical level of 10,000 ppb h accumulated over 6 months is defined. The definition of a no-damage level for human health was more controversial. Ultimately, reference was made to the assessment of the World Health Organization for Europe (WHO-EH), where a health guideline value of 60 ppb as an 8-h average was recommended. Despite criticism from the industry, this position was confirmed by the independent Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) established by the Commission after the BSE crisis [9].

3.3. The choice of an environmental interim target

Early analysis demonstrated that the no-damage levels put forward as the long-term policy objective will not be achievable until 2010 (the time horizon of the analysis), given the limitations of presently available control measures and excluding fundamental changes in the structure of economic activities and in personal lifestyles [10].

As a consequence, the daughter directive specifies these no-damage thresholds for human health and vegetation as the environmental long-term objective, which is based exclusively on consideration of the effect and impact of ozone. As required by the air quality framework directive and for practical purposes, a 'target value' was introduced as an interim objective to be achieved as far as possible by 2010, taking into account the long-term objective and practical implementation issues.

Obviously, the choice of appropriate interim targets for ozone became a central question, since it highlights conflicting views about the appropriate ambition level, e.g., between industry and environmentalists. There was consensus that the target value should not be expressed as an absolute maximum concentrations (no exceedances allowed), but instead as a percentile of daily maximum concentrations over the year to allow for few extreme and untypical events (e.g., meteorological conditions). When choosing a concrete numerical value, however, opinions diverged over two possibilities:

- the target value could be directly based on the WHO guideline for the protection of human health (120 $\mu g/m^3$), but allowing a sufficient high number of exceedances (between 20 and 25 days) in each year, or
- it could be expressed as a higher concentration (e.g., 160 $\mu g/m^3$) with a smaller number of allowed exceedances (e.g., between three and four per year).

Important arguments addressed potential differences in reducing the risk to public health. It might be argued that a target value of 160 $\mu g/m^3$ with few exceedances would be more effective in reducing peak ozone concentrations than a target value of 120 $\mu g/m^3$ with more exceedances. If peak ozone concentrations were the main concern, indeed the first option would provide better protection. However, model calculations suggested that measures aimed at complying with a 120 $\mu g/m^3$ target will reduce peak ozone concentrations more rapidly than lower concentrations. Finally, the main argument for choosing the 120 μg option was that a synthesis of the available controlled exposure studies suggests linear relationships between exposure in the environment and health effects in the general population over a range extending below 120 $\mu g/m^3$. Therefore, the impacts of incremental ozone exposure are independent from the actual concentration, so that frequent and small reductions at lower concentrations might be at least equally important as reducing relatively infrequent high peaks. Furthermore, more population is benefiting from the 'low level' improvements than from a cut in less widespread ozone peaks. Additional arguments addressed the transparency of the selected rationale (i.e., maintaining the connection with the WHO guideline) and statistical problems associated with high percentiles, which are relevant for monitoring performance and compliance check.

Finally, the Commission's proposal for the ozone daughter directive contains a target value for human health of 120 $\mu g/m^3$ as an 8-h average, not to be exceeded on more than 20 days a year. Similarly, it proposes a target value for the protection of vegetation which is set at an interim AOT40 level of 8500 ppb h, whilst the critical level amounts to only 3000 ppb h. Member states have to inform the Commission of any non-compliance with the target values and, within 2 years, of abatement plans and programs developed and implemented with the aim of attaining the target values. Conversely, the Commission has to assess this information as a basis for the requisite back-reporting by 2004 to the Council and the European Parliament. This report has to be accompanied by ideas on how to revise the air quality objectives and how to come up with an integrated air pollution abatement strategy for Europe with the aim of approaching the long-term objectives.

3.4. The cost-effectiveness analysis

The Commission explored the practical possibilities for reducing ground-level ozone to various levels of environmental interim targets and the implications of alternative emission control strategies, comparing the environmental achievements of the emission reductions with the incurred costs for the individual countries.

The ‘cost-effectiveness’ principle emerged as the driving rationale for deciding about the appropriate stringency of emission controls. This principle aims at the least-cost solution to achieve given environmental air quality criteria and thereby guarantees that all proposed emission reductions will be justified by actual environmental improvements. The cost-effectiveness principle implies that more stringent measures are required in ecologically sensitive zones while avoiding over-controls in areas where the environmental objectives are already met, possibly resulting in an uneven distribution of reduction costs among the Member States. The argument for uniform environmental standards in all Member States to respect the precautionary principle as it was earlier used for justification of the emission-related directives (e.g., the Large Combustion Plant Directive) was transformed from uniform emission-related standards to uniform standards of environmental air quality. In the interest of cost-effectiveness, differences in emission-related standards became acceptable.

It is important to mention that the cost-effectiveness concept is fundamentally different from a cost-benefit analysis. Under the cost-effectiveness concept, the extent of emission reductions is driven by exogenously specified targets for environmental quality — in this particular case by the environmental policy objectives specified in the EU Treaty and the Fifth Environment Action Programme. Under a cost-benefit approach, the appropriate stringency of emission controls would be determined by the balance between emission control costs and monetized environmental benefits.

The cost-effectiveness analysis was carried out using the ‘Regional Air Pollution Information and Simulation’ (RAINS) model developed at the International Institute for Applied Systems Analysis (IIASA) in Austria [11]. The RAINS model integrates information on the sources of emissions including economic development in all Member States, the technical possibilities, the current status and the costs for reducing emissions, the atmospheric dispersion processes and the environmental impacts of pollution on a regional scale. The optimization feature of the RAINS model enables the identification of least-cost combinations of available emission controls in order to meet exogeneously specified regional air quality targets (Fig. 2).

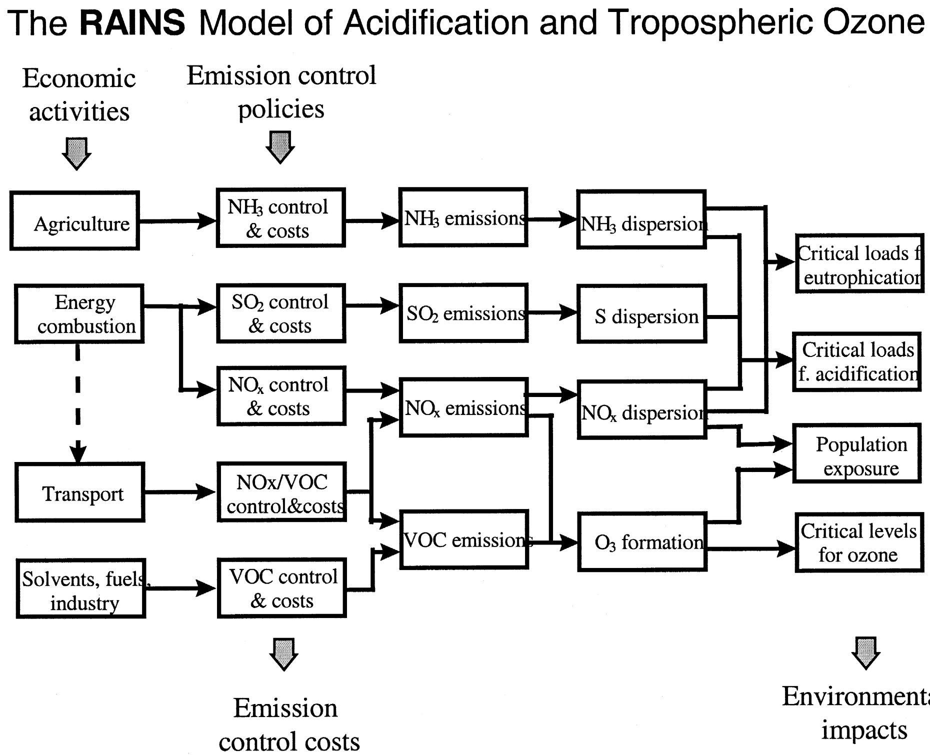

Fig. 2. The structure of the RAINS model.

The cost-effectiveness concept and the use of the integrated assessment tool responds to paragraph 3 of Article 174 of the Community Treaty, which requests the Community, when preparing its environmental policy, to take account of

- available scientific and technical data,
- the environmental conditions in the various regions of the Community,
- the potential benefits and costs of action or lack of action, and
- the economic and social development of the Community as a whole and the balanced development of the regions.

3.5. The assessment model: RAINS

The RAINS model, developed and maintained by the IIASA, is a tool for an integrated assessment of multi-pollutant emission control strategies addressing multiple environmental effects including ground-level ozone, acidification and eutrophication. The model combines information on the sources of emissions (e.g., economic development, the present and future structure of emission sources, the potential and costs for controlling emissions) with scientific information about the dispersion of pollutants in the atmosphere including the ozone formation processes. It compares the resulting regional air quality with various indicators of risk at stock (e.g., population, critical loads and critical levels for vegetation, etc.). For describing ozone formation, the RAINS model uses a 'reduced-form' model derived by a statistical analysis from a large sample of scenarios calculated with the comprehensive EMEP photo-oxidants model [12]. The full EMEP model performs calculations in six hourly intervals for 6-month periods (April–September) for actual meteorological conditions of 5 years, covering in its model domain all of Europe with a spatial grid resolution of 150 × 150 km [2]. The reduced-form model captures the response of regional long-term ozone levels (expressed as AOT40 and/or AOT60) to changes in annual emissions of the precursor emissions (NO_x and VOC) in the European countries.

The optimization feature of the RAINS model was extensively used to identify the least-cost allocation of emission controls for individual pollutants (SO_2, NO_x, VOC, NH_3) in the various economic sectors in the 15 Member States of the European Union. A comprehensive description of the RAINS model is provided in Amann et al. [12].

The use of the RAINS model was facilitated by the fact that, at the same time of developing the EU ozone directive, negotiations on the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone proceeded under the UN/ECE Convention on Long-range Transboundary Air Pollution. These negotiations included, inter alia, all Member States of the European Union and relied heavily on RAINS model calculations. Under this umbrella, the development of the RAINS model and of all its components was continuously reviewed by national experts within the UN/ECE Task Force on Integrated Assessment Modelling. The 1998 in-depth review of the RAINS databases on national emission control potentials and costs, which was strongly seconded by the European Commission, led to the formal acceptance of the model as a common scenario analysis tool.

3.6. Emission reductions to meet the environmental interim targets

Using the integrated assessment model, iterative analyses were carried out to explore appropriate interim environmental objectives for the year 2010. For proposing a target value, a series of optimization (cost-minimization) analyses were conducted for a range of potential target values for health and vegetation protection. The target values discussed for the daughter directive had to be translated into model parameters of the reduced-form model. This was straightforward for vegetation protection, since the proposed target value was expressed in terms of excess ozone exposure above the threshold of 40 ppb/m^3 (the AOT40), which is a direct output of the RAINS model. For health protection, the excess frequency of the WHO guideline value had to be approximated by an AOT60, i.e., by the accumulated excess over the 60 ppb/m^3 (120 $\mu g/m^3$) threshold, which could then be used as an environmental constraint in the optimization analysis. As a result of the optimization series, it was concluded that target values of 2.9 ppm h of the AOT60 (meaning approximately 22 days with excess of the WHO guideline) and of 10 ppm h for the AOT40 would represent a medium ambition level (Figs. 3 and 4).

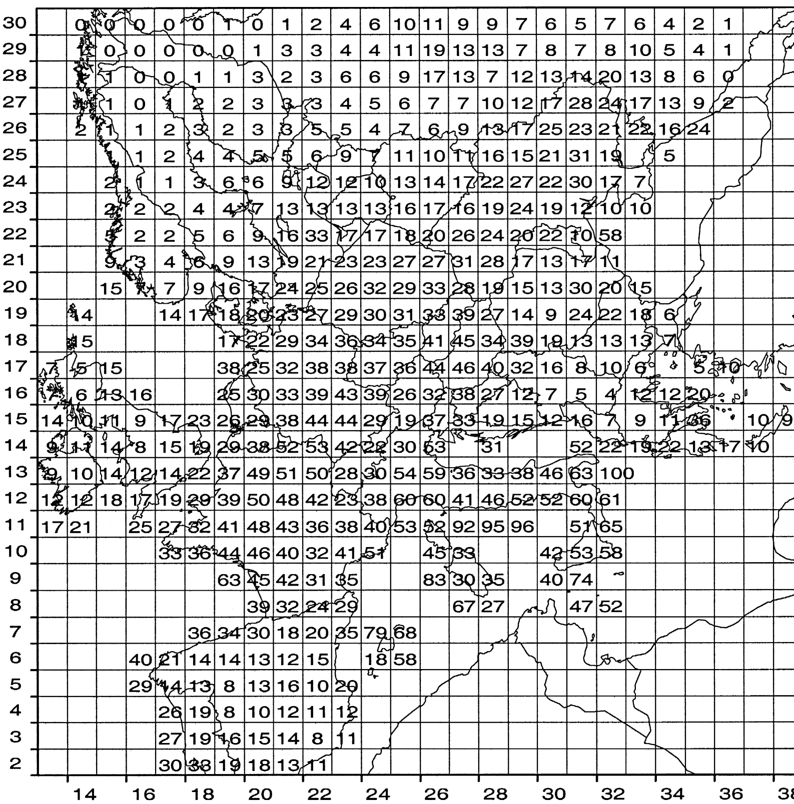

Fig. 3. Number of days with ozone above 60 ppb, emissions of 1990, maximum of the 3-year moving average over the 5 meteorological years.

It was found that, if imposed on the entire EU territory, the health-related criterion would be most difficult to attain and would thereby imply most stringent emission controls in northern France and the Benelux region. Compliance with the vegetation-related target value would be most demanding for France and northern Italy. In all other countries, presently decided emission controls and the measures necessary to limit their atmospheric long-range contribution to the 'hot spots' (Benelux, France, Italy) would result in ozone levels below the proposed target values.

The existence of few isolated 'hot spot' areas steering the emission controls throughout the Community highlighted a problematic feature of using a uniform 'target value' approach for determining effective emission control pathways towards the environmental long-term targets. First, the target value must be high enough to be practically achievable at the 'hot spots'. It turned out that most regions in the EU are already now in compliance with such a high target value, although they are definitely far above the long-term objective. A uniform target value would therefore concentrate all emission control efforts to the most polluted regions, but does not induce progress towards the

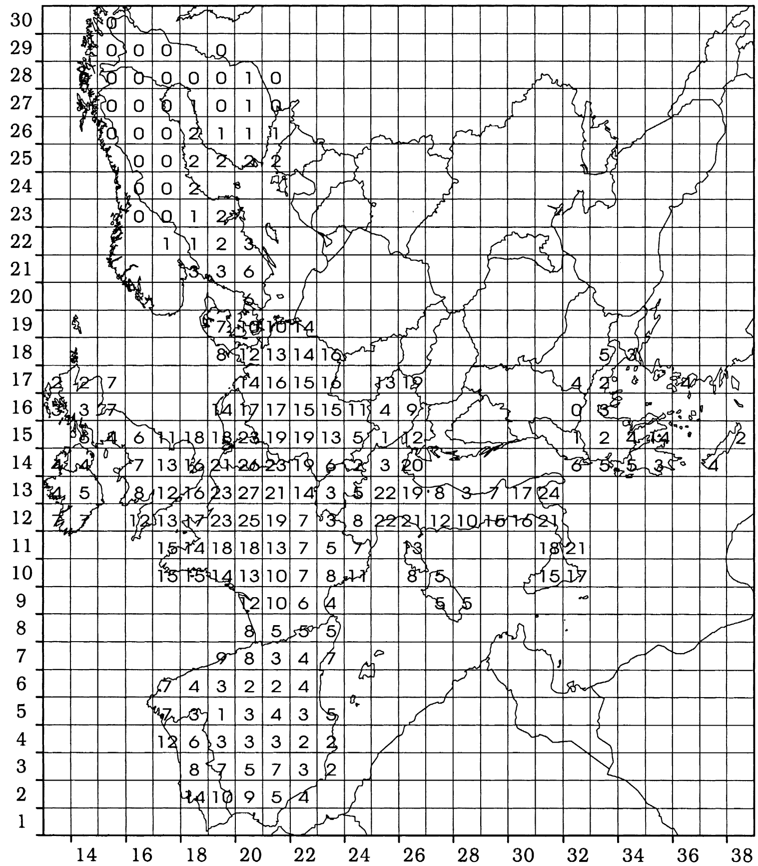

Fig. 4. Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the H1 scenario, 3-year moving average over 5 years.

environmental long-term objective in areas where the ozone problem still exists, but is less severe. Second, atmospheric photo-oxidant modeling suggests that, depending inter alia on the prevailing NO_x emission densities, there are different regimes of NO_x and VOC limitations in Europe [13]. For meeting the target values in the 'high ozone' areas, VOC controls are generally most effective. A least-cost strategy would therefore mainly focus on VOC controls throughout Europe, as long as they reduce the ozone problem at the few hot spots. In contrast to this, however, further ozone reductions in most of the other areas where present ozone levels are comparatively low need to engage cuts in NO_x emissions as an important element. Thereby, a 'hot spot' policy emphasizing VOC controls would suggest measures which would be inefficient for approaching the environmental long-term targets in a large fraction of the European Union.

As a consequence, a uniform 'gap closure' type target was explored as a second complementary objective to bring all areas in the EU closer towards the long-term objective. Optimization analyses studied the least-cost emission controls to achieve equal relative (percentage) reductions of the present excess ozone throughout the Community. It was found that, compared to a ‘hot spot’ strategy, indeed controls are more balanced among the countries and among the precursor emissions NO_x and VOC.

However, a not negligible fraction of ozone originates from sources outside the direct control of the Community, inter alia from natural emissions and from ‘background’ ozone induced from the free troposphere, to which sources from the entire northern hemisphere contribute. Therefore, a ‘uniform cutback’ approach requires relatively more stringent controls in areas where the controllable anthropogenic fraction is small (i.e., in ‘low ozone’ areas) than in heavy polluted region, where the share of natural and background ozone is minor.

Ultimately, it was found that a combination of a ‘target value’ and a ‘gap closure’ objective used as simultaneous constraints for the cost minimization optimization renders feasible, balanced and politically acceptable emission reduction requirements.

Uncertainties and the robustness of model calculations were subject to intensive analysis. The general assessment and treatment of uncertainties in the scenario analysis is described in Heyes et al. [14]. It was found that, in the given policy context, the appropriate treatment of extreme meteorological conditions is most relevant, including the inter-annual meteorological variability. As mentioned above, the RAINS model in its present implementation contains source–receptor relationships between the precursor emissions and the long-term ozone concentrations (AOT60) for the summer periods of 5 years (1989, 1990, 1992, 1993, 1994). Analysis demonstrated that long-term ozone (AOT60) from a constant field of emissions varies typically by a factor of two, depending on the meteorology of the selected year (Amann et al., 1997). This variability is further enhanced in the optimization mode, where even larger differences in optimized emission reduction levels emerge for the range of considered meteorological conditions [12]. It has been shown (i) that the extreme cases are often related with meteorological regimes fundamentally different from the average situation, (ii) that in different parts of Europe the extreme situations occurred in different years, and (iii) that preparing for the extreme situation may require extreme resources spent in a way which would not yield maximum benefits in an average situation. Obviously, the existing data set does not allow conclusions about the long-term representativeness of the meteorological conditions of the five years.

With the need for taking a pragmatic decision, the optimization constraints related to the uniform target value were specified in such a way that they would be met in four out of the five years. This means that at each grid cell the (2.9 ppm h) AOT60 limit must be achieved under at least four meteorological conditions, and it was accepted that in 1 year the targets may be exceeded. Technically this was implemented as a ‘composite’ optimization problem, in which the source–receptor relationships for the four years taken into consideration (leaving out the extreme year) were implemented simultaneously and the related constraints had all to be satisfied by the optimized emission pattern. Ignoring the extreme situation (with unknown representativeness) was considered to be acceptable for an interim environmental target, particularly since the resulting allocation of emission controls was more tailored to the typical situation when ozone thresholds are exceeded.

For meeting the vegetation targets (AOT40) the meteorological variability is of less relevance, since the target value as such is defined as a mean AOT40 averaged over 5 years.

A further subject of discussion was the spatial reliability of the ozone model calculations, i.e., how accurate model predictions are for individual grid cells. Obviously, there are many factors such as the spatial accuracy of meteorological information which contribute elements of uncertainties to the model estimate. The strategic question was how much weight should be given to the precise achievement of the interim gap closure targets in each of the 225 grid cells covering the EU territory. Similar to meteorology, it has been shown that insisting on full compliance everywhere might put heavy weight on isolated hot spots and tie up major resources for solving untypical situations. For an environmental interim target it was finally felt more appropriate to accept a certain flexibility without lifting the overall environmental ambition level. This was practically implemented in the optimization approach by a compensation scheme, which allows violations of the ‘gap closure’ targets at single grid cells if the excess is compensated by additional achievements at other grid cells in the same country. This approach was refined by a population weighting scheme which requires, e.g., small excess ozone in population centers to be compensated by larger improvements in less populated grid cells.

4. The ‘national emission ceilings’ scenario

Using the target setting principles outlined above, the RAINS model was applied to explore the implications of a range of environmental ambition levels for ground-level ozone. Ultimately, the European Commission decided to propose following combination of targets:

- For health-relevant ozone exposure, the principal interim target for moving towards the environmental long-term objective is a relative reduction of the AOT60 (the surrogate indicator for health-related excess ozone exposure) by two thirds between 1990 and 2010.
- In addition, highest excess ozone in the EU15 is addressed by introducing an absolute ceiling on the AOT60 of 2.9 ppm h.
- For vegetation-relevant ozone exposure, the general objective is to reduce the excess AOT40 (the indicator for vegetation-related excess ozone) by one third between 1990 and 2010.
- In addition, the highest excess AOT40 in the EU15 is limited to an absolute ceiling of 10.0 ppm h.

Furthermore, the policy concept of the Commission aimed for ‘national emission ceilings’ simultaneously responding to both transboundary air quality problems of concern, i.e, to ground level ozone and to acidification. This is of particular relevance since (i) there should be only one legally binding set of emission ceilings for each country, which should address both problems, and (ii) in some areas in Europe ozone

Table 1
Emissions for the central scenario H1 compared to the REF case. Percentage changes relate to the year 1990

	SO_2				NO_x				VOC				NH_3			
	REF		H1		REF		H1		REF		H1		REF		H1	
	kt	Change	*kt*	Change	*kt*	Change	*kt*	Change	*kt*	Change	*kt*	Change	*kt*	Change	*kt*	Change
Austria	40	−57%	40	−57%	103	−46%	91	−53%	205	−42%	129	−63%	67	−13%	67	−13%
Belgium	193	−43%	76	−77%	191	−46%	127	−64%	193	−48%	102	−73%	96	−1%	57	−41%
Denmark	90	−51%	77	−58%	128	−53%	127	−54%	85	−53%	85	−53%	72	−6%	71	−8%
Finland	116	−49%	116	−49%	152	−45%	152	−45%	110	−48%	110	−48%	31	−23%	31	−23%
France	448	−64%	218	−83%	858	−54%	679	−64%	1223	−49%	932	−61%	777	−4%	718	−11%
Germany	581	−89%	463	−91%	1184	−56%	1051	−61%	1137	−64%	924	−70%	571	−25%	413	−45%
Greece	546	8%	546	8%	344	0%	264	−23%	267	−21%	173	−49%	74	−8%	74	−8%
Ireland	66	−63%	28	−84%	70	−38%	59	−48%	55	−50%	55	−50%	126	−1%	123	−3%
Italy	567	−66%	566	−66%	1130	−45%	869	−57%	1159	−44%	962	−53%	432	−6%	430	−7%
Luxembourg	4	−71%	3	−79%	10	−55%	8	−64%	7	−63%	6	−68%	7	0%	7	0%
Netherlands	73	−64%	50	−75%	280	−48%	238	−56%	233	−52%	156	−68%	136	−42%	104	−55%
Portugal	141	−50%	141	−50%	177	−15%	144	−31%	144	−32%	102	−52%	67	−6%	67	−6%
Spain	774	−65%	746	−66%	847	−27%	781	−33%	669	−34%	662	−34%	353	0%	353	0%
Sweden	67	−44%	67	−44%	190	−44%	152	−55%	290	−43%	219	−57%	48	−21%	48	−21%
UK	980	−74%	497	−87%	1186	−58%	1181	−58%	1351	−49%	964	−64%	297	−10%	264	−20%
EU-15	4687	−71%	3637	−78%	6849	−48%	5922	−55%	7128	−49%	5581	−60%	3154	−12%	2826	−21%

control tends to focus on VOC reductions while keeping NO_x as high as possible. For acidification, however, NO_x makes an important contribution and NO_x reductions will be absolutely necessary to meet the targets specified in the EU Acidification Strategy.

With the optimization feature of the RAINS model it became possible to systematically tackle these trade-offs as well as the synergisms in NO_x control occurring in other areas and to identify cost-effective balances to emission controls, which simultaneously meet the specified environmental targets for acidification and for ground-level ozone. Technically this was achieved by joining the 'acidification' and 'ozone' parts of the RAINS model, which ended up in a comprehensive multi-effect/multi-pollutant assessment tool. In terms of pollutants, the strategy balanced emission reductions among countries between SO_2, NO_x, NH_3 and VOC.

To address the environmental objectives of the EU Acidification strategy, i.e., to reduce in the year 2010 the area of ecosystems not protected against acidification everywhere by at least 50% compared to 1990, an additional set of appropriate constraints on acid deposition were introduced in the optimization problem.

In the resulting H1 scenario [12] for the EU-15, SO_2 emissions would be reduced from 71% in the REF case (i.e., from the current legislation) to 78% (compared to 1990), NO_x emissions from 48% to 55%, VOC from 49% to 60% and ammonia from 12% to 21% (Table 1). This would increase total emission control costs from 58.5 billion EURO/year to 66 billion EURO, i.e., by 14% (Table 2). Out of these 7.5 billion EURO extra costs, 11% would be spent for additional SO_2 control, 60% for further measures to reduce NO_x and VOC, and 29% for ammonia.

Compared to current legislation, the proposed emission reductions of the H1 scenario would cut the population exposure index (i.e., the product of the ozone (AOT60) levels and the population exposed to these levels) by 36% (Table 3).

Table 2
Emission control costs for the central scenario H1 compared to the REF case. Control costs in million EURO/year

	SO_2			NO_x/VOC			NH_3			Total		
	REF	H1	Total	REF	H1	Total	REF	H1	Total	REF	H1	Total
Austria	191	0	191	902	119	1021	0	0	0	1093	119	1212
Belgium	426	127	553	1278	459	1737	0	467	467	1704	1053	2757
Denmark	138	5	143	484	0	484	0	0	0	623	6	629
Finland	247	0	247	642	0	642	0	0	0	889	0	889
France	1276	136	1412	7383	739	8122	0	41	41	8659	916	9575
Germany	3264	244	3508	10,549	1048	11,597	0	854	854	13,813	2147	15,960
Greece	434	0	434	1048	338	1386	0	0	0	1482	338	1820
Ireland	132	20	152	477	4	481	9	20	29	618	44	662
Italy	1776	0	1776	7868	403	8271	0	0	0	9644	403	10,047
Luxembourg	13	1	14	71	4	75	15	0	15	98	4	102
Netherlands	340	19	359	1731	211	1942	196	741	937	2267	971	3238
Portugal	181	0	181	1349	57	1406	0	0	0	1530	57	1587
Spain	809	9	818	5658	13	5671	28	0	28	6495	22	6517
Sweden	316	0	316	1125	87	1212	113	0	113	1554	87	1641
UK	1269	299	1568	6695	1026	7721	0	23	23	7964	1348	9312
EU-15	10,813	861	11,674	47,258	4508	51,766	361	2146	2507	58,433	7514	65,947

Table 3
Population exposure indices for the REF and the H1 scenarios

	Cumulative population exposure index (million person ppm h)		Average population exposure index (excess ppm h)	
	REF	H1	REF	H1
Austria	3	2	0.5	0.3
Begium	34	23	3.1	2.1
Denmark	3	1	0.5	0.3
Finland	0	0	0.0	0.0
France	89	53	1.6	0.9
Germany	140	99	1.8	1.3
Greece	4	2	0.4	0.2
Ireland	1	0	0.3	0.1
Italy	63	38	1.1	0.7
Luxembourg	1	1	3.0	2.1
Netherlands	38	27	2.6	1.8
Portugal	8	6	0.8	0.6
Spain	7	4	0.2	0.1
Sweden	0	0	0.0	0.0
United Kingdom	77	45	1.3	0.8
EU-15	466	300	1.3	0.8

The H1 scenario would reduce in the EU-15 the unprotected area from 6.4 million hectares in the REF case to 4.3 million hectares. On a national scale, least ecosystems protection occurs in the Netherlands (with 24% of the ecosystems still experiencing acid deposition above critical loads), followed by Belgium, Germany and UK with about 7% (Table 4).

Table 4
Ecosystems with acid deposition above their critical loads for acidification for the H1 and the REF scenarios

	1000 ha		Percent of ecosystems	
	REF	H1	REF	H1
Austria	162	99	3.3%	2.0%
Belgium	155	52	22.1%	7.4%
Denmark	9	6	2.3%	1.5%
Finland	1183	1150	4.3%	4.2%
France	218	88	0.7%	0.3%
Germany	1617	727	15.8%	7.1%
Greece	0	0	0.0%	0.0%
Ireland	12	9	1.3%	1.0%
Italy	74	58	0.7%	0.6%
Luxembourg	5	1	5.9%	0.9%
Netherlands	193	76	60.4%	23.7%
Portugal	1	1	0.0%	0.0%
Spain	17	17	0.2%	0.2%
Sweden	1605	1420	4.1%	3.7%
United Kingdom	1182	649	12.3%	6.8%
EU-15	6433	4351	4.3%	2.9%

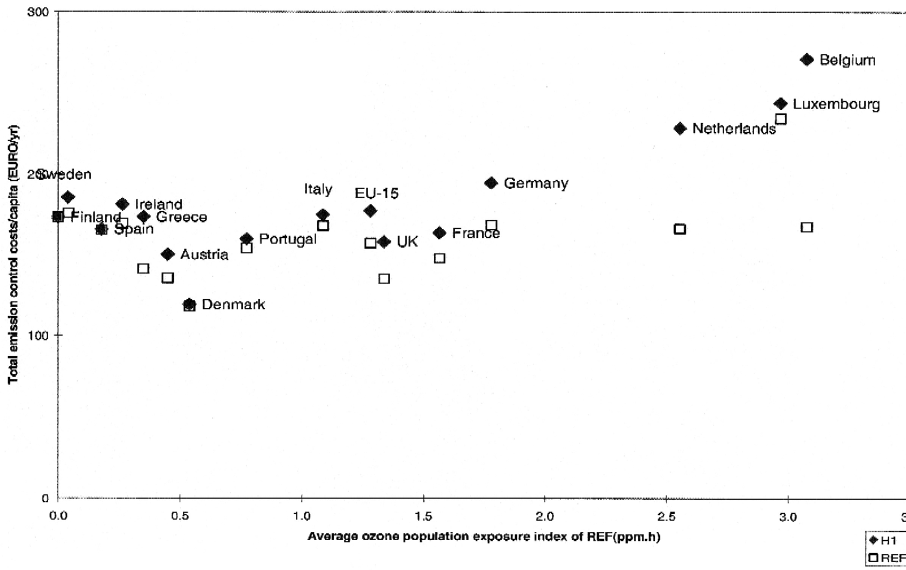

Fig. 5. Total per-capita emission control costs of the REF and H1 scenarios (for SO_2, NO_x, VOC and NH_3 emissions) plotted against the average ozone population exposure indices of the REF case.

As it was discussed above, the acceptance of the cost-effectiveness principle may be associated with uneven distribution of emission reduction burdens. This is illustrated in Fig. 5, which displays on the *y*-axis the per-capita emission control costs of the REF (the open squares) and of the H1 scenario (the filled diamonds). The *x*-axis differentiates the countries along their ozone pollution (the average exposure index) in the REF case. While the present legislation imposes equal burdens on all countries, the cost-effectiveness principle in the H1 scenario results in a differentiated allocation of the additional measures (costs) following the actual ozone pollution. To what extent this new concept will survive the political consensus process remains to be seen.

Although the rationale of the cost-effectiveness analysis is distinctively different from a cost-benefit analysis, an attempt was made to monetize the environmental benefits of the emission reductions determined with the cost-effectiveness analysis. Although it was not possible to quantify the monetary benefits for a number of effects (e.g., ecosystems damage, cultural heritage, etc.), the benefits for the categories which could be quantified ranged between 17.5 and 30 billion EURO/year, depending on the assumptions made [15]. This can be compared against the additional costs of the strategy of 7.5 billion EURO/year.

5. Conclusions

Since the initial attempts to address ground-level ozone in the European Union in the early 1990s, several changes in paradigms can be detected. The 1992 directive on ozone was a first attempt to set the ground for a Community-wide assessment of photochemical air pollution while it still did not include harmonized and coordinated commitment for control measures on Member State level. Since then, the transboundary character of the oxidant problem was recognized, and for the recent air quality daughter directive a framework for solving the ozone problem in international cooperation was developed.

In the early stages, Community legislation followed a clear two-track approach in managing emissions and air quality. Air quality directives specify environmental objectives, how to measure them and how to report to the public and to the Commission. Emission-related directives impose source-specific emission limit values and fuel and product standards.

Recently, attempts were made for ozone as a transboundary problem to integrate these two lines of action and to quantitatively link the extent of required emission controls with the air quality objectives. The concept of ‘national emission ceilings’ as a new policy instrument should safeguard the achievement of the environmental objectives, while leaving maximum flexibility to Member States on how to actually implement the required emission controls in the most effective way.

Recently, national emission ceilings, which simultaneously address concerns on ground-level ozone and acidification, were proposed by the European Commission. These proposed emission ceilings were determined based on a cost-effectiveness analysis, using a wealth of scientific information on economic development, technological emission control options, atmospheric dispersion and environmental impacts of pollution. Although introducing uneven distributions of emission reduction burdens to the Member States (differentiated according to the severity of the air pollution problem), the Community-wide cost-minimization principle achieves cost savings of more than 75% compared to traditional uniform approaches.

For the future, it is expected that the integration of health-impacts caused by fine particulate matter into the assessment framework will offer a further cost saving potential, if measures can rationally be balanced across the sources of primary and secondary particles responding to the conditions prevailing in the various countries of the European Union.

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