



Commentaries on the results of studies requested from IIASA by the french ministry for land-use planning and the environment

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► To cite this version:

Guy Landrieu, Shailendra Mugdal. Commentaries on the results of studies requested from IIASA by the french ministry for land-use planning and the environment. 25. Task Force on Integrated Assessment Modelling, Apr 2000, Stockholm, Sweden. ineris-00972206

HAL Id: ineris-00972206

<https://ineris.hal.science/ineris-00972206>

Submitted on 3 Apr 2014

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UNECE – Convention on Long Range Transboundary Air Pollution

**Discussion paper for the
Task Force on Integrated Assessment Modelling
25th session, Saltsjöbaden, Stockholm, 13-14 April 2000.**

**“Simple is beautiful”
... and efficient**

An illustration in the field of LRTAP strategies

**Commentaries on the results of studies
requested from IIASA
by the French Ministry for Land-Use Planning
and the Environment**

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1. Introduction

During the preparation of the recent "multi-pollutant, multi-effect" protocol of the Convention on Long-Range Transboundary Air Pollution (LRTAP), just as for that of the European Directive on emission ceilings, discussion of strategies for reducing transboundary air pollution resulting from emissions of sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOC), ammonia (NH₃), was focused on a series of highly specific scenarios.

In these scenarios, emission ceilings for different pollutants are assigned to each country for the year 2010 that are the outcome of the "optimisation" ⁽¹⁾ model RAINS taking into account for each country :

- the prospects for growth in each economic sector, the emission factors by sector if no preventive measures are taken, the available and envisaged technical options for controlling emissions and the implementation cost of such control options ;
- the risk for ecosystems resulting from acidification and eutrophication : a risk is assumed if the acid or nutrient atmospheric deposition on an ecosystem is higher than a "critical load" ; the impact on vegetation and human health of exposure to ozone : an impact is assumed if indexes like AOT40 for vegetation and AOT60 for human health (Accumulated Exposure Over 40 or 60 ppb) are higher than some "critical levels" ;
- the atmospheric transfer of pollutants from country to country.

The optimisation option chosen in these scenarios seeks to achieve at least cost particular environmental objectives. The cost to be minimised is the total cost of measures taken throughout Europe. The environmental objectives, which in the mathematical expression of the model constitute the "constraints" on optimisation, are expressed in terms of "gap closure" : the gap closure concerning for example acidification is the rate of reduction in the exposure of ecosystems to loads exceeding critical levels. In the scenarios investigated hitherto, constraints were set for each country, so that the gap closure in each country had to be above a minimum, this minimum having the same value for all European countries.

This particular approach is a generalised version of the one previously tried out in preparing the Sulphur protocol. Like all theoretical models, this approach has limitations and drawbacks. While these were regarded as acceptable in the case of the Sulphur protocol ⁽²⁾, these disadvantages appeared more of a problem for a multi-pollutant and multi-effect approach, particularly in dealing with the complex problem of tropospheric pollution by ozone.

¹ We shall use inverted commas to remind the reader that the term "optimisation" here simply means the solution of a highly specific mathematical problem. The outcome of an "optimisation" is not necessarily the "best" strategy in the meaning of common policy.

² However it turned out that one of the assumptions in the RAINS model - that the rate of reduction of emissions was the same throughout a country - did not reflect the situation in large countries. As a consequence, Spain negotiated a rate of reduction in its emissions very different from that proposed by the model.

A first drawback of this approach is that it is extremely complex: although transparent in theory, it is difficult in practice for political negotiators to grasp – and hence discuss – all the implications of the rules of the game included in the model ⁽³⁾. It is even difficult for experts to appreciate the consequences of some modelisation choice, or to evaluate the validity of model results considering all the uncertainties in problem data.

A second disadvantage of this approach is that it leads *a priori* to strategies that are different for each country, or more precisely that it is assumed that there is no benefit in different countries having similar policies. On the contrary it may be credited that a strategy involving the same policies in a large number of countries will have operational advantages (the advantage of pooling experience and the dynamism of collective action, economies of scale, a neutral effect towards international commercial competition, and so on).

The question arises therefore whether the economic advantage which is supposed to stem from the present method of optimisation is sufficiently large to make up for the drawbacks of this approach.

The French Ministry for Land Use Planning and the Environment requested in December 1998 IIASA, the developer and manager of the RAINS model, to conduct additional investigations aimed in particular at assessing the potential value of considering other methods of preparing scenarios. The IIASA submitted in December 1999 a report covering some of the investigations requested ⁽⁴⁾. The aim of the present note is to emphasise and comment upon some of the results of this work.

The point of view adopted here is a methodological one. It does not attempt directly to assess whether any particular allocation of emission ceilings between countries is “better” than those considered in recent or current international policy discussions. Indeed the studies to which reference is made are no more than preliminary investigations. One reason for that is that access to the RAINS model, which contains all the quantitative data collected on the subject in Europe, is at present limited.

An underlying objective of this note is perhaps to illustrate the fact that there is no single intelligent way of drawing up strategies for reducing transboundary pollution. Different approaches can lead to comparable environmental progress across Europe. In the future, assessment of the results of these approaches should focus more on the robustness of the strategies and should consider other aspects of strategies not taken into account in the present “optimisation” models ⁽⁵⁾.

³ The heavy process of implementing the model, and the difficulty of changing its logical approach, encloses the negotiators in a special system of mathematical equations accepted at the outset, in the dark. One may think, on the contrary, that an assessment should be open for studying different possible policies and their implications.

⁴ Further analysis of scenario results obtained with the RAINS model, IIASA, December 1999.

⁵ Making the assessment more thorough probably means, here as elsewhere, making a clearer distinction between functions of design and functions of assessment. If the design of strategies is based upon an “optimisation” model, it would be logical for the assessment function to focus on those criteria that are not taken into account by the optimisation model.

2. A first kind of alternative : optimising on the basis of countries where environmental progress is more difficult or on the basis of progress targets for Europe as a whole?

It was noted earlier that in the optimised scenarios investigated hitherto, the optimisation constraints are expressed in the form of a minimum percentage reduction in the exposure of ecosystems to the deposition of pollutants above the critical load. The parameter selected for characterising this exposure has evolved from study to study (number of ecosystems at risk, area of those ecosystems, area weighted by the deposition exceeding critical load), which certainly has policy implications ⁽⁶⁾. But it has always been assumed for the purposes of modelling that the minimum percentage of exposure reduction to be achieved should be set at the same level for all the countries in Europe.

2-1 Drawbacks of uniform national constraints

Setting the minimum rate of reduction of exposure at the same value for all the countries may appear “natural” but it is not natural at all ⁽⁷⁾.

In fact the minimum rate “selected” is necessarily determined by the situation in those countries where it is most difficult to reduce exposure, and is therefore low. The result is that there is no pressure to reduce exposure in certain other regions although it would be easy to do so at low cost ⁽⁸⁾.

⁶ “...it is very clear that the use of the accumulated exceedance gap closure approach produces a strikingly different pattern of expenditure compared to that produced by the ecosystem area gap closure approach... countries expenditures tend to shift away from NW Europe (Germany, UK, France) and Hungary, towards Poland, NE, Europe and the former USSR...”.

Rachel Warren et al. Report for UNECE/LRTAP Task Force on Integrated Assessment Modelling, May 1998.

⁷ This practice is sometimes presented as satisfying a concern for fairness in distributing the benefits of a strategy. Notwithstanding this however, the actual rate of reduction of exposure that results from the optimisation finally varies widely according to country.

The reason for this practice seems to be primarily historical; to some extent it is a hangover from the preparation of the Sulphur protocol where, in a particular context, it had the merit of leading to a politically acceptable distribution of effort between the countries.

⁸ Setting an environmental progress constraint for each country rather than for Europe as a whole means multiplying the number of constraints introduced in the optimisation process by a factor of the order of 40. However only a few of these constraints – “binding constraints” – are effective : these correspond to those countries where the situation is relatively the most difficult, for example the Netherlands as regards acidification, or Belgium for ozone. These binding constraints are usually related to countries that are relatively small in size and correspond to specific local problems.

In other words the introduction of national constraints has reduced the problem of optimising the strategy for cutting the exposure to pollution in Europe to one of optimising the strategy for reducing pollution in the Netherlands or Belgium, the other questions no longer being taken into consideration. Seeking to reduce acidification in the Netherlands will usually have a positive effect as regards improving the situation in neighbouring

The consequences of this provision of uniformity in the constraints on the reduction of exposure throughout Europe become clear when one calculates the marginal costs associated to a strategy, or more precisely the ratios of the marginal costs per tonne of pollutant non-emitted in a country to the marginal advantages per tonne of pollutant non-emitted in a country, these advantages being evaluated for the whole of Europe in terms of reductions of the exposure of ecosystems and the public to pollution.

With uniform national constraints, the marginal cost allowed for protecting one additional hectare of an ecosystem or the health of one person in Europe varies according to the country in which the ecosystem or exposed person is situated, and according to the country that has to bear the cost. Moreover these variations are very substantial.

Such consequences of this choice of a uniform constraint appear paradoxical from the standpoint of economic efficiency which is the "raison d'être" of the "optimised" approach. They may also appear unfair with regard to the distribution of the efforts made to protect the health of different populations.

Figure 1 shows for example that in the situation of the "optimal" scenario H1 it would be possible to protect at least 10 times more European ecosystems by investing in sulphur dioxide emissions reductions in Denmark or Finland the money that the model suggests should be spent in France or Spain.

In this "optimal" situation, the spending admitted for protecting against the risk of acidification one marginal hectare of a European ecosystem by reducing French sulphur dioxide emissions is more than 6000 Euros each year. This is an order of magnitude comparable with that of the purchase, every year in France, of an additional hectare of land by an institution such as the Conservatoire du Littoral in order to definitively protect it from urbanisation.

As a general rule, when an economic optimisation model is used, it is worthwhile examining the cost associated with each optimisation constraint, in order to understand what the model exactly does. In the present case it is relevant to calculate the cost of each national constraint and to look at the real environmental issues that correspond.

2-2 A strategy optimised on the basis of environmental objectives for Europe as a whole

An alternative method of optimisation is to try to determine how a global European objective – rather than certain national objectives – can be achieved at least cost. One consequence of this approach is that the same value is placed, for example, on the protection of one hectare of ecosystem against acidification whatever the country in which the ecosystem is located and whatever the country in which sulphur dioxide emissions must be reduced.

countries, but is only a partial answer to the problem. This applies even more to ozone and Belgium.

One such method of optimisation is that applied in a recently published study of the Norwegian Meteorological Institute ⁽¹⁰⁾.

For being able to compare the results of such an approach with those of the customary approach, IIASA was asked to carry out a scenario J14 illustrating this approach but using the same RAINS model and precisely the same data than scenarios previously studied.

The main characteristics of the scenario J14 are given in Table 1. The scenario J14 refers to the constraints of the scenario J1, a basis of LRTAP negotiations, but applies them only at overall European level. The scenario J14 and its performances can be more particularly compared with one of the scenarii optimised on the basis of national constraints, the scenario G5/1 ⁽¹¹⁾.

Table 1: Comparison of optimised scenarios based either
 ▪ on national constraints (G5/1)
 ▪ or a European objective (J14).

Scenario	G5/1	J14	Impact of national constraints
"Gap closure" constraints used in the optimisation (in 2010 compared with 1990).	<i>For each country</i>	<i>for Europe as a whole</i>	
Acidity	90 %	95 %	
Nitrogen load	55 %	60 %	
Ozone : AOT40	30 %	33 %	
Ozone : AOT60	60 %	67 %	
Results of the scenario: environmental benefits compared with the reference scenario	<i>at European level</i>		<i>(G5/1-J14)/J14</i>
Additional area protected from acidification (1000 km ²).	69	77	- 10 %
Additional area protected from eutrophication (1000 km ²).	190	204	- 7 %
Reduction in the exposure of vegetation to ozone (10,000 km ² .excess ppm.hours).	262	295	- 11 %
Reduction in the exposure of the population to ozone (millions persons.ppm.hours).	214	235	- 9 %
Results of the scenario: implementation cost on top of the reference scenario (billion Euros/year).	4,9	3,5	+ 41 %

It can be seen from the Table 1 that the introduction of national constraints results in a strategy globally less efficient. The scenario G5/1, by comparison with J14, shows environmental benefits lower by about 10% and implementation costs higher by about 40% (see also Figure 3).

¹⁰ D. Simpson, A. Eliassen, Tackling multi-pollutant multi-effects problems : an iterative approach, The Science of the Total Environment, 234 (Oct. 1999).

¹¹ Emission reduction scenarios to control acidification, eutrophication and ground-level ozone in Europe, part B, p.76, IIASA, Nov. 1998 (22nd meeting of the UNECE TFIAM).

The additional cost of the scenario G5/1 should be explained by the fact that the scenario J14 locally did not satisfy some of the constraints of G5/1. Actually a country-by-country analysis, covering for example the fifteen countries of the European Union (EU15) shows that the situation as regards ozone is better in all the countries in scenario J14 than in G5/1. As concerns acidification, the scenario J14 is more favourable than G5/1 to Finland (7620 km² exposed to deposition above the critical load instead of 9190 km²) but less favourable to Great Britain (8950 km² instead of 7370 km²). Finally the decisive local constraint, which apparently explains the additional cost of the scenario G5/1 compared with J14, would appear to concern the Netherlands. The area exposed to the risk of acidification is 1640 km² in J14 and 1330 km² in G5/1: it seems that the constraint of reducing areas exposed to acidification by 90% is not met in J14.

To sum up, by comparison with the scenario G5/1 based on national constraints, the scenario J14 based on European objectives provides protection in Europe for additional area of 8000 km² against acidification and 8000 km² against eutrophication, reduces the exposure of vegetation to ozone by 300,000 km².ppm.hours and that of the population by 22 million persons.ppm.hours, for a global cost that is 1.4 billion Euros/year less. On the other side of the coin, G5/1 protects an additional 310 km² in the Netherlands against acidification.

In this kind of case, if the criterion of acidification in the Netherlands appears to be the essential one, then it is certainly necessary to carry out a study - more detailed and on a finer geographical scale - of the specific problem of acidification in the Netherlands and possible control strategies.

The allocation of efforts between the different countries is of course different in the "European" scenario J14 from the "multinational" scenario G5/1. Although most countries see their effort fall very significantly in J14 (notably the Netherlands or Ireland), a small number of countries see their efforts rise (Sweden, Italy, Austria) (¹²). This shows that the way in which the constraints of the optimisation process are expressed can have substantial consequences on the results of the RAINS model.

The scenario J14 was merely an initial test : of course it is technically possible to look into European gap closure objectives that are more ambitious than those of J14.

If in the future we have to continue conducting optimisation exercises as regards transboundary air pollution, it seems to us that the approach that brings global European objectives to the fore should not be *a priori* excluded.

¹² Optimising scenario J14 on a broader European basis than G5/1 results in greater importance being given to the reduction of acidification in the north and east of Europe. The allocation of efforts between pollutants also differs according to the scenario : J14 results in greater reductions in emissions of nitrogen oxides and volatile organic compounds while G5/1 puts more emphasis on the reduction of emissions of sulphur dioxide and ammonia.

3. A second kind of alternative : an “optimised” strategy involving selective reductions in emissions for individual countries, or a “robust” strategy applying to the whole of Europe

A number of arguments throw serious and fundamental doubt on the suitability of using customary “optimisations” for designing LRTAP reduction strategies.

A first obstacle is due to the physical reality of the problem, i.e. the fact that some of the phenomena to be taken into account are non-linear. Owing to what is known as the “ozone hill”, the optimisation approach up to 2010 applied in the recent TFIAM or DG-XI exercises is counter-productive to some extent because it is a disincentive to the planning of reductions in emissions of nitrogen oxides in certain countries even though it is the only way of resolving the ozone problems in the longer term.

A second obstacle is the uncertainty of the relevant data. A strategy based upon an optimisation calculation is optimal only insofar as the real values taken by a larger number of variables are precisely the same as the hypothetical values entered as data into the model. In the field we are considering here it is obvious that estimates and long-term forecasts are, by their very nature, uncertain. The strategy taken to be optimal on the basis of particular assumptions made in 2000 is highly unlikely to turn out optimal in the actual situation of 2010.

It is only cautious to ask whether a strategy aimed at reducing all emissions in all countries as low as reasonably achievable is not more likely to prove efficient whatever the prevailing conditions – in other words, whether it is not more “robust” - than a “tricky” strategy differentiating strongly the efforts between the countries on the basis of risky assumptions concerning random variables.

One way of examining this question would be, when all the problem data prone to uncertainty are varied in a random manner, to calculate the distribution of the effects - environmental advantages and cost – of two strategies 1) a strategy “optimised” for a particular set of assumptions, 2) a robust strategy for the general reduction of emissions. Such investigations, which come under the heading of a Monte Carlo approach, have not so far been carried out. They should constitute interesting future works and could be conducted using for example the RAINS model not as an optimisation tool but as a simulation tool.

One will still present hereunder comparisons of optimised strategies with robust strategies, but the comparison being made on the basis of the very problem data for which the optimised strategy is optimal. Hence this merely gives one point of comparison, and this point corresponds to the conditions most favourable for the optimised solution.

3-1 Critical aspects of optimised approaches

Before looking into the “performances” of two robust strategies, we shall use a few examples to illustrate the problems raised by the optimisation approach.

3-1-1 The non-linearity of ozone generation

Although it is necessary in general, for lowering the concentrations of ozone in Europe, to reduce the emissions of the precursor pollutants (nitrogen oxides NO_x and volatile organic compounds VOC), the models nevertheless reveal, in the pollution conditions of certain countries, what is known as an "ozone hill" : a reduction in the NO_x emissions of such a country initially tends to increase the generation of ozone and the exposure of receptors to ozone ; to obtain a reduction in ozone concentrations it is necessary to reduce NO_x levels substantially.

If such reductions in NO_x appear difficult to achieve by the year 2010, static optimisation at that time results in the countries where there is an ozone hill not reducing at all their NO_x emissions. The objectives regarding acidification and eutrophication nevertheless persist and all the efforts to reduce NO_x emissions are therefore passed on to the other countries.

This effect is illustrated on Figure 2, based upon calculations using the Web version of the RAINS model. It can be seen that as the NO_x emissions from France are progressively reduced from the reference 2010 situation (REF), the exposure of the European population to ozone falls. The model calculates that it is "optimal" to programme a further reduction in French emissions of 180,000 tonnes a year (H1). On the other hand, when the NO_x emissions from Great Britain are reduced, the exposure of Europe's population to ozone goes up. The result is that the "optimal" emission of NO_x from Great Britain (H1) is identical with that of the REF situation.

It can be seen therefore that optimisation for 2010 carried out using scenarios such as H1 leads to a kind of trap from which one may never be able to escape. If the ultimate objective is to eliminate in Europe any exposure to ozone over the critical level, it is indispensable to reduce the NO_x emissions in all the countries, particularly in those where the emission densities are highest, i.e. precisely the countries where the ozone hill phenomenon is observed (¹³).

3-1-2 The uncertainty of the optimisation data

The design of LRTAP strategies by the method of optimisation requires a huge quantity of data concerning natural phenomena and concerning the anthropic emissions system. Such data are subject to considerable uncertainties that question even the meaning of an optimisation. We will present some examples.

Uncertainties about natural phenomena

The data that come under the natural phenomena category are essentially 1) the acidic and nutrient critical loads of ecosystems and 2) the coefficients of the atmospheric transfer matrix, i.e. the relationship between pollutant emissions in a country and acidic or nutrient loads, ozone levels in the same or another country.

¹³ Emission densities : UK 4.9 t/km²/year ; France 1.6 t/km²/year

Critical loads of ecosystems are not variables that can be directly measured. They are evaluations made on the basis of theoretical models, and the reliability of those models is difficult to verify. Without entering in details, we will only point out that :

- there is a view in the expert community that critical loads may be generally over-estimated, especially for empirical estimates like nutrient nitrogen critical loads ⁽³⁾;
- if a Mapping Manual for the evaluation of critical loads has been drawn up, this manual gives only general guidelines ; countries may use different methods for estimating their national critical loads.

If critical loads are uncertain, a general fact is that differences in critical loads between countries are more uncertain. In the present situation, it appears also that such differences are calculated on the basis of non-totally consistent methods and seem systematically over-estimated. The reliability of an optimisation of the distribution of emissions ceilings between countries based on the differences in critical loads between countries should be evaluated. In the absence of such an evaluation, one may suppose a priori that the reliability is low.

Concerning the transfer matrices, a first idea of an order of magnitude of the uncertainties that affect the coefficients of the matrices, particularly as regards the generation of ozone, can be obtained by comparing two recent EMEP studies (see Table 2).

Table 2: Cause-effect relationships, for two EMEP assessments (A and B), between :

- a 40% reduction in NO_x emissions, first in France, secondly in all the other European countries,
- a reduction in exposure of the population to ozone in Belgium and in Europe

NO _x emitting zone EMEP study	France		Other European countries		Europe as a whole	
	A	B	A	B	A	B
Zone exposed to ozone Belgium	561	284	-389	237	172	521
Europe	74	22	107	104	181	126

Exposure is evaluated using the AOT60 index (ppb.h).

Study A: David Simpson et al., Photochemical oxidant modelling in Europe: multi-annual modelling and source-receptor relationships, EMEP/MSC-W, July 1997.

Reference context: emissions in 2010, meteorological period 1989, 90, 92, 93, 94.

Study B: Transboundary Photo-oxidants in Europe, EMEP Summary Report, July 1999.

Reference context: emissions in 2010, meteorological period 1992-1996.

The two studies appear to be in reasonable agreement from a global point of view, in other words when one considers the effect on Europe as a whole of a strategy for reducing by 40% NO_x emissions from all the European countries. The effect varies

³ cf. A simple assessment of the uncertainties/systematic biases of the main elements used in RAINS impacts, Paper discussed by the Extended Bureau of the WG Effects in February 1999.

from 181 ppb.h (study A) to 126 ppb.h (study B), while the meteorological periods used are not identical.

However the uncertainty appears very great when one tries to assess the effect, even over Europe as a whole, of a change in the emissions from a particular country. From one study to the other the impact of a 40% reduction in France's NO_x emissions falls from 74 ppb.h to 22 ppb.h, a factor of something over 3.

The uncertainty becomes total when one tries to assess the effect, not for Europe but for a country such as Belgium : setting France aside for the moment, one concludes from study A that a reduction of NO_x emissions in Europe – notably in Germany or Belgium – considerably increases exposure to ozone in Belgium, while study B reaches precisely the opposite conclusion.

To sum up, we showed earlier that strategies inferred from optimisations carried out for 2010 were counter-productive in the long term as far as ozone is concerned. If, as we believe, the IIASA ozone model is fitted to the data of study A, the column "Other European countries" – A of Table 2 shows that the optimisations based upon the Belgian situation are even in 2010 counter-productive as regards Europe as a whole. In fact there is a one in two chance that they are also counter-productive for Belgium in 2010!

The last line of the Table shows finally that even the optimisations of the allocation of emission ceilings to countries based upon European objectives look very random as far as ozone is concerned (¹⁴).

Uncertainties about the future of the anthropic emissions system

As regards the costs of reducing emissions, particularly when it is a matter of predicting in 2000 the costs of reducing emissions in 2010, various studies show that the differences between predictions and actual costs are often significant, the error usually tending towards an overestimate (¹⁵). Besides if the costs of reducing emissions over the long term are uncertain, the differences in costs between countries are more so, and optimisations based upon these differences in costs between countries are even more uncertain. If the costs are over-estimated, the interest of the optimised approaches – which seek to minimise the total cost – is itself over-estimated.

¹⁴ cf. D. Simpson and A. Eliassen, *ibid.*:

"Even the current authors admit that it is possibly dangerous to rely on the results of the EMEP model (any model) to be correct for the year 2010 when emission reductions of order of 80% are being considered! Thus, the possibility exists that features such as the ozone "hill" discussed above may be artefacts, due to unavoidable uncertainties connected with, for example, biogenic or man-made emissions, model formulation, or even basic scientific understanding. Thus a global optimisation which relies upon the model results to be accurate at all extremes of its prediction may give a worse answer than a simpler iterative approach which proceeds in small steps with an emphasis on safe strategies at all emissions levels."

¹⁵ Costs and strategies presented by industry during the negotiation of environmental regulations, Stockholm Environment Institute, April 1999.

However, even before considering the costs themselves, two important parameters in the cost function for a pollutant and a country are the two extremes of the range in which the foreseeable emission ceilings lie. The upper limit (REF) is the emission level in 2010 if no measures to reduce emissions are taken specific to the country. This limit depends on the level of activity in various economic sectors in 2010 and on the conditions of implementations of policies aiming at reducing emissions. The lower limit is the minimum that is technically feasible in the same economic conditions as above. This parameter has been used in certain previous studies and was denoted Maximum Feasible Reduction (MFR).

The uncertainties on REF are certainly substantial but not easily illustrated because this parameter has varied from one IIASA report to another as EU legislation has evolved. On the other hand the variations in the estimates of certain MFRs show, in the absence of any explanatory comments, the margin of uncertainty that affects the assessment of these "standardised" emission levels. For example between the interim IIASA reports of January 1997 and May 1998 there are changes in the MFRs concerning the VOC for the EU15 countries of the order of +15% to +30% for 6 countries and -15% to -30% for five other countries : viz. relative variations of 60% between certain countries (¹⁶). In that case an order of magnitude of the uncertainty on the relative level of MFR of two countries is about 60%.

Analysis of the results of the same IIASA reports shows that on the average the MFRs account for 75% of optimised emission ceilings. Thus by subtraction we see that on the average optimisation accounts for only 25% of the emission ceilings.

Therefore optimisation, the very random nature of which we have shown, in any event plays merely second fiddle in the process of allocation of emission ceilings in the multi-pollutant, multi-effect context (¹⁷). One can even see that globally this share hardly exceeds the uncertainty on the input data such as REF and MFR. This is another reason why it does not seem to us that, in the present context, optimisation should be a major issue in the search for effective multi-pollutant, multi-effect strategies.

In the efforts seeking to validate the process of determining emission ceilings, priority should be given to checking the assessment of the REF and MFR levels themselves, the extent to which these levels are realistic (for example, in terms of coherence with the objective for reducing emissions of greenhouse gases), the international standardisation of the assessments, and their transparency.

Put another way, the effort of future studies should be focused more on the evaluation of the effectiveness of emission reduction measures on a European scale, rather than on the optimisation of differentiated strategies between countries.

¹⁶ Integrated optimisation : aren't there too many optimisation constraints and too much uncertainty? Guy Landrieu, TFIAM, London, Dec. 19998.

¹⁷ The share left for optimisation is greater for sulphur dioxide : from this standpoint also the multi-pollutant, multi-effect context is less favourable to optimisation than that of the Sulphur protocol.

3-2 A strategy for Europe-wide implementation of all technical measures for reducing emissions that have a marginal cost per tonne of non-emitted pollutant below a single limiting value

A first strategy for the general reduction of European emissions can be proposed on the basis of a technical and economic approach : implementing throughout Europe all the technical measures for reducing the emissions of a pollutant that have a marginal cost per non-emitted tonne below a ceiling that is the same for all countries.

The scenario J15 illustrates such a strategy (cf. Table 3). To facilitate the comparison with an "optimised" strategy, the marginal cost ceilings have been arbitrarily set at a level such that the total cost for Europe of emission reduction measures for a pollutant in scenario J15 are the same as the corresponding cost in the optimised reference scenario J1 previously studied by IIASA.

Table 3: Comparison of an "optimised" scenario (J1) and a "robust" scenario (J15) based upon the implementation throughout Europe of technical measures selected according to their marginal cost.

Scenario	Optimised J1	Robust J15	Comparison
"Gap closure" constraints used in the optimisation <i>(in 2010 compared with 1990).</i> Acidity Nitrogen load Ozone : AOT40 Ozone : AOT60	For each country 95% 60% 33% 67%		
Limiting values of marginal costs taken into account for selecting the emission reduction measures implemented (stationary sources) <i>(Euros/tonne).</i> SO ₂ NO _x VOC NH ₃		applicable throughout Europe 500 1160 1060 6050	
Results of the scenario: environmental benefits compared with the reference scenario	at European level		(J15 - J1)/J1
Additional area protected from acidification <i>(1000 km²).</i>	104	115	+ 11%
Additional area protected from eutrophication <i>(1000 km²).</i>	254	350	+ 38%
Reduction in the exposure of vegetation to ozone <i>(10,000 km².excess ppm.hours).</i>	346	373	+ 8%
Reduction in the exposure of the population to ozone <i>(millions persons.ppm.hours).</i>	252	198	- 21%
Results of the scenario: implementation cost on top of the reference scenario <i>(billion Euros/year).</i>	8.5	8.5	Identical by design

It can be seen that the calculated overall performance of the "robust" scenario J15 is better than that of the "optimised" scenario J1 according to three of the criteria

considered (protection against acidification and eutrophication, and exposure to ozone AOT40). It is only less advantageous according to the fourth criterion (exposure to ozone AOT60) (Cf. also Figure 3). Indeed this last criterion seems to be the one the evaluation of which is least reliable ⁽¹⁸⁾.

Of course this is only a preliminary comparison of two kinds of approaches. For one thing a better "optimised" strategy could be achieved, as we have seen, by setting optimisation targets at European level. Also the "robust" scenario J15 is probably a little crude. The limiting values of the marginal costs were – as we have pointed out – determined rather arbitrarily. It would be interesting to change these limits and look into the resulting effects on environmental and cost performances !

Notwithstanding this, the major result of this exercise is that a scenario of general reductions in European emissions does produce environmental improvements on a scale entirely comparable with that of an "optimised" scenario.

It is more surprising that such a result should show up in conditions for which the optimised scenario is supposed to be the best ⁽⁴⁾. This seems an "experimental" confirmation of the counter-productive nature of the method of setting optimisation constraints that we analysed earlier.

3-3 A strategy for the general reduction of pollutant emissions in the Europe of the fifteen based upon *per capita* emissions rates in each country

One might be tempted to look for a strategy for the general reduction of European emissions that is even simpler than that concerned with marginal costs ⁽¹⁹⁾.

The strategy involving a single rate of reduction in emissions for all countries, adopted in a number of Geneva Convention Protocols, is one such simple rule. However, when the rate of reduction is significant, it generally appears that the rule is more difficult to implement in countries that have a relatively low level of emissions than in those with a high relative level of emissions. For evaluating the relative level of emissions of different countries, the simplest way would appear to be to refer the emission level to the population of the country ⁽²⁰⁾.

¹⁸ The 21% difference between the two strategies according to the AOT60 criterion must be put in perspective when it is noted that the performance of one and the same strategy can vary by 40% between two versions of the EMEP model (see 3-1-2): the Europe-wide effect of a 40% reduction in NO_x emissions is estimated at either 181 ppb-h (Study A) or 126 ppb-h (Study B).

⁴⁴ For example the evaluation of the performances of the scenarios J1 and J15 are based on the IIASA-Ozone model, i.e. apparently the data presented as Study A in Table 2. The hypotheses of the Study B should be more favourable to J15 than J1 as regards the performance concerning AOT60.

¹⁹ In scenarios such as J15, the assignment of emission ceilings to the countries depends on assumptions about emission reduction costs in different countries. These assumptions are, as we pointed out earlier, subject to uncertainty.

²⁰ A possible alternative criterion – GNP – seems hardly appropriate when the objective is in fact to decouple economic growth from pressure on the environment.

In this approach, a first scenario for the EU15 countries has been constructed :

- in respect of each pollutant, the country that has the lowest *per capita* level of emission in the reference year 2010 is the target that all the other countries must seek to come nearer ;
- all the countries must reduce the difference between their *per capita* level of emission in the reference situation of 2010 and the emission level of the target country by the same proportion;
- an additional provision aimed at making this rule more flexible with regard to particular situations is to avoid seeking reductions in emissions that would involve marginal costs above certain limits.

Scenario H13 was constructed along these lines. For each pollutant, the rate of reduction of the difference between the reference *per capita* emission and the *per capita* emission of the target country was chosen such that the total European emissions reach the same level as in one of the scenarios designed earlier by IIASA : the scenario H1 ⁽²¹⁾. Table 4 illustrates scenario H13 and compares its performance with that of the previously “optimised” scenario the results of which are the closest : the scenario H2 ⁽²²⁾.

It can be seen that although the cost of the “robust” scenario H13 is only half that of the “optimised” scenario H2, the environmental advances contributed by H13 are better than or equivalent to those provided by H2 for three of the criteria considered (protection against acidification and eutrophication, and exposure to ozone AOT40). According to the fourth criterion (exposure to ozone AOT60 – probably the least reliable criterion), the two scenarios H13 and H2 show equivalent benefit-cost relationships.

In this case more than ever, one may be surprised by the apparent advantage of a “robust” scenario aiming at a general reduction of emissions according to a simple rule over an “optimised” scenario. Assuming the models are correct, this apparently confirms that introducing too many constraints into the optimisation, without considering the contradictory effects of various constraints, would result in lower effectiveness of the efforts to reduce emissions.

Of course the scenario H13 itself is only a first example of a strategy for generally reducing emissions on the basis of *per capita* emissions. Other scenarios, taking into account other rates of reduction for the different pollutants and possibly other ceilings on marginal costs, could be tested. More detailed analysis of their implications for each country would then be interesting.

²¹ We may note that scenario H13 reduces pollutant emissions in Europe to the same level as H1 for a cost about 4 times less: 2 billion instead of 7.5 billion Euros/year.

²² cf. : Cost-effective control of acidification and ground level ozone, IIASA, 7th Interim Report to the European Commission, DG-XI, January 1999.

Table 4 : Comparison of the performances of an "optimised" scenario (H2) with those of a "robust" scenario (H13) aiming at a general reduction of pollutant emissions in EU15 based upon the *per capita* emission rates in each country.

Scenario	Optimised H2	Robust H13	Comparison																				
"Gap closure" constraints used in the optimisation <i>(in 2010 compared with 1990)</i> Acidity Ozone : AOT40 Ozone : AOT60	For each country 90% 30% 60%																						
Rate of reduction of the gap between the per capita emission of a country in the reference 2010 situation and the per capita emission of the target country <table> <tr> <td><i>pollutant</i></td><td><i>target country</i></td><td><i>per capita emission</i></td><td></td></tr> <tr> <td>SO₂</td><td>Netherlands</td><td>4.9 kg/inhab.</td><td></td></tr> <tr> <td>NO_x</td><td>Austria</td><td>13.3 " "</td><td></td></tr> <tr> <td>VOC</td><td>Germany</td><td>14.4 " "</td><td></td></tr> <tr> <td>NH₃</td><td>UK</td><td>5.2 " "</td><td></td></tr> </table> Additional rule : <i>The marginal costs of measures to reduce emissions must remain below 2000 Euros/tonne SO₂, NO_x or VOC and 4000 Euros/tonne NH₃.</i>	<i>pollutant</i>	<i>target country</i>	<i>per capita emission</i>		SO ₂	Netherlands	4.9 kg/inhab.		NO _x	Austria	13.3 " "		VOC	Germany	14.4 " "		NH ₃	UK	5.2 " "			for each of the fifteen 36% 46% 82% 26%	
<i>pollutant</i>	<i>target country</i>	<i>per capita emission</i>																					
SO ₂	Netherlands	4.9 kg/inhab.																					
NO _x	Austria	13.3 " "																					
VOC	Germany	14.4 " "																					
NH ₃	UK	5.2 " "																					
Results of the scenario: environmental benefits compared with the reference scenario Additional area protected from acidification <i>(1000 km²)</i> Additional area protected from eutrophication <i>(1000 km²)</i> Reduction in the exposure of vegetation to ozone <i>(10,000 km².excess ppm.hours)</i> Reduction in the exposure of the population to ozone <i>(millions persons.ppm.hours)</i>	for EU15 12 29 115 149		11 50 142 75																				
Results of the scenario: implementation cost on top of the reference scenario <i>(billion Euros/year).</i>	4.2	2																					
Benefit/cost ratios (for 1000 Euros/year).			(H13 -H2)/H2																				
Area protected from acidification <i>(ha)</i>	0.28	0.52	+ 85%																				
Area protected from eutrophication <i>(ha)</i>	0.69	2.45	+ 250%																				
Reduction in the exposure of vegetation to ozone <i>(ha.excess ppm.hours)</i>	27	70	+ 150%																				
Reduction in the exposure of the population to ozone <i>(persons.ppm.hours)</i>	35	37	+ 4%																				

3-4 Advantages common to the strategies for the general reduction of emissions

It would appear from the above examples that certain strategies aiming at a general reduction of emissions in Europe may turn out to be as effective as, if not more effective than, the optimised multi-pollutant, multi-effect strategies examined hitherto by TFIAM or in the studies done for DG-XI.

However these strategies for the general reduction of emissions have the major advantage of being intrinsically more robust than the "optimised" ones since their construction did not involve uncertain assumptions about atmospheric transfers from country to country and the generation of ozone, or local critical loads. In those approaches, these two sets of data are used at the level where they are the most reliable : for evaluating the relationship between the overall effort to reduce emissions and the environmental progress achieved.

Nevertheless both the strategies for the general reduction of emissions investigated depend upon assumptions about emissions in the 2010 reference situation, i.e. assumptions about industrial growth, emission factors, effectiveness of technical reduction measures, and so on. Moreover the strategy based upon marginal costs also depends on assumptions about cost functions. Hence there is room for uncertainty in the design of these strategies ⁽²³⁾. However one may regard as an advantage the fact that the data for which there is most incentive to reduce uncertainties are those related to the anthropic emission system, i.e. the "action variables" ⁽²⁴⁾.

Another important aspect of the two strategies aiming at a general reduction of emissions is that the level of costs borne by the different countries are more balanced – notably in terms of *per capita* costs – than the "optimised" strategies in which certain countries are subjected to significant economic pressures while others bear no load (cf. Figure 4).

The economic criterion taken into account in the RAINS optimisation is the total cost at the European level, but this should not be the only economic criterion for determining the suitability of a strategy. In this field, it seems to us that the strategies aiming at a general reduction of emissions comply more closely with the Polluter-Pays Principle and also are closer to a degree of European solidarity than the strategies determined by the non-linearity in the generation of ozone.

Finally, if the long-term objective is to eliminate all the damaging effects of transboundary air pollution, it is clear that this will necessarily involve a continuous effort by all countries ⁽²⁵⁾. From this point of view the strategies aiming at general

²³ Indeed one might wonder whether a general reduction strategy based on *per capita* emissions could not make reference to data more immediate than the "reference 2010" emission data, for example those for 2000.

²⁴ Perhaps one can make use of the experience of the countries that have low emission levels and better understand why certain other countries have particularly high emission levels.

²⁵ A further illustration of this was given in a recent study by the British Meteorological Office, that confirms the need for action to reduce emissions of ozone precursors on a global scale, even wider than Europe.

reductions in emissions seem to us to give a clearer indication of the direction to take⁽²⁶⁾.

4. Conclusion

The results of studies recently carried out by the IIASA at the request of the French Ministry for Land-Use Planning and the Environment throw up a new light on the matter of UNECE and DG-XI LRTAP strategies.

In the present context of the multi-pollutant, multi-effect approach, these results show that the strategies aiming at a general reduction of emissions in Europe are globally as efficient as, if not more efficient than, the "optimised" strategies investigated hitherto in the TFIAM or DG-XI framework. In addition to their efficiency these strategies for general emissions reductions have other significant advantages⁽²⁷⁾.

The results set out illustrate also some more general guidelines that may seem obvious but which are still difficult to apply in practice :

- Distinguishing the design of strategies from the assessment of strategies ;
- Aiming at simplicity and transparency in models ;
- Leaving the possibility to study various strategies open for as long as possible ;
- Evaluating the robustness of strategies in view of the uncertain nature of the data involved in the problem ;
- Identifying in the first place strategies that improve the quality of the environment throughout Europe and seeking in the second place to resolve remaining specific regional problems ;
- Keeping in view, beyond the immediate goals, the long-term objectives, the supra-European issues, and the kinds of impacts not directly taken into account in the models ;
- Making explicit, in a multi-pollutant approach, the relative importance given to the different issues ;

cf. R. G Derwent et al., The European regional ozone distribution and its links with the global scale for the years 1992 and 2015, *Atmospheric Environment* 34 (2000).

²⁶ If a postponement in the efforts of certain countries should be envisaged for particular reasons, this should remain a subject of political discussion. Implicit considerations should not obscure the way in which environmental problems are considered..

²⁷ This does not mean of course that additional, more refined studies based upon the principles set out above may not conclude that it is efficient to introduce a degree of regional differentiation into the efforts to reduce emissions.

An interesting point of reference is the strategy for preventing tropospheric ozone now being worked out in the United States. Three different levels can be distinguished :

- 1) all the continental states are subject to the general federal regulations concerning the control of pollutant emission ;
- 2) a group of 22 states is regarded as forming the basin emitting the pollutants that are precursors of the ozone problems observed in certain regions : this group is the subject of a more stringent policy applied uniformly to the 22 states ;
- 3) the regions most affected by ozone problems must submit specific plans of action.

- Taking notice of the different economic aspects of the strategies ;
- Giving priority to a thorough and realistic assessment of the technical and structural measures for reducing emissions and the associated reduction potentials in Europe.

Acknowledgements

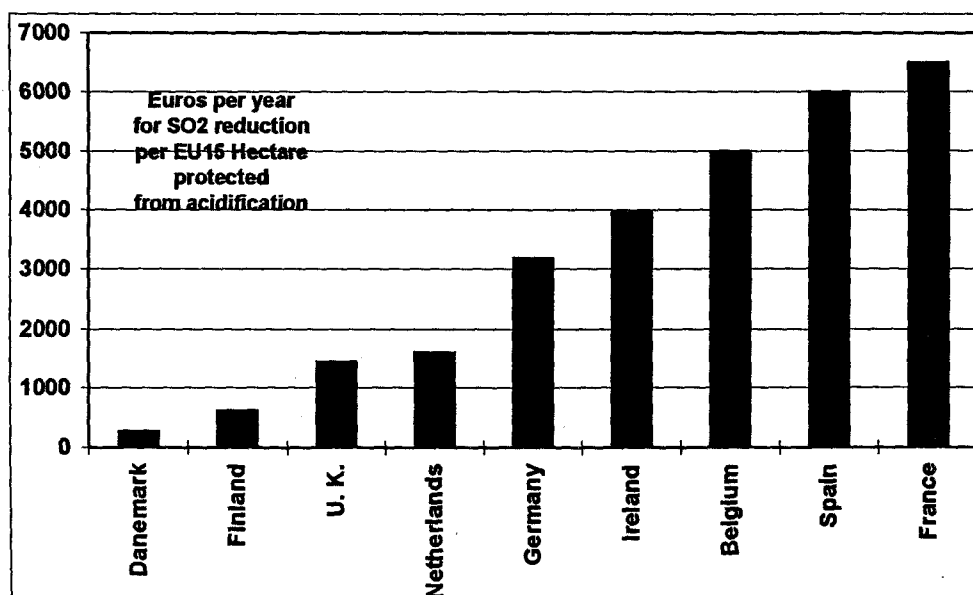
The authors wish to thank all their colleagues in the Task Force on Integrated Assessment Modelling, and particularly those in the IIASA Transboundary Air Pollution Team, with which they have had many fruitful discussions in recent years.

They would also like to thank the participants in the "Forum Pollution Transfrontière" that brought together experts from all the parties involved (ministries, ADEME, industry, and so on) on the initiative of the French Ministry for Land-Use Planning and the Environment, with the secretariat provided by the CITEPA. The exchanges that took place in this forum were of valuable assistance in setting out their point of view.

Finally they wish to stress that the ideas expressed here are their own personal views.

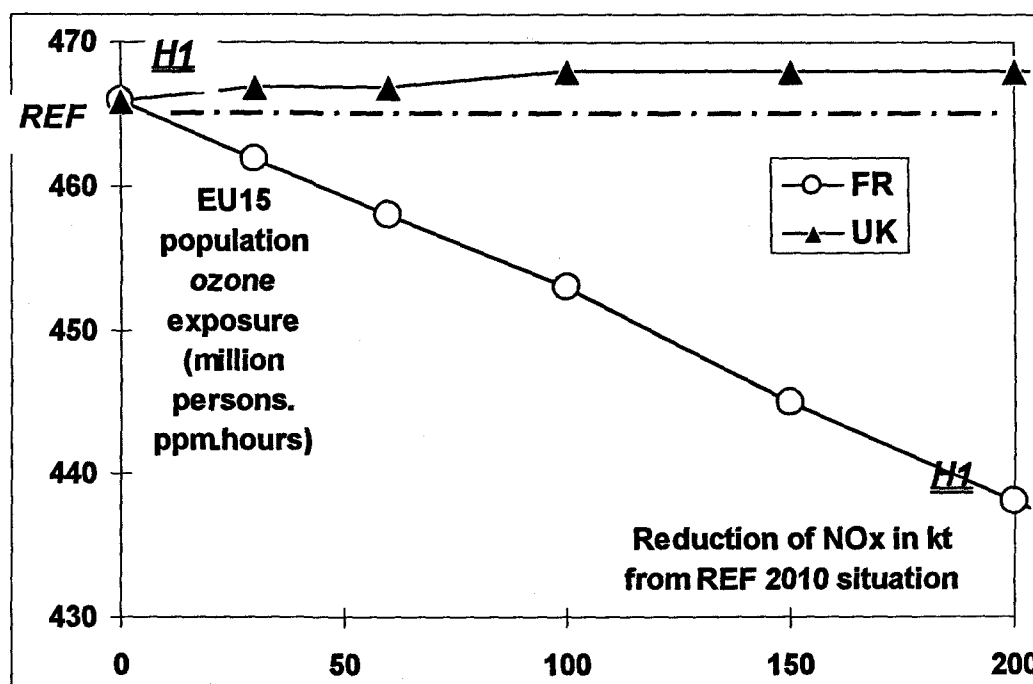
Fig. 1: Cost-advantage ratio of a marginal reduction of SO₂ emissions in various countries with respect to the European (EU15) area protected from acidification.

Evaluation in the vicinity of the optimum of a scenario optimised with uniform national gap closure constraints (H1) ⁽⁹⁾



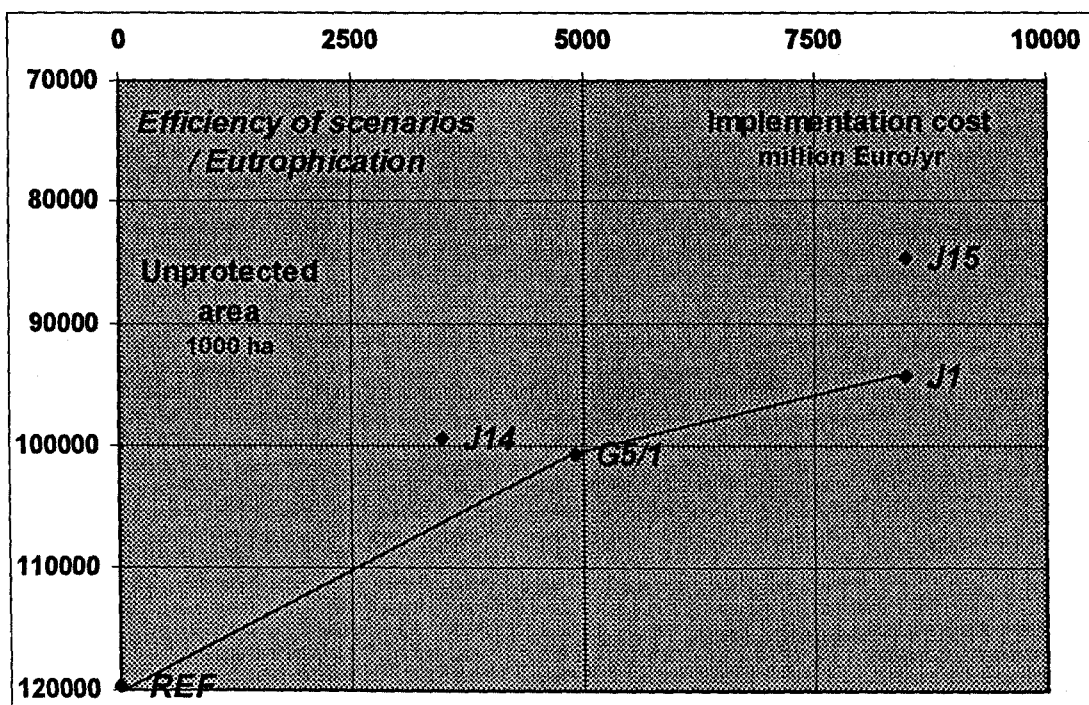
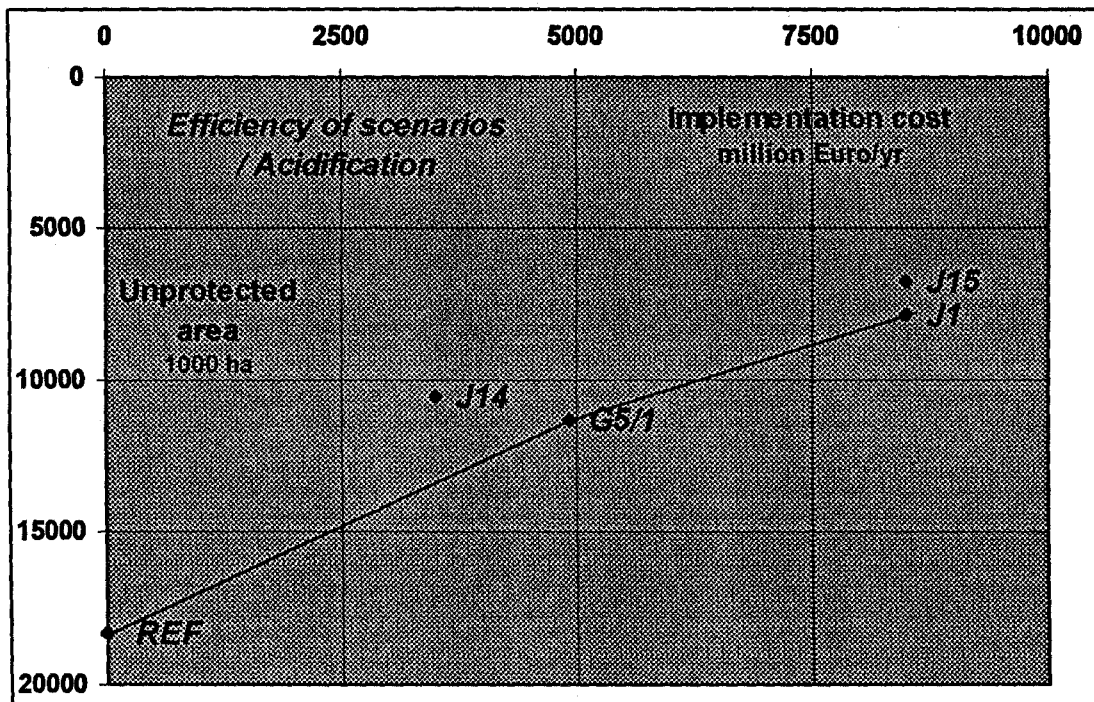
⁹ Landrieu (G.), Mudgal (S.): to be or not to be optimal? That is one of many questions..., UNECE Task Force on Integrated Assessment Modelling, 24th meeting, Rome, 8-9 June 1999.

Fig. 2 : Variations of EU-15 cumulative ozone population exposure index (AOT60) when one reduces NO_x emissions of France or UK departing from REF 2010 situation



In the Reference situation,
 NO_x emissions are 858 kt for France and 1186 kt for the United Kingdom.
 That corresponds to average NO_x emissions densities
 of 1.56 t/km² for France and 4.86 t/km² for the United Kingdom.

Fig. 3 : Cost-effectiveness of various scenarios in relation to environmental indicators
J1 and G5/1 scenarios "optimised" on the basis of national constraints
J14 scenario "optimised" on the basis of European objectives
J15 scenario "robust" based upon the selection of technical measures according to their marginal cost



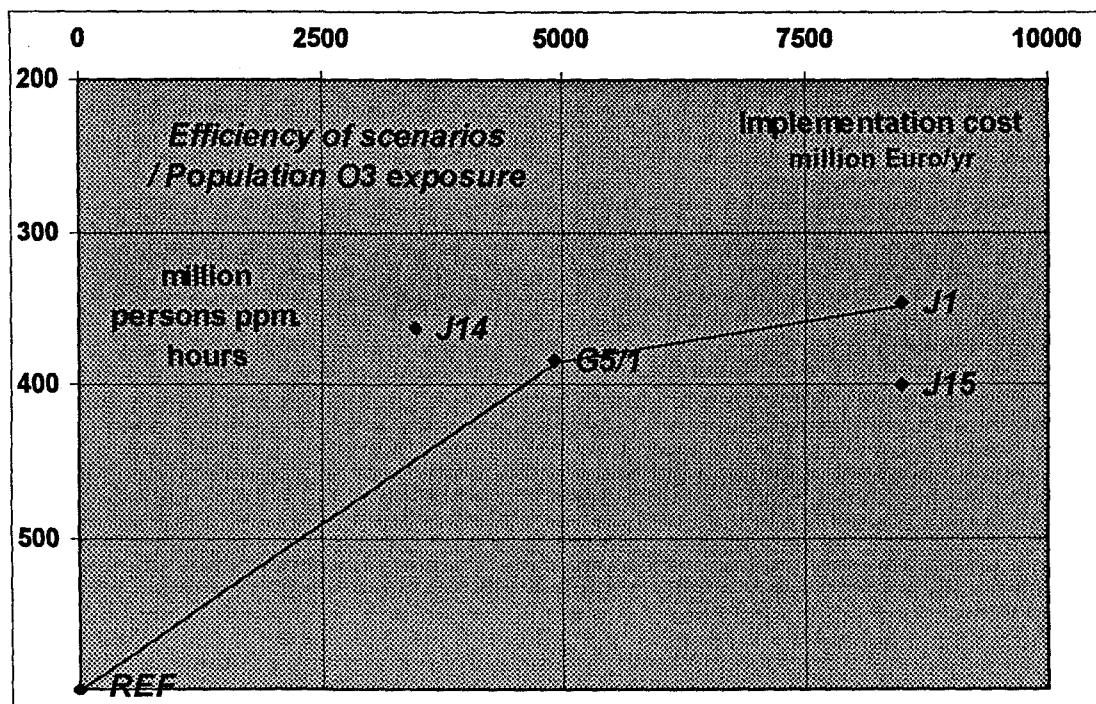
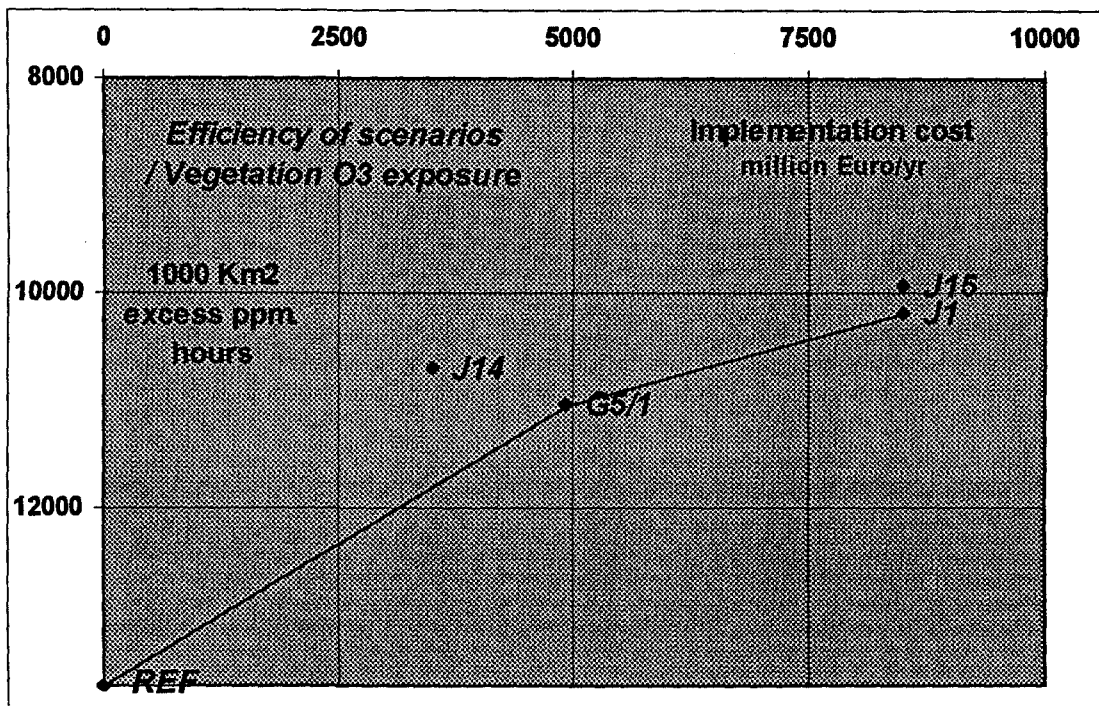


Fig. 4 : Implementation cost per inhabitant in EU15 countries

- for two "optimised" scenarios (J1 and H2)
- and two scenarios for a general reduction of emissions (J15 and H13)

