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A comparison between the cost curves in the RAINS-model and the Swedish environmental quality objectives

Catarina Sternhufvud Peringe Grennfelt

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Organisation/Organization

IVL Svenska Miljöinstitutet AB
IVL Swedish Environmental Research Institute Ltd.

Adress/address

Box 47086
402 58 Göteborg

Telefonnr/Telephone

031-725 62 00

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A comparison between the cost curves in the RAINS-model and the Swedish environmental quality objectives

Sammanfattning/Summary

The Swedish Parliament has adopted fifteen environmental quality objectives. To be able to attain these goals in a cost-efficient way, cost curves have been created for sulphur dioxide (SO_2), nitrogen oxides (NO_X), and volatile organic compounds (VOC). These pollutants are also restricted in international protocols under the Convention on Long-Range Transboundary Air Pollution (CLRTAP). Most of the analyses underlying the protocols have been performed by the Regional Acidification Information and Simulation model (RAINS) developed at the International Institute for Applied Systems Analysis (IIASA) in Austria.

This study compare the cost-effectiveness principles used in the RAINS model with the principles used in the proposal to meet the Swedish environmental quality objectives. The two approaches use different methodologies to solve the problem with air pollution and do therefore receive different results. The advantages and disadvantages are discussed in this report.

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Summary

The Swedish Parliament has adopted fifteen environmental quality objectives. These objectives aim to make possible a dynamic but sustainable society within one generation (until 2020). To be able to attain these goals in a cost-efficient way, the Parliament Committee on Environmental Objectives was set, which has presented a proposal how to reach the goals. For the objectives Clean air and Natural acidification only, the three main responsible pollutants are sulphur dioxide (SO_2), nitrogen oxides (NO_X), and volatile organic compounds (VOC). These pollutants are also restricted in international protocols under the Convention on Long-Range Transboundary Air Pollution (CLRTAP). The Convention is an international instrument, including 43 countries, aiming to reduce and prevent pollution.

To provide a scientific basis for emission reductions under CLRTAP an integrated assessment model has been used to carry out scenario analyses. Most of the analyses underlying the negotiations have been performed by the Regional Acidification Information and Simulation model (RAINS) developed at the International Institute for Applied Systems Analysis (IIASA) in Austria. RAINS generates scenarios, which help countries to understand the impacts of future actions and to design strategies to achieve long-term environmental goals at the lowest possible cost.

The purpose of this study is to compare the cost-effectiveness principles used in the RAINS model with the principles used in the proposal to meet the Swedish environmental quality objectives. The two approaches use different methodologies to solve the problem with air pollution and do therefore receive different results.

One of the most important differences is that RAINS only takes technical measures to decrease specific pollutants into account, while the Committee try to include everything that will influence the emission situation. The measures estimated by the include many different techniques, energy conservation measures, and structural changes, such as changed driving behavior etc. For instance, 24% of the estimated NO_X reduction in tons, is due to 'non-technical methods'. A second essential difference is the use of negative costs in the Swedish proposal. RAINS only considers the costs for the measures and rank them according to their marginal costs, while the Committee also takes the benefits of the measures into account and rank the measures after their net present value. The two methods also deal with the allocation of the costs differently. In RAINS no allocation is used as the technologies are assumed only to influence one pollutant each, while the Committee has used a complicated model to allocate the cost between different environmental targets and pollutants.

The Committee's mode of procedure to use 'negative costs', including 'non-technical measures', and trying to find solutions for many targets at the same time gives a more comprehensive picture. The difficulty to do this internationally is self-explanatory since there is no internationally accepted method to handle 'non-technical measures' nor is there any agreement how to value benefits in terms of energy savings etc.. It also requires more information from all countries involved. A first step could be to include other kinds

of measures, such as energy conservation methods and structural changes, to make it possible to reach lower emission levels to low cost in the review of the Gothenburg protocol 2004-2005.

During this study the lack of documentation of the RAINS model has been obvious, which made the understanding of the methodology very time-consuming, especially regarding the creation of cost curves for the different pollutants. It is important that the information becomes easier to access and to understand as this will increase the countries confidence in the model. Also the documentation of the Swedish approach has been defective and the information about the cost curve calculations has to a large extent been received through personal communication with the creators of the curves. The lack of background data has forced them to do a lot of assumptions and it is important for the future work to improve the input data. Cost-effectiveness will be even more important when the low-cost options for abating emissions are adopted and more costly actions have to be implemented.

Contents

Abbreviation

ASTA	International and national abatement strategies for transboundary air pollution
BAU	Business as usual
CL	Critical load
CLE	Current legislation
CO_2	Carbon dioxide
DEP	Acid deposition and ecosystems impact module
EMCO	Emission-cost module
EMEP	European monitoring and evaluation programme
IIASA	International Institute for Applied Systems Analysis
MC	Marginal cost
MFR	Maximum feasible reduction
NH_3	Ammonia
NO_X	Nitrogen oxides
RAINS	Regional Acidification Information and Simulation
REF	Reference scenario
SO_2	Sulphur dioxide
OPT	Optimisation module
PM	Particulate matter
UN/ECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds
WHO	World Health Organisation

1. Introduction

1.1 Purpose of the study

The purpose of this project is to compare the cost-effectiveness principles used in the Regional Acidification Information and Simulation model (RAINS) with the principles used in the proposal to meet the Swedish environmental quality objectives adopted by the Swedish Parliament. In RAINS only technical abatement options are taken into consideration and the model uses an optimisation program to find the most cost-efficient solution for Europe (IIASA homepage, 2000). The Swedish approach tries to include everything that will influence the emission situation in Sweden including energy conservation measures and structural changes (Miljömålskommittén, 2000).

This study will investigate how these different approaches will influence the final result and it will be possible to make a statement if the costs calculated at the International Institute for Applied Systems Analysis (IIASA) in Austria and the Swedish estimates are of the same magnitude. The project will also contribute to increased knowledge about the RAINS methodology and how to use the model in practice.

1.2 Method

To find out how the RAINS model is built up a three weeks visit to IIASA in Austria was carried out during November 2000. During the visit knowledge was reached about the methodology and the field of application.

The second part of the project included an analysis and comparison of the control measures and costs applied by IIASA with the control measures and costs estimated in connection with the work by the Parliament Committee on Environmental Objectives. The information about the Committee’s work has mainly been achieved by taking part of their report about how to reach the fifteen environmental quality objectives and e-mail correspondence with Thomas Levander and Erika Budh, responsible for the calculations of the cost curves.

1.3 Limitations

The main focus in this study is on the sulphur dioxide (SO_2) and nitrogen oxides (NO_X) cost curves. The reason is that the interpretation of the volatile organic compounds (VOC) cost curves in RAINS is partly different than the others and due to lack of resources they can not be discussed in details within this project. A cost curve for ammonia (NH_3) has not been calculated by the Committee and can therefore not be compared with the cost curve in RAINS.

The lack of complete background information about the costs calculated by the Committee has made some assumptions necessary and preclude a more detailed comparison of the cost calculations for each technique. More emphasis is therefore put on the principles of the cost curves than the actual cost of each measure.

1.4 The structure of the paper

The study is divided into six chapters. The aim of chapter 2 is to provide a sufficient background and it includes a description of the Swedish environmental quality objectives and the work within the Convention on Long-Range Transboundary Air Pollution. In chapter 3 the theory behind the approaches and the calculations of cost curves are discussed. The empirical data is reported in chapter 4 and diagram and tables show cost curves calculated by RAINS and the Committee. The empirical results are analysed and discussed in chapter 5 and the conclusions from the study can be found in chapter 6. In the appendices the calculations of the costs and the theory behind the cost curves are specified as well as necessary abbreviation to interpret the cost curves.

2. Background

2.1 The Swedish environmental quality objectives

The Swedish Parliament has adopted fifteen environmental quality objectives. These objectives are based on five principles: encouraging human health, guarantee biological diversity, preserving cultural heritage, protecting the long-term productive capacity of the ecosystems, and ensuring that natural resources are properly managed. The aim is to make possible a dynamic but sustainable society within one generation (until 2020) (Miljömålskommittén, 2000).

To be able to attain these goals in an efficient way, a Committee (The Parliament Committee on Environmental Objectives) was nominated. The Committee focused on the causes of the environmental problems and presented in co-operation with twenty government agencies and all of Sweden's county administrative boards, a proposal how to reach the goals. The proposal includes:

- The quality levels that are to be attained within one generation;
- Intermediate targets – usually for 2010;
- Action strategies and policy instruments to be used;
- Follow-up systems;
- Allocation of responsibilities between national agencies, county administrative boards, and local authorities.

The emphasis in this project is on the environmental quality objectives: Clean air and Natural acidification only. The three main responsible pollutants are sulphur dioxide (SO_2), nitrogen oxides (NO_X), volatile organic compounds (VOC), and ammonia (NH_3).

The overall objectives are that "the air must be clean enough not to represent a risk to health or to animals, plants or cultural heritage assets" and that " the acidifying effects of acid depositions and land use may not exceed the limits that can be tolerated by soil and water". To fulfil the Clean air objective target levels have been set which are shown in table 1.

Table 1. The target levels for the Clean air objective (Miljömålskommittén, 2000).

Pollutant	**Levels not to be exceeded ($\mu g\ m^{-3}$)**	**Mean measurement period**
Sulphur dioxide	5	Year
Nitrogen dioxide	100	Hour
	20	Year
Ozone	80	Hour
	50	Summer months (Apr-Oct)

To be able to reach the objectives mentioned above within one generation, the emissions of SO_2, NO_X and VOC have to decrease substantial. By the year 2010, airborne emissions of sulphur dioxide have to decrease by at least 25% from the 1995 level, to 72 000 tons (including international sea and air traffic). Nitrogen oxides and VOC have to decrease even more, with 55% from 1995 levels, to 155 000 tons respectively 220 000 tons (including international sea and air traffic). Estimates for 2020 are 40-60 kt of SO_2, 55-110 kt of NO_X and 80-160 kt of VOC. The higher levels are needed to reach the goals in the whole of Europe (Miljömålskommittén, 2000).

The Committee has also suggested targets and abatement options for NH_3 and the objective stresses that "nutrient levels in soil and water must not be such that they adversely affect health, the conditions for biological diversity or the possibility for varied land and water use". As there has not been any cost curve created for NH_3 it will not be further discussed in this report, even if it is an important component in the environmental discussion and there are international agreements concerning the emission levels.

The Committee has as a reference scenario called "Business as usual" (BAU). This scenario shows the expected emission levels for 2010 if the legislation and regulations of today will be the same and if decisions already taken will be implemented. In Table 2 the emission levels are separated into different sectors for 1995, 1998 and 2010. The values for 2010 are estimated according to BAU.

Table 2. Emissions of SO_2, NO_X and VOC in kton 1995-2010 (Miljömålskommittén,2000).

Sector		**SO_2**			**NO_X**			**VOC**	
	1995	*1998*	*2010*	*1995*	*1998*	*2010*	*1995*	*1998*	*2010*
Energy	14	14	14	14	14	12	5	7	10
Manufacturing	31	28	27	33	32	26.5	42	26	26
Transport	24	19	7.6	213.1	173	74.2	174.6	121.6	37.6
Others	6	6	5	8	8	9.9	132	123	83
Off-road machinery	1	0.4	0.4	74	68	45	30	28	29.6
Solvent							113	111	90
Sum[1]	**76**	**67**	**54**	**342**	**295**	**168**	**497**	**417**	**276**
Sum[2]	**61**	**55**	**49**	**291**	**254**	**146**	**495**	**415**	**275**

The Committee has stressed the importance of cost-effectiveness when deciding and creating different instruments of control. The decrease in emissions is to be carried out to the lowest cost for the society. This means in principle that all polluters should decrease their emissions until their marginal cost for the most expensive control option is X SEK and therefore different polluters have to decrease their emissions to different extent (Miljömålskommittén, 2000).

Much of the deposition in Sweden is due to transboundary air pollution from other countries. Therefore, it is essential with international collaboration and work within EU to reach the Swedish environmental quality objectives. When it comes to limiting airborne pollution, the international efforts have been very successful. One important factor is the work carried out by the UN/ECE.

[1] Including international sea and air traffic.
[2] Excluding international sea and air traffic.

2.2 Convention on Long-Range Transboundary Air Pollution (CLRTAP)

The control of air pollution in Europe began in the 1970s, caused by the concerns over the link between sulphur emissions in continental Europe and the acidification of Scandinavian lakes. Studies confirmed that pollutants often travelled long distances before falling to earth and influencing ecosystems and human health. Many thousands of tons of pollution are today 'imported' and 'exported' between countries and emission reductions by the countries influence both the local ecosystems as well as the burden of long-range transport of air pollution (IIASA homepage, 2000).

The UN/ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) is an international instrument aiming at the reduction and prevention of pollution (WHO, 1999). The Convention was initially signed by 33 countries 1979 and entered into force in 1983, and does now include 43 countries. The Convention was the first international agreement to recognise both the environmental and health problems caused by the flux of air pollutants across boarders (UN/ECE, 1998). It establishes a broad framework for co-operative action and sets up a process for negotiating concrete measures to control specific pollutants through legally binding protocols.

Five protocols are currently in force:
- European monitoring and evaluation programme (EMEP), 1984;
- Thirty per cent reduction in sulphur emissions, 1985;
- Nitrogen oxides, 1988;
- Volatile organic compounds, 1991;
- Further reduction of sulphur emissions, 1994.

Three additional protocols are open for signature but are to be entry into force:
- Heavy metals, 1998;
- Persistent organic pollutants,1998;
- Acidification, eutrophication and ground-level ozone, 1999 (UN/ECE, 1999).

The latest protocol has, after the signing ceremony in Gothenburg in December 1999, been called the Gothenburg protocol. The protocol sets emission ceilings for 2010 for four pollutants: SO_2, NO_X, VOC and NH_3. These ceilings were negotiated on the basis of scientific assessments of pollution effects and abatement options. Countries whose emissions have a more severe environmental or health impact and whose emissions are relatively cheap to reduce will have to make the biggest reductions. Once the protocol is fully implemented, Europe's SO_2 should be cut by at least 63%, NO_X emissions by 41%, VOC emissions by 40%, and NH_3 emissions by 17% compared to 1990. The emission ceilings for Sweden are 67 000 tons (44%) for SO_2, 148 000 tons (56%) for NO_X, 241 000 tons (54%) for VOC, and 57 000 tons (7%) for NH_3 (UN/ECE homepage, 2000).

In the initial position, before the negotiations, Sweden's emission levels were set to 67 kt for SO_2, 159 kt for NO_X, 241 kt for VOC, and 48 kt for NH_3. During the negotiations the emission ceilings for NO_X and NH_3 were changed in different directions. The protocol has been signed by Sweden but is yet to be ratified (February 2001).

2.3 The Regional Acidification Information and Simulation model (RAINS)

To provide a scientific basis for emission reductions under CLRTAP an integrated assessment model has been used to carry out scenario analyses. Most of the analyses underlying the negotiations have been performed by the Regional Acidification

Information and Simulation model (RAINS) developed at the International Institute for Applied Systems Analysis (IIASA) in Austria.

The RAINS model is the best example so far of an environmental economic model actually being used to help countries design policies of reducing emissions of pollutants. It generates scenarios, which help users to understand the impacts of future actions and to design strategies to achieve long-term environmental goals at the lowest possible cost (IIASA homepage, 2000). Since most low-cost options for abating emissions are already adopted in current strategies further action have to embark on more costly measures. Therefore cost-effectiveness will be an important argument for gaining acceptance of further reductions. The methodology of RAINS is discussed further in 3.1 and 3.2.

2.4 Comparison between emission targets for 2010

The Committee has analysed three different ambitions for SO_2, NO_X and VOC – low, medium and high ambition. The medium ambition has been suggested as it will make possible that Sweden reach both the intermediate targets as well as the targets in the Gothenburg protocol.

To facilitate a comparison between the different emission levels and targets, all values have been put into the same table (Table 3) and are also plotted in Figure 1-3. The values are all excluding international sea and air traffic (Miljömålskommittén, 2000, IIASA homepage, 2000).

Table 3. Emission levels and targets for Sweden 2010, excluding international sea and air traffic.

	SO_2 (ton)	NO_X (ton)	VOC (ton)
Emissions 1990[3]	120 000	338 000	513 000
Emissions 1995[4]	61 000	291 000	495 000
Emissions 1998[4]	55 000	254 000	415 000
Business as usual (BAU) 2010[4]	49 000	146 000	275 000
Low ambition (LA) 2010[4]	48 000	140 000	244 000
Medium ambition (MA) 2010[4]	47 000	125 000	215 000
High ambition (HA) 2010[4]	41 000	124 000	190 000
Current legislation (CLE) 2010[5]	67 000	190 000	291 000
No control 2010[5]			399 000
Gothenburg protocol (GOT) 2010[5]	67 000	148 000	241 000
MFR 2010[5]	53 000	134 000	?

The table makes clear that the emission ceilings in the Gothenburg protocol are higher than the Swedish BAU scenario for both SO_2 and NO_X. For VOC a reduction of 34 000 tons is necessary to fulfil the protocol. Also worth noting is that the maximum feasible reduction (MFR) levels for SO_2 and NO_X are higher than the medium ambition proposed by the Committee, which means that those emission levels are not possible to reach according to the calculations in RAINS.

[3] EMEP homepage, September 2000.
[4] Miljömålskommittén, 2000.
[5] IIASA homepage, 2000 and information from the RAINS model.

When it comes to VOC the cost curve calculated in RAINS is a combination of four separate curves which use different starting points – no control and current legislation. The theory about the starting points is discussed in chapter 3.2 and in appendix 2. Due to the complexity of the curve it has not been investigated further in this report and information about MFR has not been accessible.

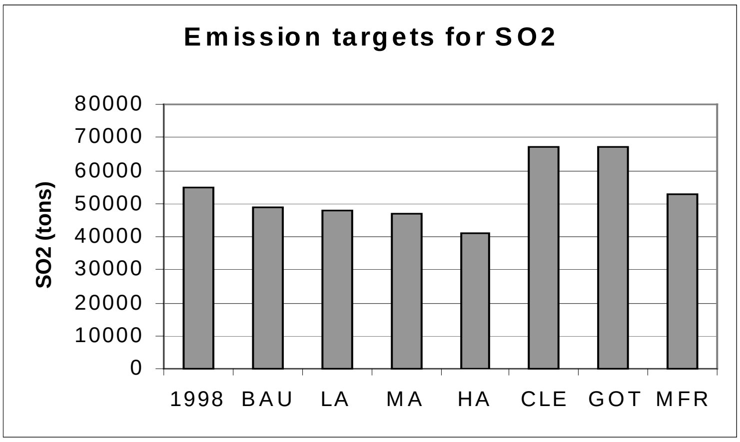

Figure 1. Emission targets for SO_2 according to table 3.

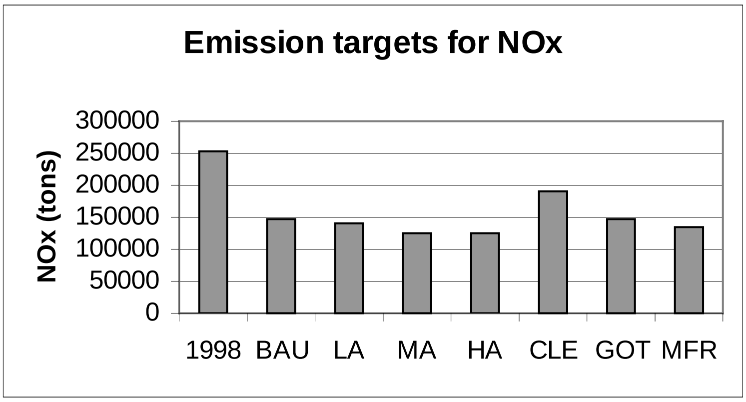

Figure 2. Emission targets for NO_X according to table 3.

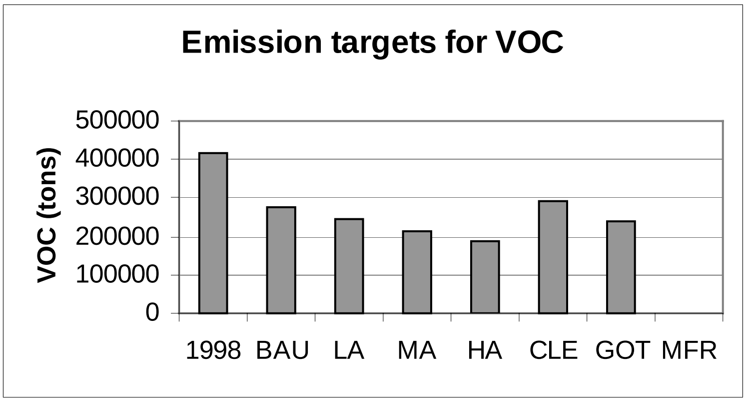

Figure 3. Emission targets for VOC according to table 3.

3. Theory

3.1 The RAINS-model

The RAINS model has four components (see Figure 4). The first component focuses on energy use and emissions of pollutants, the second on possible emission controls and their costs, the third on the geographic dispersion, and the fourth on the environmental effects.

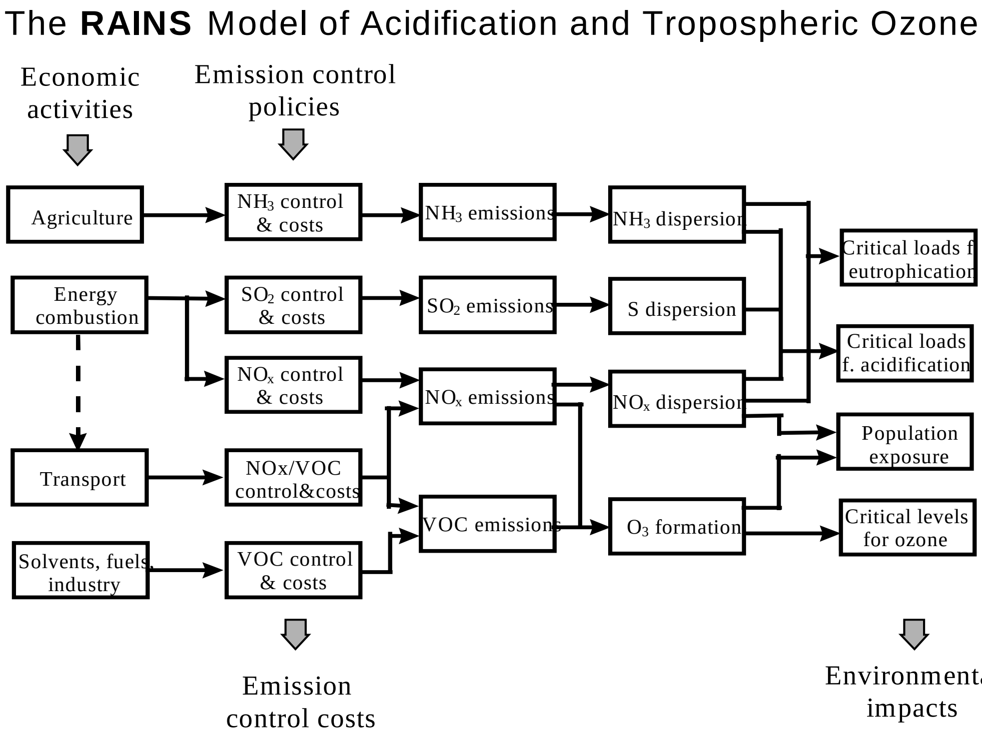

Figure 4. The structure of the RAINS-model - four pollutants responsible for three major environmental problems (Amann et al, 1998).

The first two components are simulated in the emission-cost modules (EMCO). There are four different EMCOs in RAINS one for each pollutant – SO_2, NO_X, VOC and NH_3. In EMCO emission estimates are performed on a disaggregated level that are determined by the details available on economic, energy and agricultural projections. The emissions are also influenced by the use of different control measures. Each emission source category has a limited list of characteristic control options, which can be implemented to abate the emission. The cost and the applicability of the different control options are influenced by the most important country- and situation-specific circumstances. The control costs and emission control potential in the different countries are combined into the national emission control cost curves (Cofala, 1998). Cost curves are created for each scenario and will be described in more detail further down.

The third and the fourth components are part of the acid deposition and ecosystems impact module (DEP). It is in this module possible to calculate the deposition of sulphur and nitrogen resulting from the emissions of each country. These contributions can be summed up together with the background deposition to obtain the total deposition in any of the grids (150*150 km), that Europe has been separated into. The deposition can in DEP be compared with the critical loads (CL). A critical load is defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to the present knowledge (IIASA homepage, 2000). The user in DEP can decide the desirable maximum exceedance of critical loads in the grids and create target files.

Finally, the cost curves simulated in EMCO and the targets files created in DEP can be used in the optimisation module (OPT). OPT identifies, for given set of regional target deposition levels, the cost-minimal allocation of measures to reduce emissions. This optimisation takes into account that some emission sources are linked via the atmosphere to sensitive receptors more strongly than others and that some sources are cheaper to control than others. The OPT gives information about the optimal emission reductions, total costs and marginal costs for each country. It also calculates the deposition in each grid after the optimisation (IIASA homepage, 2000).

The information flow between the different modules in RAINS are shown in Figure 5.

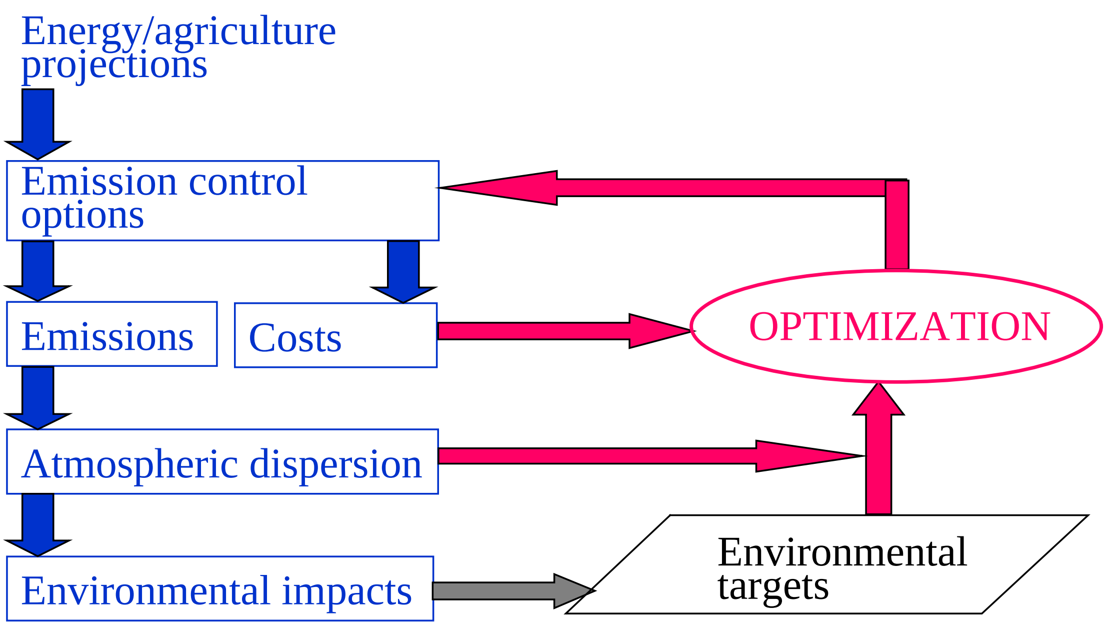

Figure 5. The framework of the RAINS model (Cofala et al, 2000).

Weaknesses

The model has a number of known weaknesses and imperfections. One of the problems relates to the uncertainties and incomplete data. The model relies to a large extent on national data deliveries and correct statistical databases are crucial for the determination of the control options. A major problem is that the methods used to determine emissions are changed constantly and the estimates therefore have to be revised frequently.

Estimates are needed in all the international agreements, such as the Kyoto protocol, the Gothenburg protocol and the emission ceilings directive proposed by the EU, but many countries have nevertheless problems do deliver consistent data.

Another weaknesses is the fact that only technical measures are taken into consideration in RAINS and not structural changes. Structural changes might have a huge impact on the emissions levels and costs. The reasons not to include these kinds of changes are due to lack of methodology and difficulties to predict the effects in the future.

A third shortcoming is that the Kyoto protocol is not considered in any of the scenarios used in the RAINS model for the negotiations. In the protocol it is defined that EU will decrease the emission of CO_2 with 8% until 2010. If this is not taken into account in the energy scenarios it will result in a systematic overestimate of the costs for initiatives aimed at reducing emissions of ozone-forming, acidifying and eutrophying air pollutants. According to calculations carried out by the Commission the impact of a low-CO_2 scenario decreases the costs with 40-60% compared to the REF scenario in RAINS (Ågren, 1999).

RAINS does nor take into account the impact of the air quality in populated areas or eutrophication of lakes and the ocean.

Future possibilities with the model

The growing concern regarding the relationship between health effects and fine particulate matter (PM) has lead to an attempt to extend the RAINS model to incorporate PM. Several emission sources contribute via various pathways to the concentrations of PM in ambient air (Lükewille, 2000). Particulate matter can be either primary or secondary. Primary particles are emitted directly into the atmosphere while secondary particles are formed in the atmosphere from oxidation and reactions with SO_2, NO_X, VOC and NH_3. A draft methodology to estimate the potential and the costs for controlling primary emissions of fine particulate matter has been carried out at IIASA and the aim is to also include secondary PM into the model, in time for the review of the Gothenburg protocol 2004-2005 (IIASA homepage, 2000).

There are also plans to include ozone-concentrations in populated areas in the future. This will make possible estimates of health effects due to transboundary air pollution.

3.2 Calculation of cost curves in the RAINS-model

For each of the available emission control options, RAINS estimates the specific cost of reduction. The costs estimated are at the production level and are not the consumer price nor do they include taxes. The impact on the competitiveness and transfer of money between different groups is also ignored.

RAINS assumes a free market for abatement technologies throughout Europe. All equipment is available to all countries at the same cost and differences are related only to technical factors and some country specific parameters. The technical performance as well as investments, maintenance and material consumption are considered to be technology-specific and thereby, for a given technology, equal for all European countries. Fuel characteristics, capacity utilisation, labour and material costs are, among others, country-specific factors influencing the costs of emission reduction in each country

(Cofala and Syri, 1998a). Technology and country specific cost parameters taken into account in the RAINS model are:

Technology specific parameters:
- Investment cost;
- Fixed operating and maintenance cost;
- Catalyst cost;
- Catalyst demand;
- Sorbent demand;
- Labour demand;
- Removal efficiency;
- By-product production.

Country specific parameters:
- Wages;
- Sorbent price;
- Electricity price;
- By-product disposal cost;
- Annual operating hours;
- Boiler size;
- Emission factor.

(Karvosenoja and Johansson, 1999)

It is not possible to use more than one technology at the same time for the same capacity[6] in a certain fuel-sector combination. To be able to use two technologies, CM[7] plus SCR[8], certain technology combinations have been created in the RAINS model and they are treated as one single technology in the cost curves.

In RAINS no allocation of costs have been used as the abatement measures are assumed to only influence one pollutant each.[9]

Calculation of unit and marginal cost

The unit cost is calculated for every control technology for each sector-fuel combination. All cost calculations are based on the same principles but the assessment differs between different pollutants and between stationary and mobile sources. For stationary sources the average annual cost is calculated by adding annualised investment, fixed operating costs, and variable operating costs. The annualised investment takes into account normal technical lifetime as well as an interest rate of 4%. The unit cost for each technique is calculated by relating the annual cost to abated emission:

Unit cost = annual costs / annual reduction [Euro/ton reduced pollution]

The unit costs for mobile sources are similar to the stationary cost calculations but with some modification for structural differences, for instance, the investment costs are given per vehicle and not per MW capacity (Cofala and Syri, 1998a).

To be able to rank the available abatement options according to their cost-effectiveness it is not enough to know the different unit costs it is also necessary to know how much each measure can reduce of the total emission in each fuel-sector combination. If this information is accessible the marginal cost (MC) can be calculated. Marginal cost is the cost to remove the last unit of emission for each technique. It relates the extra cost for a more effective measure to the marginal abatement of that measure given a comparison

[6] Capacity is the energy use in all activity levels expressed in PJ/a.
[7] Combustion modification
[8] Selective catalytic reduction
[9] Some NO_X-measures in the traffic sector do also reduce VOC, but the total cost is allocated to NO_X.

with a less effective option. The calculation is shown in equation 1 (Cofala and Syri, 1998a).

$$mc_m = \frac{c_m \eta_m - c_{m-1}\eta_{m-1}}{\eta_m - \eta_{m-1}} \quad \text{(Equation 1)}$$

$mc_m =$ marginal cost technique m

$c_m =$ unit cost technique m

$\eta_m =$ removal efficiency technique m

$c_{m-1} =$ unit cost technique m-1

$\eta_{m-1} =$ removal efficiency technique m-1

All the equations used for the NO_X cost calculations are to be found in Appendix 1.

Cost curves

The cost curves created in EMCO illustrate how to achieve a certain emission reduction with least cost by using the optimal combination of abatement techniques. All techniques appearing on the cost-curve are cost-efficient. For example, if for a given economic activity (sector-fuel combination in RAINS) there are two control options with the same reduction efficiency, only the one with the lower unit cost appears on the cost curve.

The cost curves start from a certain level of emission and are composed for a specific year (2010 in the Gothenburg protocol). The total cost as well as the marginal cost increase as the emission decrease. The curve is piece-wise linear, and the lengths of the segments are determined by the reduction potentials of the techniques. The slopes for individual segments are determined by the costs of applying the various techniques in the different sectors (Karvosenoja and Johansson, 1999).

There are two possible starting points on the cost curves in RAINS. The “no control” cost curve assumes that non of the technical control options discussed in RAINS have been implemented in the country and it starts with the, so called, unabated emission value. The other possibility is to start with the emission implied by the emission and fuel standards in force in a given country, the so called current legislation (CLE). A more detailed discussion about the difference between the starting points is found in appendix 2.

3.4 Calculation of cost curves in the Committee’s approach

The creation of the cost curves estimated by the Parliament Committee on Environmental Objectives started with a comparison of the Business as usual scenario and the targets for 2020. When the gap between them had been estimated it was possible to decide which measures that were necessary to implement to reach the targets. Each measure, found in appendix 5, might include more than one technique and can be either technical, structural or energy saving measures. The most cost-efficient measures for the society were chosen and their effect on the long-term targets were also considered as well as the total cost (Swedish Environmental Protection Agency, 2000). The sectors, who did the valuation themselves, have taken other sector targets into account as well as the environmental goals. This means that measures, which influence many sector targets at the same time might have been favoured.

The estimated costs can be both positive and negative. The reason is that both cost and benefits have been included in the valuation of the measures to receive the net present value. The valued benefits are the decreased costs for a sector due to implementation of a measure and not the positive effects on the environment, which have not been valued due to the lack of methodology. If the cost is negative the implementation of the measure leads to higher benefits than costs. According to the proposal, the marginal cost has been calculated, but according to Erika Budh (personal communication, 2001) the average cost in each group has been used. When the measures do not effect each other, which is basically the case in these cost curves, the marginal cost is the same as the average cost. To prevent misunderstanding the abbreviation unit cost is used instead of marginal cost. (In a few cases measures influence each other bur this has been considered in the emission levels and no measure is assumed to replace another measure.)

The calculations of cost curves carried out by the Committee are based on a reference scenario of the future use of energy made by the Swedish National Energy Administration. The basic assumptions for the scenario are (Miljömålskommittén, 2000):

European electricity market	Fully implemented by 2010
GDP	+1.9% per year
Industry production	+2.3% per year
Private consumption	+2.4% per year
Import price of petrol	-11% 1997-2010
Price bio fuel	Constant 1997-2010
Price electricity	-4 to –8% 1997-2010
Price district heating	Constant 1997-2010
Need of transport	Follows the industry production and private consumption
Energy intensity for transport	Decrease 7-12% between 1997-2010
Infrastructure	No major differences except already planned changes

As a lot of the abatement options influence more than one environmental objective and pollutant, the costs have been allocated between the four objectives Clean air, Natural acidification, No eutrophication, and Limited influence on climate. As the final goals are known, the effect of a measure can be related to its contribution to fulfil the goal. There are gaps between today's emissions of the four pollutants and the emission ceilings necessary to fulfil the goals. To allocate the costs by using the "gap-method" the part of the total cost of a measure allocated to NO_X for instance, depends on the effect on the gap for NO_X. The important thing is how the gaps are in comparison to each other, not the assumption about the absolute reduction needed. Sensitivity analyses show that the allocation of costs are not very sensitive when it comes to possible variations in the gaps (Miljömålskommittén, 2000). The theory and equations used can be found in appendix 3.

4. Empirical part

4.1 Cost curves calculated in RAINS

The cost curves, discussed in this chapter, are the ones used in the negotiations of the Gothenburg protocol and are created in RAINS. The curves have been updated since then and an improvement of the data is always in progress. The values are in 1990 year price-level. The cost curves for NO_X and SO_2 start with current legislation (CLE), which means that the total cost are positive from the beginning. All values are excluding international sea and air traffic.

The first three columns in NO_X and SO_2 show the combination of fuel, sector and technology and the abbreviation is found in appendix 4. The fourth column shows the emission that remains after the reduction, and the fifth shows the total cost in million Euro. In the last two columns the unit cost and the marginal cost for each abatement option are reported.

In every table the most effective measures, when it comes to total amount reduced NO_X or SO_2, are highlighted and they are described in each sector. A diagram, where the total cost and the marginal cost are plotted, follows each table.

The NO_X cost curve

According to the cost curves for NO_X in the RAINS model (Table 4), the less expensive measures are to be found in the conversion & industry sector, with emphasis on the combustion in the industry. The highlighted measures which reduce most in tons are:

OS2/IN_OC/ISFCM	Conversion and industry sector / Combustion modification (two different capacities are influenced);
MD/TRA_OT_LB/EUR3	Traffic sector / Euro III;
MD/TRA_OT_LB/EUR4	Traffic sector / Euro IV;
NOF/IN_PR/PRNOX2	Industrial process sector / Stage 2 control;
NOF/IN_PR/PRNOX3	Industrial process sector / Stage 3 control.

To reach the Gothenburg protocol of 148 000 tons (the marked line), measures are needed in most sectors. The cost to reach the target is estimated to 1069 million Euro per year. To fulfil the Swedish Committee's medium ambition of 125 000 tons 2010 is not possible according to this cost curve as the maximum feasible reduction, MFR, is 134 300 tons.

Table 4. Cost curve for NO_X according to IIASA. The marked line in the medium of the cost curve shows the target in the Gothenburg protocol.

FUEL_ABB	SEC_ABB	TECH_ABB	REMAIN	TOTAL	UNIT_C	MARG
			1000 ton	Mio Euro	Euro/t NOx	Euro/t NOx
			189.7	1 016.1	0.0	0.0
HC1	CON_COMB	ISFCM	189.5	1 016.1	215.7	215.7
HC1	CON_COMB	ISFCM	189.4	1 016.2	215.7	215.7
HC1	IN_OC	ISFCM	189.3	1 016.2	215.7	215.7
HC1	IN_OC	ISFCM	189.1	1 016.2	215.7	215.7
HF	IN_OC	IOGCM	188.6	1 016.4	262.5	262.5
HF	IN_OC	IOGCM	188.0	1 016.5	262.5	262.5
HF	CON_COMB	IOGCM	188.0	1 016.5	262.5	262.5
HF	CON_COMB	IOGCM	188.0	1 016.5	262.5	262.5
MD	TRA_OTS_L	STLCM	186.4	1 017.1	350.1	350.1
OS2	IN_OC	ISFCM	181.6	1 018.9	388.2	388.2
OS1	IN_OC	ISFCM	180.2	1 019.5	388.2	388.2
OS2	IN_OC	ISFCM	175.4	1 021.3	388.2	388.2
OS1	IN_OC	ISFCM	173.9	1 021.9	388.2	388.2
OS1	PP_EX_OTH	PHCCM	172.9	1 022.3	391.5	391.5
MD	TRA_OTS_M	STMCM	171.4	1 023.1	484.9	484.9
MD	IN_OC	IOGCM	171.0	1 023.3	567.5	567.5
LF	PP_EX_OTH	POGCM	171.0	1 023.3	600.2	600.2
MD	TRA_OTS_L	STLSCR	169.0	1 024.5	493.9	609.0
GAS	IN_OC	IOGCM	169.0	1 024.5	648.5	648.5
LF	IN_OC	IOGCM	168.8	1 024.6	648.5	648.5
GAS	IN_OC	IOGCM	168.8	1 024.6	648.5	648.5
LF	IN_OC	IOGCM	168.6	1 024.7	648.5	648.5
HF	TRA_OT_LB	DHFCM	168.5	1 024.8	804.9	804.9
HF	TRA_OT_LB	DHFCM	168.4	1 024.9	804.9	804.9
NOF	IN_PR	PRNOX1	166.9	1 026.4	1 000.0	1 000.0
MD	TRA_OT_LB	EUR2	165.9	1 027.6	1 103.8	1 103.8
MD	TRA_OT_LB	EUR3	162.6	1 032.2	1 192.0	1 412.2
MD	TRA_OT_LB	EUR4	159.5	1 037.5	1 344.9	1 719.8
HC1	CON_COMB	ISFCSN	159.3	1 038.0	737.8	2 043.2
HC1	IN_OC	ISFCSN	159.0	1 038.6	737.8	2 043.2
HC1	CON_COMB	ISFCSN	158.7	1 039.1	737.8	2 043.2
HC1	IN_OC	ISFCSN	158.4	1 039.7	737.8	2 043.2
HF	CON_COMB	IOGCSN	158.4	1 039.7	818.5	2 208.4
HF	CON_COMB	IOGCSN	158.4	1 039.8	818.5	2 208.4
BC1	PP_NEW	PBCSCR	157.2	1 042.5	2 222.9	2 222.9
BC1	PP_NEW	PBCSCR	156.0	1 045.1	2 222.9	2 222.9
HC1	PP_EX_OTH	PHCCSC	155.3	1 046.6	943.1	2 344.6
GAS	DOM	DGCCOM	155.3	1 046.7	2 581.0	2 581.0
GAS	DOM	DGCCOM	155.2	1 046.9	2 581.0	2 581.0
HF	IN_OC	ISFCSN	154.7	1 048.4	963.8	2 717.1
HF	IN_OC	ISFCSN	154.1	1 050.0	963.8	2 717.1
HF	PP_NEW	POGSCR	153.8	1 050.9	2 727.5	2 727.5
HF	PP_NEW	POGSCR	153.4	1 051.8	2 727.5	2 727.5
LF	TRA_OT_LB	LFCC2	151.8	1 056.4	2 873.1	2 873.1
OS2	IN_OC	ISFCSN	149.9	1 062.9	1 251.7	3 410.6
OS2	IN_OC	ISFCSN	148.0	1 069.4	1 251.7	3 410.6
HF	IN_OC	IOGCSC	147.8	1 070.2	1 296.3	3 623.3
HF	IN_OC	IOGCSC	147.6	1 071.0	1 296.3	3 623.3
HF	CON_COMB	IOGCSC	147.6	1 071.0	1 296.3	4 640.6
HF	CON_COMB	IOGCSC	147.6	1 071.1	1 296.3	4 640.6
MD	DOM	DMDCCO	146.8	1 074.7	4 731.7	4 731.7
LF	DOM	DMDCCO	146.8	1 074.8	4 731.7	4 731.7
LF	DOM	DMDCCO	146.8	1 074.8	4 731.7	4 731.7
GAS	IN_OC	IOGCSN	146.7	1 075.2	1 878.8	4 954.5
GAS	IN_OC	IOGCSN	146.6	1 075.5	1 878.8	4 954.5
HC1	CON_COMB	ISFCSC	146.5	1 076.1	1 446.1	6 403.7
HC1	CON_COMB	ISFCSC	146.4	1 076.7	1 446.1	6 403.7
HC1	IN_OC	ISFCSC	146.3	1 077.5	1 446.1	6 403.7
HC1	IN_OC	ISFCSC	146.2	1 078.3	1 446.1	6 403.7
NOF	IN_PR	PRNOX2	142.5	1 104.0	3 000.0	7 000.0
BC1	PP_EX_OTH	PBCCSC	141.3	1 113.3	1 604.2	7 672.6
MD	DOM	DMDCCR	140.1	1 124.3	7 570.8	9 463.5
LF	DOM	DMDCCR	140.1	1 124.4	7 570.8	9 463.5
LF	DOM	DMDCCR	140.1	1 124.6	7 570.8	9 463.5
NOF	IN_PR	PRNOX3	136.4	1 165.0	5 000.0	11 000.0
GAS	DOM	DGCCR	136.4	1 165.5	7 381.5	11 153.4
GAS	DOM	DGCCR	136.3	1 166.4	7 381.5	11 153.4
OS2	IN_OC	ISFCSC	135.6	1 175.4	2 566.3	11 768.2
OS2	IN_OC	ISFCSC	134.8	1 184.4	2 566.3	11 768.2
GAS	IN_OC	IOGCSC	134.8	1 184.7	3 141.0	11 976.1
GAS	IN_OC	IOGCSC	134.7	1 185.1	3 141.0	11 976.1
LF	TRA_OT_LB	LFCC4	134.6	1 187.4	3 936.7	13 710.5
GAS	PP_EX_OTH	POGCSC	134.4	1 189.2	3 054.9	15 079.2
HF	PP_EX_OTH	POGCSC	134.3	1 191.4	3 227.3	15 395.4

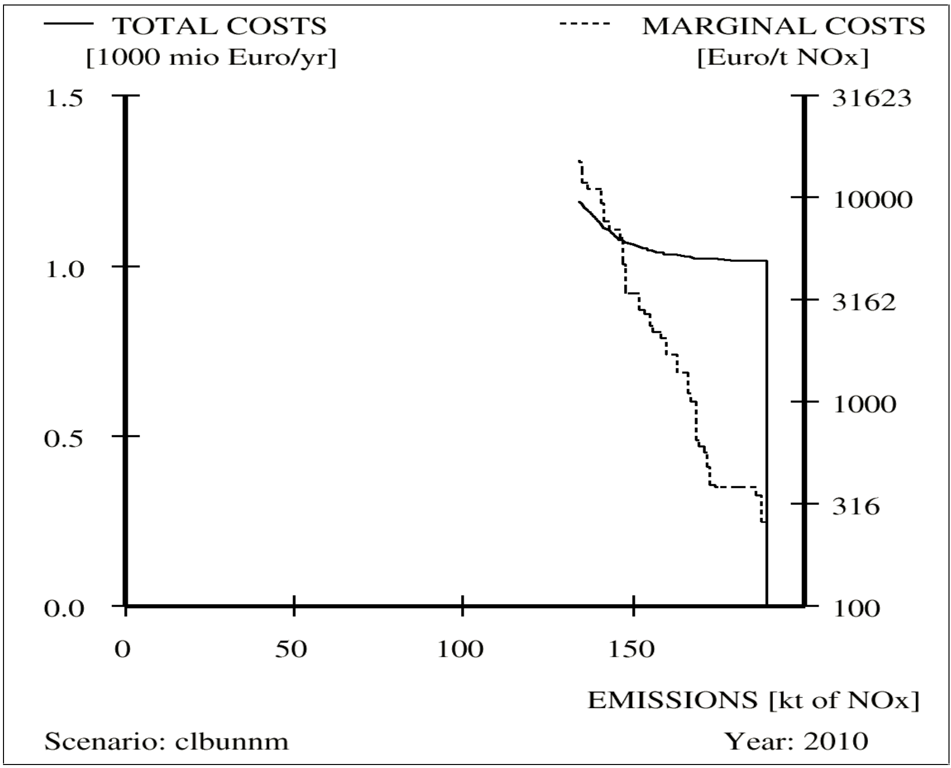

Figure 6. Total and marginal cost for NO_X according to IIASA.

The SO_2 cost curve

The cost curve for SO_2 implies that almost all possible measures are in the conversion & industry sector and a few in the power plant sector. Most of the measures do reduce approximately the same amount of SO_2 but the following four reduce the most:

HC1/CON_COMB/IWFGD	Conversion and industry / Industry wet flue gas desulfurization;
OS2/IN_OC/LINJ	Conversion and industry / Limestone injection;
MD/DOM/LSMD2	Household / Low sulphur diesel oil stage 2;
OS2/IN_OC/IWFGD	Conversion and industry / Industry wet flue gas desulfurization.

Sweden has in the Gothenburg protocol promised not to emit more than 67 000 tons SO_2 in 2010. This level is assumed to be reached with today's legislation and reduction plan and therefore it is not necessary to implement any of the measures in the cost curve. To reach the Swedish target of 47 000 tons all the measures have to be implemented but it will still not be enough as the MFR is 53 200 tons.

Table 5. Cost curve for SO_2 according to IIASA.

FUEL_ABB	SEC_ABB	TECH_ABB	REMAIN 1000 ton	TOTAL Mio Euro	Unit_c Euro/t NOx	MARG Euro/t NOx
			66.6	316.3	0.0	0.0
HC1	CON_COMB	LSCO	66.1	316.5	424.5	424.5
HF	CON_COMB	IWFGD	66.1	316.6	623.5	1 367.8
HF	CON_COMB	IWFGD	66.0	316.6	623.5	1 367.8
HF	IN_OC	IWFGD	65.0	318.1	641.9	1 415.9
HF	IN_OC	IWFGD	64.0	319.5	641.9	1 415.9
HC1	CON_COMB	IWFGD	63.4	320.5	1 148.7	1 615.2
HC1	IN_OC	IWFGD	62.6	321.8	1 148.7	1 615.2
HC1	IN_OC	IWFGD	61.8	323.1	1 148.7	1 615.2
HC1	CON_COMB	IWFGD	60.7	324.8	1 148.7	1 615.2
HC1	CON_COMB	LINJ	60.6	325.0	1 117.8	2 511.9
HC1	IN_OC	LINJ	60.5	325.2	1 117.8	2 511.9
HC1	IN_OC	LINJ	60.4	325.5	1 117.8	2 511.9
HC1	CON_COMB	LINJ	60.4	325.7	1 117.8	2 511.9
OS2	IN_OC	LINJ	58.7	332.5	4 113.2	4 113.2
OS2	IN_OC	LINJ	58.7	332.6	4 113.2	4 113.2
MD	DOM	LSMD2	55.9	344.7	3 201.1	4 331.4
MD	IN_OC	LSMD2	55.6	345.8	3 201.1	4 331.4
OS2	IN_OC	IWFGD	54.0	359.0	5 326.8	8 239.4
HC1	PP_NEW	RFGD	53.9	362.5	1 264.3	22 585.5
BC1	PP_NEW	RFGD	53.7	370.7	2 676.5	49 277.2
HF	PP_NEW	RFGD	53.2	396.6	2 760.5	51 014.2

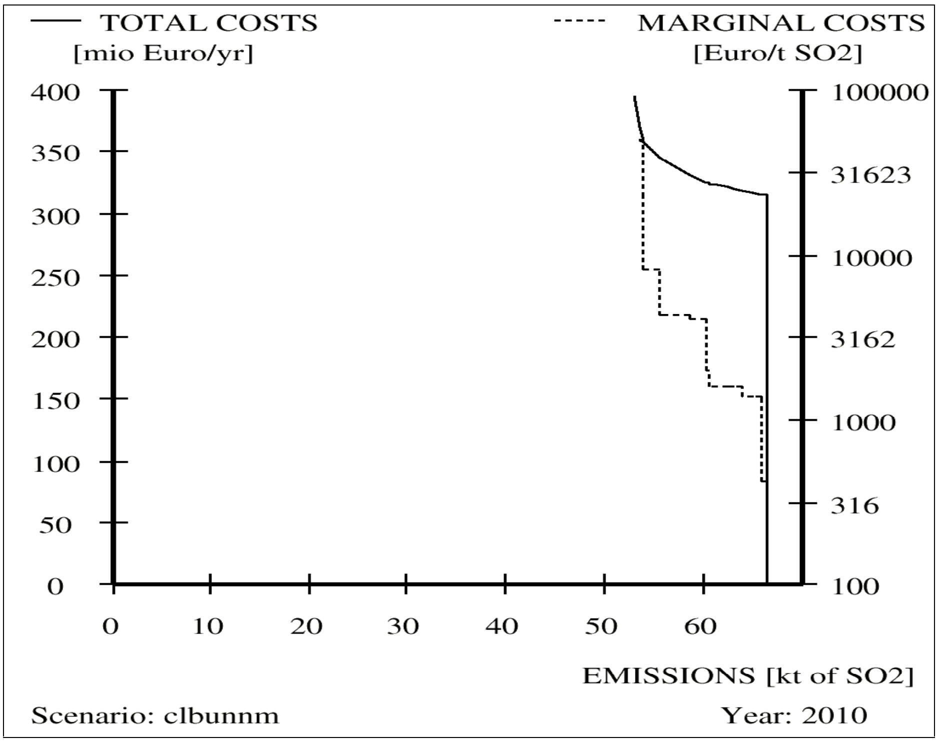

Figure 7. Total and marginal costs for SO_2 according to IIASA.

4.2 Cost curves calculated by the Parliament Committee on Environmental Objectives

The Parliament Committee on Environmental Objectives has calculated the cost curves in today's price level and in Swedish currency. To enable a comparison with the cost curves calculated in the RAINS model the costs have been discounted to the 1990 years price level and into Euro. The prices used by the Committee are from 1995 to 1998, and the producer price index (PPI) has been used to convert them into the price level of 1990. The mean value of PPI for 1995-98 has been used, which was approximately 119 (1990 = 100). The exchange rate used was 1 Euro = 8.942 SEK.

The cost curves start with the estimated emissions for 2010 according to the BAU scenario and are excluding international sea and air traffic. In principle the international sea and air traffic should be included, but as hardly any measures including in the strategies influence these emissions they have been excluded. This facilitate a comparison with the calculations in RAINS. Only the measures, which have been possible to put a monetary value on and where the emission reduction has been estimated, are included in the following cost curves. The negative costs in the cost curves indicate that the benefits (in terms of lower costs for the sectors) are higher than the costs. The cost curves are created for the medium ambition, as the choice of measures depend on the target.

The ranking of the measures are very similar for all the pollutants. Measures within the domestic & facilities sector as well as the transport sector are mostly found in the beginning of the cost curves. Measures in the off-road machinery and industry sectors are generally found at the end of the cost curves due to their higher unit costs.

The different measures can be separated into the following groups:

1-20	Transport
21-30	Off-road machinery
40-59	Domestic & facilities
60-69	District heating sector
80-	Industry

The measures, which reduce most tons of pollution, are highlighted in the tables and described in the text. All the measures are included in the medium ambition. Complete abbreviation for all the measures can be found in appendix 5, but detailed information about the different techniques included in each measure has not been possible to receive.

NO_X

Most of the control measures listed in the Committee’s report influence the emission of NO_X. Much can be done in the domestic & facilities and transport sector for zero or negative cost. The Gothenburg protocol is assumed to be fulfilled without any further measures. To reach the medium ambition of 125 000 tons in 2010, excluding international sea and air traffic, the measures above the line in Table 6 need to be implemented. The cost for this is estimated to approximately 7 million Euro. The reduction of NO_X, which is due to energy saving measures and structural changes basically in the transport sector, is approximately 5000 tons of the 21 000 tons required to reach the target. These measures stands for about 60% of the 35 suggested measures.

The most effective measures, needed to reach the target and when it comes to amount of tons reduced, are:

22	Prematurely introduction of more stringent legislation on off-road machinery 2006;
21	Introduction of more stringent legislation on off-road machinery 2008;
12	Prematurely introduction of 2005/2006 exhaust legislation on heavy vehicles;
83	Reduction of NO_X within the cement industry.

Table 6. The NO_X cost curve based on the Committee's calculations (excluding international sea and air traffic).

Measure	Remain 1000 ton	Total Mio Euro	UNIT_C Euro/ t NOx
46	145.7	-0.8	-12347
49	145.3	-7.3	-12117
47	145.2	-7.9	-6509
43	145.2	-8.3	-5365
48	144.9	-9.9	-4372
81	144.8	-10.3	-3590
50	144.7	-10.5	-3546
45	144.7	-10.6	-2976
42	144.6	-10.8	-2518
44	144.6	-10.9	-932
56	144.5	-11.0	-701
80	144.2	-11.1	-326
1	143.2	-11.1	0
2	142.9	-11.1	0
3	142.7	-11.1	0
4	142.6	-11.1	0
5	142.6	-11.1	0
6	142.5	-11.1	0
7	142.5	-11.1	0
8	142.4	-11.1	0
10	142.1	-11.1	0
63	142.0	-11.1	0
66	141.9	-11.1	0
18	141.0	-11.1	0
52	141.0	-11.1	117
53	141.1	-11.1	431
61	141.0	-10.9	758
108	140.9	-10.9	939
22	134.8	-4.5	1038
21	131.7	-0.9	1155
12	129.2	2.2	1255
84	128.3	3.4	1356
92	128.1	3.7	1408
83	126.2	6.5	1482
87	126.0	6.9	1878
15	122.5	13.4	1878
62	122.2	13.9	2025
11	121.8	14.9	2126
13	121.5	15.6	2774
93	121.4	15.9	3004
89	121.2	16.8	4224
26	121.2	16.8	4300
98	120.7	19.1	4694
90	118.3	31.6	5202
64	117.1	38.4	5633
82	117.1	38.7	5633
99	116.3	43.8	6454
103	115.1	51.8	6650
110	114.6	55.1	7468
86	110.0	92.7	8167
25	91.0	281.3	9925
23	89.3	300.4	11247
111	89.3	301.8	18776
28	89.2	302.8	25915
14	88.9	316.4	51562

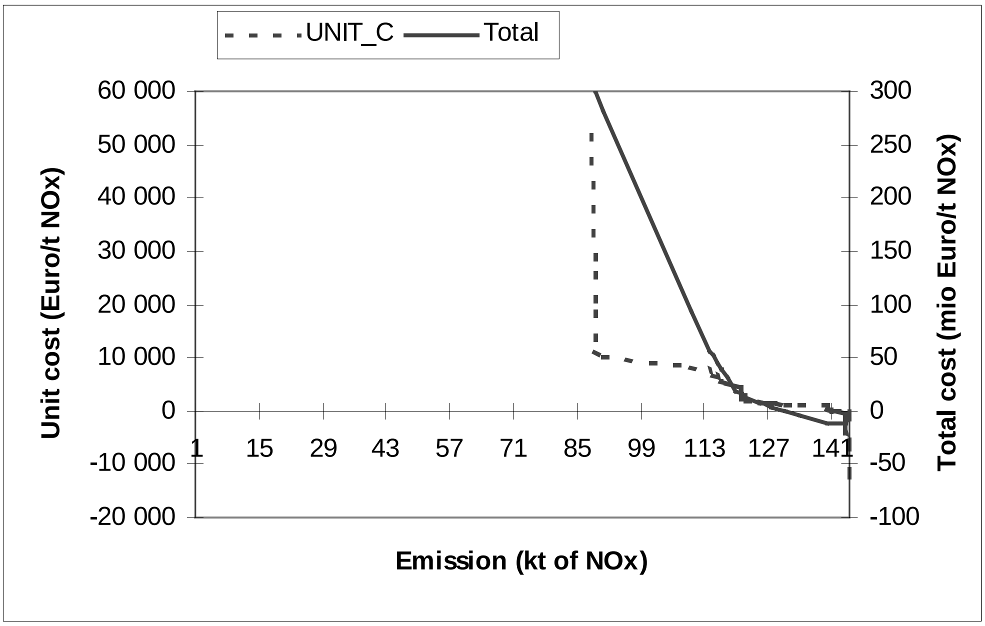

Figure 8. Total and unit cost for the reduction of NO_X according to the Committee.

SO_2

The cost curve for SO_2 also shows that the domestic & facilities and traffic sectors have the less expensive measures. Only a few measures are to be implemented in the industry and off-road machinery sectors due to the reduction of SO_2. To reach the level of 57 000 tons, requested in the Gothenburg protocol, non of the measures need to be implemented. To reach the Swedish target of 47 000 tons, excluding international sea and air traffic, about half of the measures ought to be implemented. All these measures have either a negative or zero cost, which means that the society receives an economical profit of approximately 83 million Euro 2010, by the proposed reductions.

Almost all of the measures, which are needed to reach the medium ambition, are energy saving or structural changing measures. The once which reduce most SO_2 are:

49	More efficient management of properties;
48	Isolation of facades;
81	More efficient use of energy in ancillary systems of the industry;
80	Process related energy saving;
66	Decreased domestic heating temperature.

Table 7. The SO_2 cost curve based on the Committee's calculations (excluding international sea and air traffic).

Measure	Remain 1000 ton	Total Mio Euro	UNIT_C Euro/ t SO2
46	49.2	-5.8	-128 407
49	48.9	-51.1	-126 018
47	48.8	-55.4	-67 690
43	48.8	-58.3	-55 799
48	48.6	-69.2	-45 472
81	48.4	-76.7	-37 341
50	48.4	-78.0	-36 884
45	48.3	-78.9	-30 948
42	48.3	-80.6	-26 183
44	48.2	-81.3	-9 695
56	48.2	-81.6	-7 292
80	47.9	-82.7	-3 387
1	47.9	-82.7	0
2	47.9	-82.7	0
3	47.9	-82.7	0
5	47.9	-82.7	0
6	47.9	-82.7	0
8	47.9	-82.7	0
10	47.8	-82.7	0
63	47.8	-82.7	0
66	47.6	-82.7	0
102	46.7	-81.9	939
60	46.5	-81.7	1 056
54	46.3	-81.1	2 841
88	42.1	-68.2	3 015
104	41.3	-65.2	3 755
91	40.8	-63.1	4 318
53	40.7	-62.5	4 478
65	40.0	-58.3	6 087
120	38.4	-47.0	7 041
61	37.1	-37.3	7 887
51	33.9	17.6	16 898
62	33.5	26.5	21 060
55	33.4	28.4	25 630
25	33.4	28.5	103 224

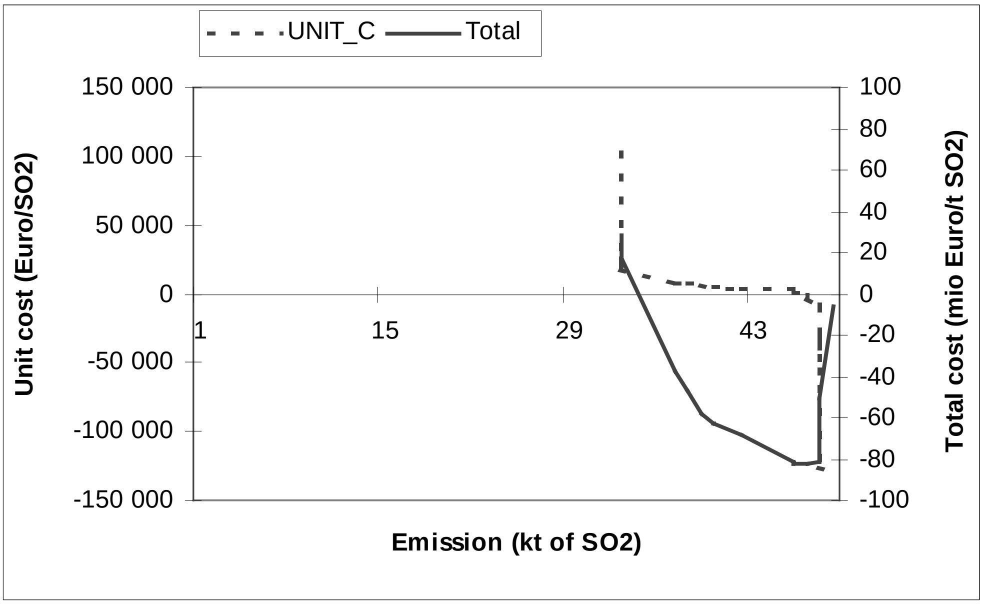

Figure 9. Total and unit cost for the reduction of SO_2 according to the Committee.

VOC

The VOC cost curve also implies a reduction in the domestic & facilities and traffic sectors. To reach the Gothenburg protocol of 241 000 tons quite a few measures need to be implemented (the highest marked line in Table8). The Swedish target of 214 500 tons, excluding international sea and air traffic, requires even more measures (the lowest marked line in Table 8). The measures highlighted are:

100	VOC cleaning refineries;
54	Installation of accumulator tank for wood boilers;
105	Collection of non condensable gases, pulp and paper;
96	VOC-cleaning, wood industry;
29	More stringent legislation on snowmobiles from 2003;
55	Forced exchange on older wood boilers.

Table 8. The VOC cost curve based on the Committee's calculations (excluding international sea and air traffic).

Measure	Remain 1000 ton	Total Mio Euro	UNIT_C Euro/ t VOC
46	275.2	-0.1	-8448
49	275.1	-0.7	-8291
47	275.1	-0.8	-4453
43	275.1	-0.8	-3671
48	275.1	-1.0	-2992
81	275.0	-1.0	-2457
50	275.0	-1.1	-2427
45	275.0	-1.1	-2036
42	275.0	-1.2	-1723
44	275.0	-1.2	-638
56	275.0	-1.2	-480
1	274.9	-1.2	0
2	274.9	-1.2	0
3	274.8	-1.2	0
4	274.8	-1.2	0
5	274.7	-1.2	0
6	274.7	-1.2	0
7	274.6	-1.2	0
8	274.6	-1.2	0
10	274.5	-1.2	0
63	274.5	-1.2	0
66	274.5	-1.2	0
18	274.4	-1.2	0
100	272.4	-1.2	1
54	232.4	6.3	187
53	232.4	6.3	295
105	227.4	8.9	516
61	227.5	8.9	519
22	226.9	9.3	710
21	226.6	9.5	790
12	226.5	9.5	859
96	223.5	12.3	939
29	218.3	17.6	1008
11	217.9	18.2	1455
55	205.4	39.3	1686
106	201.4	46.8	1878
94	200.3	49.0	1963
97	199.4	50.8	2086
15	199.4	51.0	2816
26	198.6	53.2	2942
109	198.4	54.2	4694
101	198.4	54.2	5867
25	194.2	82.7	6791
95	193.4	88.4	7041
23	188.7	124.5	7695
107	188.5	126.9	11735
24	183.7	193.5	13874
27	182.4	214.1	16530
28	181.4	231.9	17731

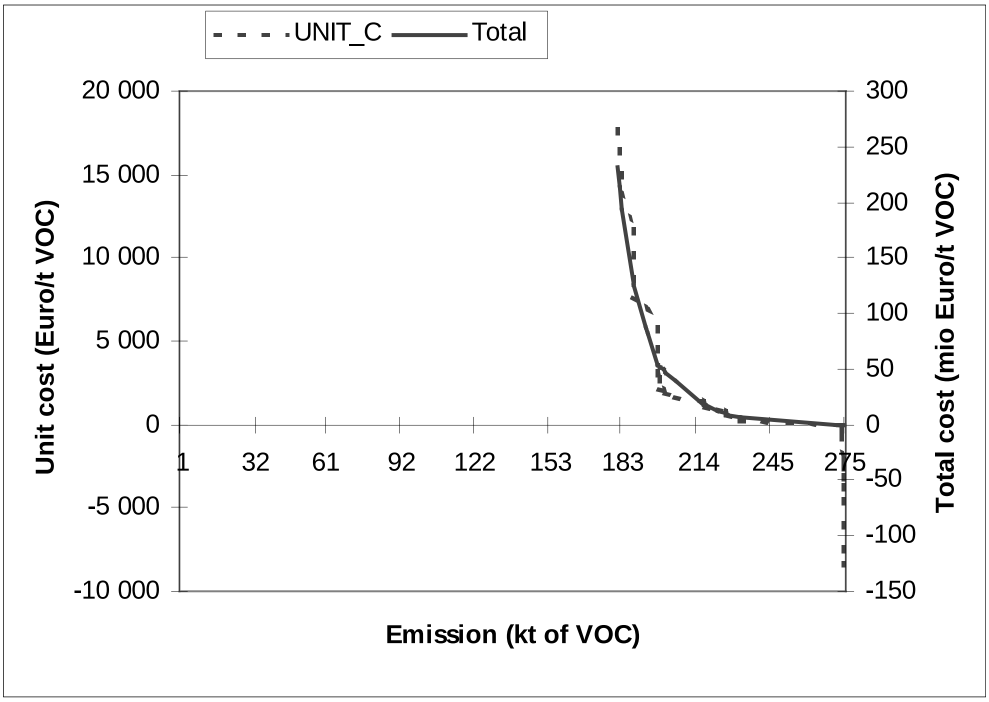

Figure 10. Total and unit cost for the reduction of VOC according to the Committee.

5. Analysis and discussion

5.1 Two different structures

The objective with the cost calculations, in RAINS and in the proposal from The Parliament Committee on Environmental Objectives, is to find the most cost-efficient solutions to decrease emissions. As the initial positions for the calculations are not the same the problem has been solved differently. RAINS only deals with four pollutants and the goal is to provide the optimal solution for the countries involved in the CLRTAP. The Committee has a different starting point. The proposal only takes emission in Sweden into consideration and in opposition to RAINS the Committee needs to fulfil 15 environmental objectives in an optimal way - four of them are influenced by the same pollutants as are discussed in RAINS. The fact that the cost curves are calculated in two complete different ways and that they do not include the same kinds of measures leads to different results when it comes to reduction costs and reduction possibilities.

In RAINS specific technologies are ranked according to their costs and the main objective is not to inform the countries exactly which measures to implement, but to provide them with an estimated cost to reach required levels of emissions. The Swedish calculations are also supposed to be used as rough estimations and is a first attempt to do this kind of total cost estimations. The Committee does not, however, restrict itself to single techniques, but use a much wider approach and include energy saving measures as well as structural changes (basically in the transport sector), such as replace transport of people by using IT (7) and process related energy savings (80). Each measure might include a lot of different techniques. Some of the measures, though, are more precise such as trimming of oil fired boilers 60-1000kW (43) and energy efficient windows (46).

Another difference is how the cost curves are constructed when it comes to the unit and marginal cost. In RAINS the measures are ranked according to their marginal costs and only one technology can be used for the same capacity. This means that not all measures in the cost curve ought to be implemented – only the last one in each fuel and sector combination. According to the Swedish proposal the marginal cost has been calculated, but in this report the costs have been called unit cost. The reason is that the average cost in each group has been used and the measures do not effect each other, which means that the average cost and the marginal cost are the same. (In those cases they actually influence each other, the reduction has been reduced with 20%). To reach a certain level of emissions all measures mentioned in the cost curve before that level need to be implemented.

A third essential difference in the calculations is the allocation of costs. In RAINS no allocation has been used as the techniques are not assumed to reduce more than one pollutant each. An exception is some NO_X-measures in the traffic sector, which also reduce VOC. This problem has been solved by using a direct relationship between NO_X and VOC, which implies that a certain amount of NO_X reduction will lead to a certain amount of VOC reduction. The total cost, though, is allocated to the NO_X reduction. In the Swedish approach the cost for each measure has been allocated between different pollutants in relation to the reduction of the gap, which is described in more detail in appendix 4. This leads to a lower cost for the measures in the separate cost curves.

Both approaches are supposed to provide the most cost-efficient solution. In RAINS this is fulfilled by only including cost-efficient techniques and rank them. A cost-efficient technology removes a certain amount of emission to the lowest cost. In RAINS all measures have been assigned positive values and possible decrease of costs for the ones who implement the measures have not been taken into account. The Committee uses the cost-efficient term in a different way. They also rank the measures in accordance to their costs but they also take the lower costs due to the implementations into account and use the net value as the cost. This method makes the measures less expensive and in many cases zero or even negative. This does, of course, influence the total cost for all pollutants.

The measures in both approaches are separated into different sectors. RAINS has quite a few sectors and the capacity is also separated into different kinds of fuels used. The Committee only separate the measures into five sectors. As the measures in most cases include more than one technology and influence many pollutants the measures can often be found in the cost curves created for all pollutants.

5.2 Different ranking

The differences in the methodologies and uncertainties in the background data make a direct comparison of the ranking of the measures more or less impossible. RAINS starts from a higher emission level than the Committee and only takes technical measures into account. The Committee's use of energy conservation methods and structural changes, makes a major difference in the ranking. It is interesting to notice that all the 'non-technical measures' are in the beginning of the cost curves as they are the least expensive to implement, which is due to the valuation of benefits in terms of lower costs. There are many of these kinds of measures in number (60% of the NO_X measures to reach the goal) but they have a limited effect compared to the other measures (only 24% of the NO_X reduction in tons). The rest of the cost curves (after the targets) do not include any 'non-technical measure'.

RAINS uses different technologies for different pollutants and the technologies are not assumed to influence each other, which make the measures in the cost curves for the pollutants complete different. Due to the group of technologies used by the Committee and to the allocation of costs, the ranking of the measures is almost identical for NO_X, SO_2 and VOC in the Swedish proposal. (According to Erika Budh (personal communication, 2001), who carried out the computer calculations, the program did not optimise the measures to receive a similar result. There might, though, have been some kind of auto correlation.)

A comparison between the sectors for NO_X and SO_2 implies that the most cost-efficient and cheapest measures in RAINS are found in the conversion & industry sector and some in the power plant and traffic sectors. The cost curves created by the Committee implies that the less expensive measures are found in the domestic & facilities sector and in the transport sector, which is due to the use of 'non-technical measures' in the Swedish proposal.

5.3 How the total costs differ

It is difficult to compare the total costs as the Committee uses negative costs and when different emission levels have been used as starting points. RAINS uses CLE and the Committee the BAU scenario, as base scenario. Both are supposed to reflect the situation in 2010 and to take measures already decided into account, but the initial emissions differ considerable. It is essential to notice that the major differences in the costs also have another very important reason. The total costs in the cost curves created for SO_2 and NO_X in RAINS, do not start from zero, but from the estimated cost to reach the starting point (CLE). In other words, the model estimates how much the measures already implemented, cost each year and not only the additional measures, which is the case in the Swedish approach. To make the costs more comparable the starting cost has to be submitted from total cost in the RAINS' cost curves.

According to the Committee the target of the Gothenburg protocol will be reached without further regulations for NO_X and SO_2, while RAINS estimate the reduction costs to 53 million Euro for NO_X (1069-1016=53) but zero for SO_2. To reach the medium ambition for NO_X of 125 000 tons, is according to RAINS, not possible as the MFR is 134 000 tons. The Committee estimates that the costs to reach the target of 125 000 tons would cost 7 million Euro and to reach 134 000 would cost –4.5 million Euro. The cost to reach MFR in RAINS is estimated to 175 million Euro (1191-1016=175). Neither is the SO_2 medium ambition possible to reach, according to RAINS, as the MFR is 53 000 tons and costs 81 million Euro per year (397-316=81). The Committee estimates a negative cost (or benefit) to reach the required level, to approximately 83 million Euro.

The average cost to reach the MFR for NO_X is according to RAINS 3125 Euro/ton. The Committee estimates the same cost to –375 Euro/ton.

6. Conclusions

The RAINS model and the Swedish approach suggest, as expected, different solutions to solve the problem with air pollution. The reason is the use of different methodologies and initial positions. But even if the methodologies are not the same and the data used in many calculations are uncertain and defective some conclusions can be drawn from the study.

Both the methods have their strengths and weaknesses. RAINS' strength is its possibilities to compare measures and costs in different countries and by using this information being able to estimate the most cost-efficient solutions for Europe. One important weakness is that the model to a large extent relies on national data deliveries, and complete and consistent data is not always available. The fact that RAINS only takes technical measures into account and ignores structural changes and energy conservation measures due to lack of methodology, is another shortcoming, which leads to over-estimation of the reduction costs and makes it impossible to reach very low emission levels. This is evident in the NO_X and SO_2 cost curves, in which maximum feasible reductions are higher than the Swedish medium ambition targets. It is, with other words, not possible to reach the goals according to RAINS.

The advantages with the method used by the Committee are its comprehensive view of the environmental problems and the use of negative costs, which gives a more realistic value of the costs. It is important to make clear the benefits of the options to the country, as this will increase the possibility that the measures will be implemented and lower emission ceilings will be accepted. The comprise of structural changes and energy saving measures is also a major advantage as the emission levels can decrease further and to a lower cost. The energy saving measures stand for 24% of the suggested NO_X reduction in tons, but for 60% in number. The weaknesses are the lack of methods to value the effects correctly and the lack of accessibility to complete data in all sectors. The Committee, therefore, had to restrict itself to the measures which could be assigned a monetary value and where data were available.

Due to the differences, the results from the cost calculations in Sweden can not be used as input in the RAINS model. The Committee's mode of procedure to 'negative costs', including 'non-technical measures', and trying to find solutions for many targets at the same time gives a more comprehensive picture. The difficulty to do this internationally is self-explanatory since there is no internationally accepted method to handle 'non-technical measures' nor is there any agreement how to value benefits in terms of energy savings etc. (or valuation of environmental improvements). It also requires more information from all countries involved. A first step could be to include other kinds of measures, such as energy conservation methods and structural changes, to make it possible to reach lower emission levels to low cost in the review of the Gothenburg protocol 2004-2005.

During this study the lack of documentation of the RAINS model has been obvious, which made the understanding of the methodology very time-consuming, especially regarding the creation of cost curves for the different pollutants. It is important that the information become easier to access and to understand as this will increase the countries confidence in the model. Also the documentation of the Committee's approach has been defective and the information about the cost curve calculations has to a large extent been received through personal communication with the creators of the curves. The lack of background data has forced them to do a lot of assumptions and it is important for the future work to improve the input data from the sectors. Cost-effectiveness will be even more important when the low-cost options for abating emissions are adopted and more costly actions have to be implemented.

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Appendix 1

Stationary sources

Investment

An investment function aggregates the expenditure accumulated until the start-up of an installation. The coefficients ci are given separately for three capacity classes: less than $20MW_{th}$, from 20 to 300 MW_{th} and above 300 MW_{th}.

$$I = (ci_1^{\ f} + \frac{ci_1^{\ v}}{bs}) + (ci_2^{\ f} + \frac{ci_2^{\ v}}{bs}) * (1 + r) + \lambda^{cat} * ci^{cat}$$

I	investment [ECU/kW_{th}]
ci_1^f, ci_2^f	coefficients of investment function; ci_1^f has non-zero values only for combinations of technologies (e.g. CM plus SCR) [ECU/kW_{th}]
ci_1^v, ci_2^v	coefficients of investment function; ci_1^v has non-zero values only for combinations of technologies [10^3 ECU]
bs	boiler size [MW_{th}]
λ^{cat}	catalyst volume per unit of installed capacity [m^3/MW_{th}]
ci^{cat}	unit cost of catalyst [ECU/m^3]
r	retrofit cost factor if installed on an existing plant, e.g. 0.5

To be able to calculate the cost per year, the investments are annualised over the technical lifetime of each control option.

$$I^{an} = I * \frac{(1+q)^{lt} * q}{(1+q)^{lt} - 1}$$

I^{an}	annual investment [ECU/kW_{th}/year]
q	real interest rate [%/100]
lt	technical lifetime of the plant [year]

Fixed operating costs

The annual costs for maintenance and administrative overheads are calculated in the following equation.

$$OM^{fix} = I * f$$

OM^{fix}	fixed expenditures [ECU/kW_{th}/year]
f	standard percentage [%/100]

Variable operating costs

Costs related to the operation of the control option, such as additional electricity and sorbent material demand, are included in OM^{var}

$$OM^{var} = \lambda^e c^e + ef * \eta * \lambda^s * c^s$$

OM^{var}	variable operating costs [ECU/PJ]
λ^e	additional electricity demand [GWh/PJ fule input]
c^e	energy price [ECU/kWh]
ef	unabated NO_X emission factor [tons NO_X/PJ]
η	removal efficiency of control technology [%/100]
λ^s	sorbent material [ton/ton NO_X]
c^s	sorbent price [ECU/ton]

If a catalyst is used the costs for replacing the catalyst must be included.

$$OM^{cat} = (pf / lt^{cat}) * (\lambda^{cat} ci^{cat}) / pf$$

OM^{cat}	periodical replacement cost for catalyst [ECU/PJ]
pf	capacity utilisation [hours/year]
lt^{cat}	lifetime of catalyst [hours]
λ^{cat}	catalyst volume [m^3/MW_{th}]
ci^{cat}	catalyst cost [ECU/m^3]

Unit cost

To calculate the unit cost per PJ all expenditures of a control option are related to one unit of fuel input (in PJ). The costs related to the investment are converted to fuel input by applying the capacity utilisation factor pf (operating hours/year).

$$C_{PJ} = \frac{I^{an} + OM^{fix}}{pf} + OM^{var} + OM^{cat}$$

C_{PJ}	cost per unit of energy input [ECU/PJ]

To evaluate the cost efficiency of different control options the abatement costs are related to reduced NO_X emissions.

$$C_{NO_X} = \frac{C_{PJ}}{noxX}$$

C_{NOx}	cost per unit of NO_X reduced [ECU/ton NO_X]
noxX	NO_X removed [NO_X/PJ]

Marginal cost

To be able to rank the available abatement options according to their cost-effectiveness, marginal cost is calculated. Marginal cost is the cost to remove the last unit of emission for each technique. It relates the extra cost for an additional measure to the marginal abatement of that measure given a comparison with a less effective option.

$$mc_m = \frac{c_m \eta_m - c_{m-1}\eta_{m-1}}{\eta_m - \eta_{m-1}}$$

mc_m	marginal cost technique m [ECU/ton NO_X]
c_m	unit cost technique m [ECU/ton NO_X]
η_m	removal efficiency technique m [%/100]
c_{m-1}	unit cost technique m-1 [ECU/ton NO_X]
η_{m-1}	removal efficiency technique m-1 [%/100]

Mobile sources

The cost calculation for mobile sources is similar to the stationary cost calculation but with some modification for structural differences, for instance, the investment costs are given per vehicle and not per MW capacity.

Investment

The investment (I) is the additional investment cost of applying control device to a vehicle and is different for each technology and vehicle catagory. The investment is annualised by using the following equation.

$$I^{an} = I * \frac{(1+q)^{lt} * q}{(1+q)^{lt} - 1}$$

I^{an}	annual investment [ECU/vehicle/year]
I	investment [ECU/vehicle]
q	real interest rate [%/100]
lt	technical lifetime of the control equipment [year]

Increase in maintenance costs

$$OM^{fix} = I * f$$

OM^{fix}	fixed expenditures [ECU/vehicle]
f	standard percentage [%/100]

Variable operating costs

Inclusion of emission controls leads to cost for additional fuel consumption.

$$OM^{e}(t) = \lambda^{e} * fuel(t) * c^{e}$$

OM^e	cost of additional fuel consumption [ECU/vehicle]
λ^e	percentage change in fuel consumption [%/100]
fuel (t)	fuel use per vehicle in time step t [GJ/vehicle]
c^e	fuel price net of taxes [ECU/GJ]

Annual fuel consumption per vehicle is a function of the consumption in the base year (t_0=1990) and the assumed fuel efficiency improvement.

$$fuel(t) = fuel(t_0)*fe(t)$$

fe(t)	fuel efficiency improvement in time step t relative to the base year (1990=1.00)

No provision is made for catalyst replacement as they have the same lifetime as the vehicles.

Unit cost

To calculate the cost per unit energy input the following equation is used.

$$ce_{PJ}(t) = \frac{I^{an} + OM^{fix} + OM^{e}(t)}{fuel(t)}$$

ce_{PJ}	cost per unit of energy input [ECU/PJ]

To evaluate the cost efficiency of different control options the abatement costs are fully related to reduced NO_X emissions. In the optimisation routine the reduction of NO_X is functionally linked to the reduction of VOC emissions.

$$cn_{NO_X} = \frac{C_{PJ}}{noxX}$$

cn_{NOx}	cost per unit of NO_X reduced [ECU/ton NO_X]
noxX	NO_X removed [NO_X/PJ]

(Cofala and Syri, 1998a)

Appendix 2

No control situation

The no control or 'green field' situation is not suitable for SO_2, NO_X and VOC in Europe. The reason is that protocols have been signed to reduce the emissions and most countries have already implemented different control options. Ammonia still uses the no control curve but will soon have to take into account the current control situation in the different countries. The no control cost curve, that is shown in Figure 11, ranks all available cost-efficient techniques according to their marginal cost and start from the unabated emission. It means that in each sector-fuel combination there is a certain number of control options. The first technique might only be able to reduce 50% of all pollution but is the cheapest and the one to be used if the country is satisfied with this reduction. If the second technology can reduce 80% and this is the goal – only the second is used for the whole capacity. If a 70% reduction is required a combination of the first and the second technology is used (Klimont, personal communication). In the total cost curve for each pollutant all cost-efficient technologies are listed. If the country wish to abate as much as possible the technologies that have the highest marginal cost in each sector-fuel combination are to be implemented to the whole capacity. If all possible options are used the achieved reduction is referred to as Maximum Feasible Reduction (MFR) (Amann et al, 1998).

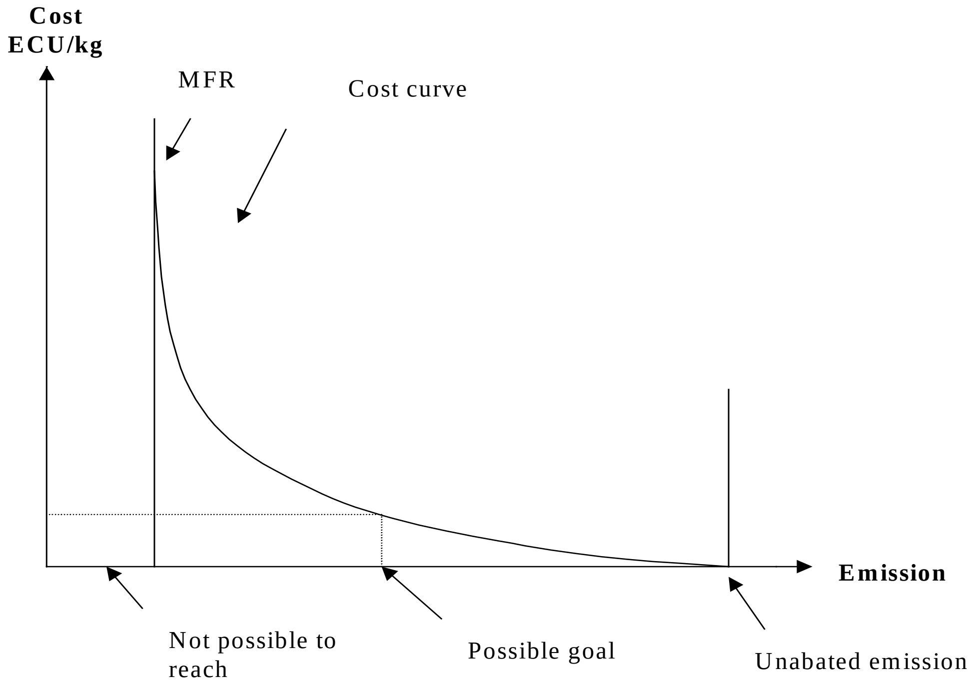

Figure 11. A no-control cost curve (author).

Current legislation

The other possibility is to start the cost curve from the actual emission control situation that includes emission and fuel standards in force (referred further as CLE). In many cases some technologies already implemented in the CLE are not cost-efficient. In these cases the RAINS model assumes that cost-efficient technologies are used instead of the actual used options – if this is not done the cost curve would not be convex. In effect, the same reduction level can be achieved at a lower cost than if the stringent implementation of the CLE control measures was considered.

Only capacity not 'blocked' by already implemented technology can be further controlled in a cost-efficient way. This approach was adopted to prevent installed technologies to be prematurely scrapped. It resulted in a cost curve that started at CLE but did not reach as far as the no-control cost curve as the capacity, that could be further controlled was limited (Cofala, 1998).

The cost curves that have been used in earlier versions of the model combined the no-control curve and the CLE curve by implementing the most important elements of the current legislation into the no-control curve (this is how it is still done for the VOC cost curve) no matter what costs these measures have. This kind of cost curves start with emissions that do not have an easy interpretation (Cofala, 1998). See diagram in Figure 12. However, for the optimisation only the part of the cost curve with lower emissions than CLE is taken into account.

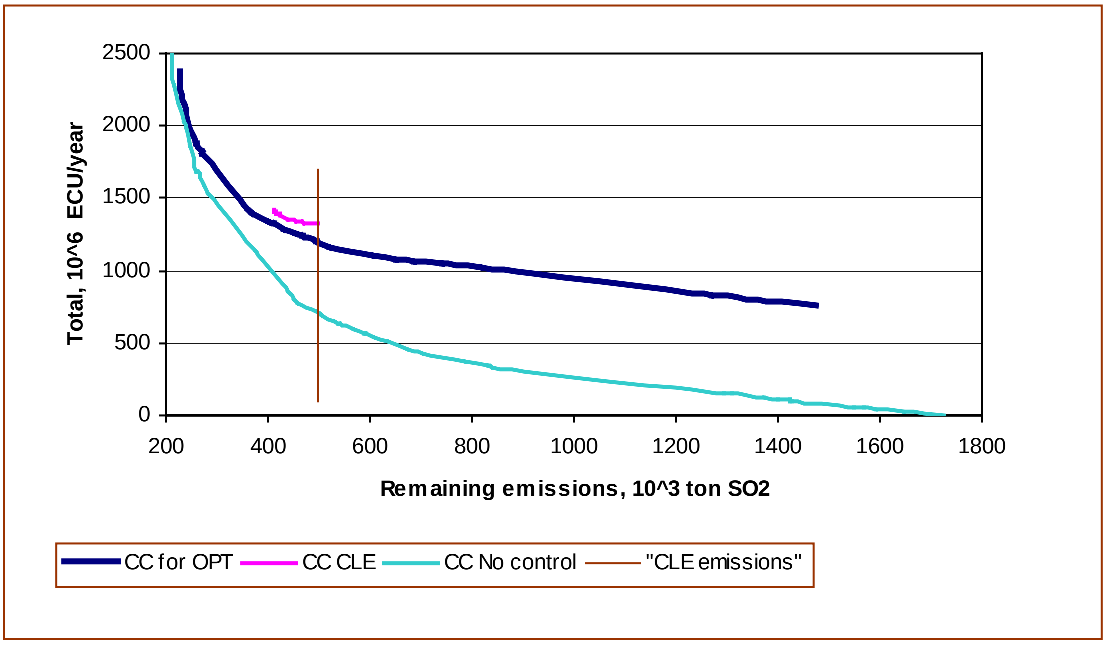

Figure 12. The difference between three cost curves (Cofala, 1998).

The cost curves used for NO_X and SO_2 in the work for the Gothenburg protocol (CC for OPT) include the current legislation in a more realistic way. The technologies are separated between technologies that can be replaced by more efficient technology (A-technology), as they do not require any investment at a plant level, and technologies if installed cannot be replaced by more efficient ones (B-technology). They also separate the capacity into two classes. Class 1 includes capacity with technology installed before year 2000 and assumes that technology B cannot be replaced, while technology A can be replaced with B if it is more cost-efficient. Class 2 includes capacities commissioned after year 2000 and for this class all cost-efficient technologies are possible to use. This means that the same technology might turn up twice at the cost curve as it influence different capacities. (Cofala, 1998).

The VOC cost curves are calculated in a slightly more complicated way, which will not be discussed in details due to lack of resources.

Appendix 3

Allocation of costs

To reflect the cost-efficiency of different abatement options, especially structural changes, it is necessary to observe the effect on more than one environmental objective. The costs are allocated between the objectives in accordance to their effect and the main part of the cost is allocated to the objective which receive most benefit of the measure. In the gap method, used by the Committee, the effect of the measure is compared to the gap between today's emission and the sustainable emission level. This means that a lower average cost is received if the gap is large. If any target is fulfilled (probably SO_2) no additional cost will be allocated to that pollutant.

To calculate the share of the total cost for a measure for respective target the following equation is used:

$$p_i^j = \frac{\left(a_i^j / G^j \right)}{\sum_j \left(a_i^j / G^j \right)}$$

i	measure
j	pollutant
p_i^j	share of the total cost for measure i and pollutant j
a_i^j	amount of ton reduced by measure i of pollutant j
G^j	the gap for pollutant j

The gap is the difference between the emission 1995 and the target of 2020. The following values have been used in the calculations:

CO_2	11 620 000 tons
SO_2	23 500 tons
NO_X	244 000 tons
PM	45 000 tons
VOC	366 000 tons

The average cost for the measure i and pollutant j per kg reduced emission is calculated in the following equation:

$$k_i^j = \frac{p_i^j C_i}{a_i^j}$$

k_i^j	average cost for measure i and pollutant j per kg reduced emission
C_i	Total cost for measure i

Appendix 4

Fuel categories

BC1	Brown coal/lignite, high grade
BC2	Brown coal/lignite, low grade
HC1	Hard coal, high quality
HC2	Hard coal, medium quality
HC3	Hard coal, low quality
DC	Derived coal
OS1	Other solid-low S
OS2	Other solid-high S
HF	Heavy fuel oil
MD	Medium distillates
LF	Light fractions
GAS	Natural gas
REN	Renewable
HYD	Hydro
NUC	Nuclear
ELE	Electricity
HT	Heat
NOF	No fuel use

Sector categories

Power plants & district heating

PP_EX_WB	Power plant, Existing, Wet bottom boiler before 1990
PP_EX_OTH	Power plant, Existing, Other before 1990
PP_NEW	Power plant, New after 1990
PP_TOTAL	Power plant, Total

Conversion and industry

CON_COMB	Conversion, Combustion
CON_LOSS	Conversion, Combustion
IN_OC	Other, Combustion
IN_BO	Industry, Boilers
IN_OCTOT	Industry, Other, Combustion, Total
NONEN	Non-energy use

Household and transport.

DOM	Domestic
TRA_RD	Transport, Road
TRA_OTHER	Transport, Other

Industrial processes

IN_PR	Process emissions – emissions not directly attributed to fuel consumption

IN_PR_REF	Industrial, Process, Oil refineries
IN_PR_COKE	Industrial, Process, Coke plants
IN_PR_SINT	Industrial, Process, Sinter plants
IN_PR_PIGI	Industrial, Process, Pig iron
IN_PR_NFME	Industrial, Process, Non-ferrous metal smelter
IN_PR_SUAC	Industrial, Process, Sulfuric acid plants
IN_PR_NIAC	Industrial, Process, Nitric acid plants
IN_PR_CELI	Industrial, Process, Cement and lime plants
IN_PR_PULP	Industrial, Process, Pulp mills

Maritime activities

TRA_OTS_M	Medium vessels
TRA_OTS_L	Large vessels

Road transport

TRA_RD_LD2	Transport, Road, Light duty, Two-stroke engines
TRA_RD_LD4	Transport, Road, Light duty, Four-stroke engines
TRA_RD_HD	Transport, Road, Heavy duty

Off-road transport

TRA_OT_LD2	Other mobile sources and machinery with two-stroke engines
TRA_OT_LB	Other land-based mobile sources and machinery with four-stroke engines

Control options

Control options for NO_X:

NOC	No control
PBCCM	Power Plants, Brown Coal, Combustion Modification (CM)
PBCSCR	Power Plants, Brown Coal, Selective Catalytic Reduction (SCR)
PBCCSC	Power Plants, Brown Coal, CM + SCR
PHCCM	Power Plants, Hard Coal, CM
PHCSCR	Power Plants, Hard Coal, SCR
PHCCSC	Power Plants, Hard Coal, CM + SCR
POGCM	Power Plants, Oil & Gas, CM
POGSCR	Power Plants, Oil & Gas, SCR
POGCSC	Power Plants, Oil & Gas, CM + SCR
ISFCM	Industrial Boilers and Other Combustion in Industry, Solid Fuels, CM
IOGCM	Industrial Boilers and Other Combustion in Industry, Oil & Gas, CM
ISFCSC	Industrial Boilers and Other Combustion in Industry, Solid Fuels, SCR
IOGCSC	Industrial Boilers and Other Combustion in Industry, Oil & Gas, SCR
ISFCSN	Industrial Boilers and Other Combustion in Industry, Solid Fuels, CM+SCR
IOGCSN	Industrial Boilers and Other Combustion in Industry, Oil & Gas, CM+SCR
DHFCM	Commercial Sector, Heavy Fuel Oil, CM
DMDCCO	Commercial Sector, Light Fuel Oil, CM
DGCCOM	Commercial Sector, Natural Gas, CM
DMDCCR	Commercial and Residential Sector, Light Fuel Oil, CM
DGCCR	Commercial and Residential Sector, Natural Gas, CM
PRNOX1	Process/technology emissions, Stage 1 control
PRNOX2	Process/technology emissions, Stage 2 control

PRNOX3	Process/technology emissions, Stage 3 control
GLDCC	Transport, Natural Gas, 4-stroke cars & Light Duty Trucks – three-way catalytic converter
LFCC1	Transport, Gasoline, 4-stroke cars & Light Duty Trucks – three-way catalytic converter (1992 standard)
LFCC2	Transport, Gasoline, 4-stroke cars & Light Duty Trucks – advanced three-way catalytic converter (1996 standard)
LFCC3	Transport, Gasoline, 4-stroke cars & Light Duty Trucks – advanced three-way catalytic converter (2000 standard)
LFCC4	Transport, Gasoline, 4-stroke cars & Light Duty Trucks – advanced three-way catalytic converter (~2005 standard)
MDLDCM	Transport, Diesel, Light Duty Vehicles, CM (1992 standard)
MDLDAM	Transport, Diesel, Light Duty Vehicles, CM (1996 standard)
MDLDEC	Transport, Diesel, Light Duty Vehicles, Advanced combustion (2000 standard)
MDLDNX	Transport, Diesel, Light Duty Vehicles, NO_X converter
GHDCC	Transport, Natural Gas, Heavy Duty Vehicles, Catalytic converter
LFHDCC	Transport, Gasoline, Heavy Duty Vehicles, Catalytic converter
EUR1	Transport, Diesel, Heavy Duty Vehicles, Euro I (model year 1992/93)
EUR2	Transport, Diesel, Heavy Duty Vehicles, Euro II (model year 1995/96)
EUR3	Transport, Diesel, Heavy Duty Vehicles, Euro III (model year 1999)
EUR4	Transport, Diesel, Heavy Duty Vehicles, Euro IV
SCRSH	Transport, Ships, SCR
STMCM	Combustion modification on medium vessels
STLCM	Combustion modification on large vessels
STLSCR	SCR on large vessels

Control options for SO_2:

NOC	No control
LSCO	Low sulphur coal
LSCK	Low sulphur coke
LSHF	Low sulphur fuel oil
LINJ	Limestone injection
IWFGD	Industry wet flue gas desulfurization FGD
PRWFGD	Power plant wet FGD, already retrofitted
PWFGD	Power plant wet FGD
RFGD	Regenerative FGD
SO2PR1	Process emissions – Stage 1 control
SO2PR2	Process emissions – Stage 2 control
SO2PR3	Process emissions – Stage 3 control
LSMD1	Low sulphur gas oil – Stage 1 (0.2% S)
LSMD2	Low sulphur gas oil – Stage 2 (0.045% S)
LSMD3	Low sulphur gas oil – Stage 3 (0.003% S)

(Cofala and Syri, 1998 a and b, IIASA homepage, 2000.)

Appendix 5

Control measures used in the Committee's approach

1 Increase the load factor for long transports.
2 Restrict the speed on the roads.
3 More constant way of driving.
4 Co-ordinate the distribution of goods in populated areas.
5 Transfer car transport to walking and cycling.
6 Restrict the need of transport by plan the built-up areas in a way that decrease the need of too much transport.
7 Replace transport of people with IT.
8 Increase the covering of people in the cars.
9 Decrease the emissions from cold starting.
10 Decrease flying distances and minimise the cues.
11 Prematurely introduction of 2005/2006 exhaust legislation on light vehicles.
12 Prematurely introduction of 2005/2006 exhaust legislation on heavy vehicles.
13 Optimise the emission from existing diesel engines in the railway sector.
14 Change to new engines with improved emission qualities in motor carriage.
15 Develop and introduce low emitting aeroplane.
16 Transferring of goods from road to railway.
17 Increase the degree of coverage on aeroplanes.
18 Transferring long distance traffic of people from car/aeroplane to railway.
19 Provide the mine vessels with NOx-decreasing technology.
20 Provide the mine vessels and corvettes with NOx-decreasing technology.
21 Introduction of more stringent exhaust legislation on off-road machinery 2008.
22 Prematurely introduction of more stringent legislation on off-road machinery 2006.
23 Retrofit installation of particle filter for diesel engines.
24 Retrofit installation of oxidising catalysts for diesel engines.
25 Retrofit installation of particle filter in combination with EGR.
26 Improved cleaning of waste gas on new working tools from 2003.
27 Retrofit installation of catalysts on working tools.
28 Power drive on some new working tools.
29 More stringent legislation on snowmobiles from 2003.
40 Decreased use of electricity in facilities.
41 More efficient domestic appliances.
42 Energy efficiency of new buildings.
43 Trimming of oil-fired boilers 60-1000kW.
44 Individual measure of heat in oil-fired apartments.
45 Adjustment of the heat in oil-fired block of flats.
46 Energy efficient windows.
47 Extra isolation of attics.
48 Isolation of facades.
49 More efficient management of properties.
50 Conversion from electricity heat and oil heat to domestic heating.
51 Decreased content of sulphur in light fuel oil.

52 Conversion to pellets firing.
53 More efficient boilers in small self-contained houses.
54 Installation of accumulator tank for wood boilers.
55 Forced exchange of older wood boilers.
56 Partly conversion to solar heat in small self-contained houses.
60 Change of fuel from coal to bio fuel in domestic heating systems.
61 Change of fuel from heavy fuel oil to bio fuel in domestic heating systems.
62 Change of fuel from light fuel oil to bio fuel in domestic heating systems.
63 Increased use of waste heat.
64 Reduction of NO_X within the NO_X system.
65 Decreased content of sulphur in heavy fuel oil.
66 Decreased domestic heating temperature.
67 Reduced emission of particles <10 MW.
80 Process related energy saving.
81 More efficient use of energy in ancillary systems of the industry.
82 Reduction of NO_X within the petrochemical industry.
83 Reduction of NO_X within the cement industry.
84 Reduction of NO_X in black liquor recovery boilers, OFA.
85 Reduction of NO_X in black liquor recovery boilers, SNCR.
86 Reduction of NO_X in black liquor recovery boilers, SCR.
87 Reduction of NO_X within the iron and steel industry, SNCR.
88 Decreased content of sulphur in heavy fuel oil.
89 Reduction of NO_X in the mining industry, no heavy investments.
90 Reduction of NO_X mining industry SCR.
91 Reduction of sulphur in the mining industry.
92 Reduction of NO_X, carbon black industries SCR.
93 Use of catalysts in the nitric acid industries.
94 Restore gas when distributing and storing oil products.
95 Thermal and catalytic cleaning in the food industry.
96 VOC-cleaning, wood industry.
97 VOC-cleaning, graphic industry.
98 Reduction of NO_X refineries 1.
99 Reduction of NO_X refineries 2.
100 VOC cleaning refineries.
101 VOC cleaning petro chemistry.
102 Reduction of sulphur, rayon fibre manufacturing.
103 Reduction of NO_X within the NO_X system.
104 Reduction of sulphur, pulp and paper.
105 Collection of non condensable gases, pulp and paper.
106 VOC reduction, engineering industry.
107 VOC reduction, plastic industry.
108 VOC reduction, glass industry.
109 VOC reduction, organic chemical industry.
110 Reduction of NO_X, iron and steel industry, SCR.
111 Supplement hydroperoxide when pickling in iron and steel industry.

(Levander, personal communication, 2001)

IVL Svenska Miljöinstitutet AB | IVL Swedish Environmental Research Institute Ltd

P.O.Box 210 60, SE-100 31 Stockholm
Hälsingegatan 43, Stockholm
Tel: +46 8 598 563 00
Fax: +46 8 598 563 90

P.O.Box 470 86, SE-402 58 Göteborg
Dagjämningsgatan 1, Göteborg
Tel: +46 31 725 62 00
Fax: +46 31 725 62 90

Aneboda, SE-360 30 Lammhult
Aneboda, Lammhult
Tel: +46 472 26 77 80
Fax: +46 472 26 77 90

www.ivl.se