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Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe

European Environment Agency

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Executive summary

Many of the traditional air pollutants and greenhouse gases have common sources and either separately or jointly they lead to a variety of environmental effects on local, regional and global scales. As a result, policies that look at cost-effectiveness and environmental effectiveness of proposed solutions in an integrated way can be more effective and efficient than policies that only focus on one issue, as integration can prevent inefficient use of resources and implementation of sub-optimal solutions.

Objective/scope

Our objective here is to explore reductions of air pollutant emissions as well as the change in control costs and environmental impacts (the potential ’ancillary benefits’) resulting from different ways of implementing the Kyoto Protocol in Europe, in particular with reference to the use of Kyoto mechanisms. The term ’Kyoto mechanisms’ refers here to all instruments that, in addition to domestic implementation, parties are allowed to use under the protocol to achieve their reduction targets. These instruments are: emission trading, joint implementation (JI) and the clean development mechanism (CDM). The results presented have a descriptive ’what-if’ character and do not intend to be prescriptive for any future implementation of the Kyoto Protocol and air pollution policies. Furthermore, we need to emphasise that all our scenarios concentrate exclusively on the reduction of CO_2 emissions, CO_2 being, by far, the most important greenhouse gas. Possibilities for reducing other gases (CH_4, N_2O, HFCs, PFCs and SF_6) are not considered.

This technical report underpins the information presented in the report ’Europe’s Environment: the third assessment’, produced by the European Environment Agency for the ministerial conference held in Kiev, May 2003. Compared to the information presented in *Europe’s Environment: the third assessment* this report provides a more indepth presentation of the used methodology, models and the underlying assumptions. Furthermore this technical report elaborates on the details of the results. The discussion focuses primarily on three country groupings/regions: western Europe (WE), central and eastern Europe (CEE) and Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries (here denoted RF & EE). Results for individual countries, as shown in the annexes, are mainly for illustration since analysis of climate policies takes place at the regional level.

Methodology

Three scenarios for the implementation of Kyoto targets are compared with a baseline scenario for 2010 (without new climate policies). The three scenarios differ with regard to the use of the Kyoto mechanism. These were developed and explored using a set of linked assessment models developed by RIVM in the Netherlands and IIASA in Austria. The Kyoto Protocol targets have been implemented according to the post-Marrakech Amendments situation. The three scenarios have been designed to cover a range of potential ancillary benefits for the main region investigated.

The **baseline scenario** describes the developments in energy use and emissions of greenhouse gases and regional air pollutants, assuming that no new climate policies are implemented. The baseline scenario used in this study is consistent with several other scenarios currently used for European assessments.

The three climate policy scenarios prepared for the report are:

1. **domestic action only (DAO):** assumes that Kyoto targets are met solely through domestic implementation, allowing only for internal emission trading (e.g. within the EU),
2. **trade — with no use of surplus emission allowances (TNS):** assumes full use of the Kyoto mechanisms, but without using ‘surplus emission allowances’. These ‘surplus emission allowances’ exist as greenhouse gas emissions in many CEE and RF & EE countries are projected as being well below their Kyoto targets, even without specific climate policies. Thus, under this scenario, part of the reduction

by the parties required to reduce their emissions under the Kyoto Protocol (i.e. WE) is met by means of emission trading, JI and CDM,

3. **trade — with surplus emission allowances (TWS)** also assumes full use of Kyoto mechanisms, but includes the use of 'surplus emission allowances'. This 'surplus emission allowances' use is, however, restricted on the basis of maximising the revenues of their trade for the CEE and RF & EE regions, leading to the use of only a quarter of the available 'surplus emission allowances' during the first comment period.

Results

Baseline scenario without additional climate policies

The baseline scenario shows that if no additional climate policies are formulated after 2000, CO_2 emissions in WE will increase by 8 % compared to 1990. The projected increase in CO_2 emissions is mainly driven by an increase in energy consumption, which for WE in 2010 is about 15 % above the 1990 level. In contrast, according to the baseline scenario the 2010 emissions in the CEE and RF & EE regions are below the 1990 level. (– 10 % and – 32 %, respectively). This means that these regions already comply with their respective reduction targets without additional policies. For all three regions, emissions decrease by 7 % compared to 1990.

For regional air pollutants, the baseline scenario includes emission and fuel standards in each country according to the current legislation (CLE) (1) and emission ceilings from the National Emission Ceilings Directive of the EU and the Gothenburg Protocol to the CLRTAP. As a result, emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and particulate matter decrease in all sub-regions compared to 1990. However, at the same time, adverse impacts from this regional air pollution will continue to exist.

Climate policy scenarios and consequences for energy use

In the three-climate policy scenarios presented in the report — all meeting the European Kyoto targets but using different instruments — reduction of CO_2 emissions leads to substantial changes in primary energy use.

The DAO (domestic action only) scenario results in the most drastic changes in western Europe. Reducing 2010 CO_2 emissions from an increase of 8 % (compared to 1990) to a decrease of 7 % results in decrease of primary energy consumption of 7 % with respect to the baseline. However, the use of coal in western Europe decreases by 38 % whereas the consumption of oil and gas decreases by 9 % and 2 %, respectively. In this scenario, no changes occur in the CEE and RF & EE regions compared to baseline, since their Kyoto targets are already met under the baseline scenario.

Under the two 'emission trading' scenarios (i.e. the scenarios that assume the use of Kyoto mechanisms) part of the necessary emission reductions in WE is implemented using more cost-effective measures in other sub-regions. In these cases, obviously less substantial changes in WE are required, while, at the same time, this leads to changes in the energy system of CEE and RF & EE.

In the TNS scenario (i.e. without the use of 'surplus emission allowances') total primary energy consumption in WE decreases by 2 % and coal use by 21 % with respect to the baseline. While consumption of oil decreases 3 %, the use of gas increases simultaneously by the same percentage. Measures that are implemented in CEE and RF & EE cause a drop in the primary energy demand in these regions by 4 % and 9 %, respectively. Again, this is largely due to less use of coal (23 % in CEE and 32 % in RF & EE). Interestingly, for Europe as a whole, the CO_2 emission reductions are the same as in the DAO scenario (6 % compared to baseline). This is because the limited use of CDM by WE (resulting in measures taken outside Europe) is compensated by reductions in CEE and RF & EE as a result of trading with other Annex-B countries.

In the TWS scenario, the changes in primary energy in all three European regions are somewhat less than in the TNS scenario, as some of the required reductions are now met using surplus emission allowances. Nevertheless, here too, demand for coal decreases substantially (14 % in WE, 17 % in CEE, and 26 % in RF & EE). Under this scenario, European CO_2 emissions decrease by 4 % compared to baseline, again somewhat less than the other two scenarios.

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(1) The impacts are assessed for the year 2010 and include policies as decided per December 2001.

Changes in emissions resulting from climate policies

Since climate policies result in a reduction in energy use, particularly coal, they also reduce the emissions of air pollutants as shown in Figure I. The graphs reveal 'ancillary benefits' to be significant, but also show clear differences between the scenarios that are all based on meeting the European Kyoto targets.

In general, ancillary benefits from climate policies are highest for SO_2, followed by PM_{10}, NO_x, and lowest for VOC. The strong link between CO_2 and SO_2 results from the strong influence of decreased coal use for emissions of both compounds. This link is particularly strong in CEE and RF & EE countries (as current emission standards for SO_2 are less strict). NO_x emission reductions are less strongly coupled to changes in fuel mix and occur mainly due to implementation of energy efficiency options.

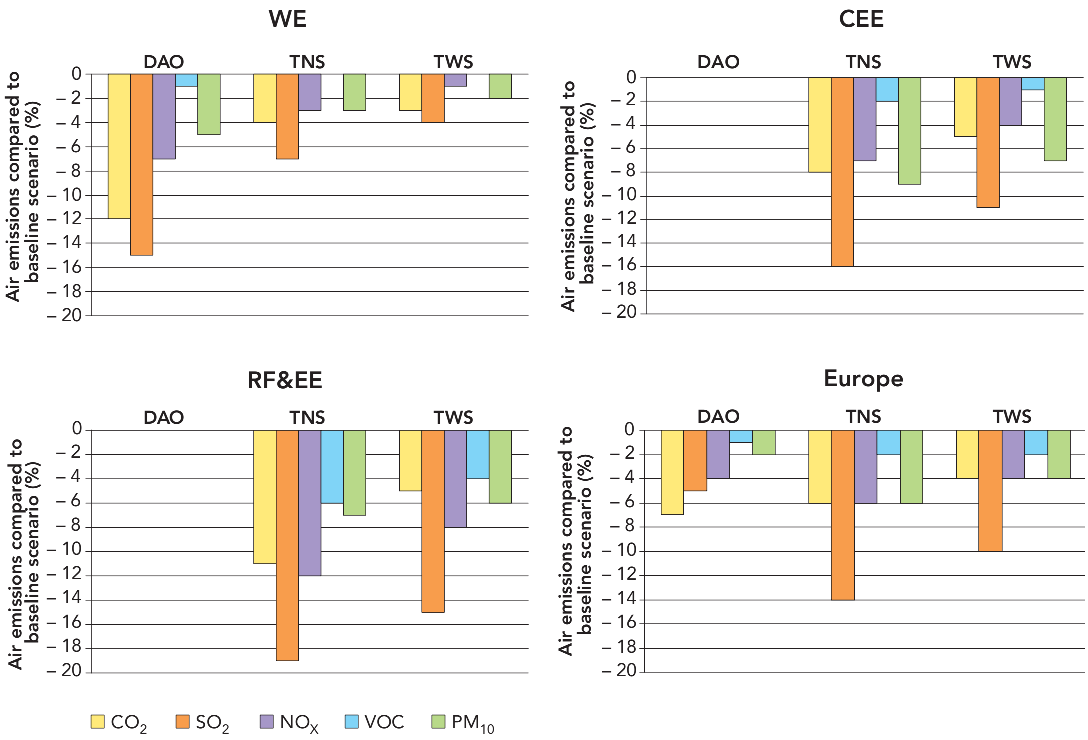
Figure I also shows the DAO scenario to yield only ancillary benefits in WE, as this scenario only includes additional action in this region to reach its Kyoto targets.

In the trading scenarios, the implementation of a significant share of the required CO_2 emission reductions in CEE and RF & EE (based on the lower implementation costs) also implies that some of the ancillary benefits are shifted from WE to the CEE and RF & EE regions. Interestingly, for Europe as a whole, the trading scenarios (TNS and TWS) actually lead to higher ancillary benefits than the DAO scenario. The reason is that carbon emission reductions have a strong effect on SO_2 emissions in CEE and RF & EE (again due to less stringent environmental policies, but also due to a larger share of coal in primary energy use in CEE). The same result can be seen for PM_{10}. The effect of climate policies, including the use of trading instruments, is less than for NO_x.

Assuming the use of 'surplus emission allowances' (the TWS scenario versus TNS scenario) means that fewer changes in the energy system will be required. This also means lower emission reductions of air pollutants, e.g. the reduction of SO_2 emission is 10 %, and not 14 %, as in the TNS scenario.

Figure I

Air emissions (%) in 2010 compared to the baseline scenario



Control costs

Climate policies obviously cost money. However, from our analysis, it is shown that these policies do not only lead to emission reductions but also to a reduction in control costs of regional air pollution (i.e. fewer control measures are needed to meet the reduction targets of these gasses). The ancillary benefits in terms of reduced control costs are very substantial and partly offset the direct costs of climate policies (Figure II).

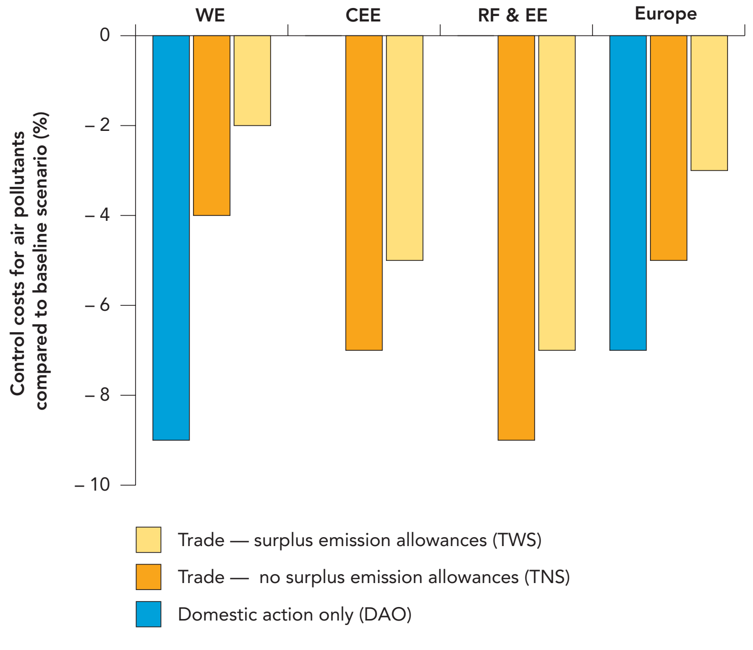
Estimating costs of future policies is beset with uncertainties, and currently, different cost concepts are used frequently in various studies. In this study too, caution should be exercised in comparing costs calculated for the different models, (climate policy and air pollution models). Nevertheless, the results can be used to obtain an indication of the relative size of costs and savings under the different scenarios.

The three climate policy (Kyoto) scenarios involve significant costs for implementing the climate policies. In this study, these climate policy costs are estimated at EUR 12 billion for the DAO scenario (domestic action in WE). In the two trading scenarios, the costs are significantly reduced, to 7 and 4 billion for the TNS and TWS scenario, respectively, by using Kyoto instruments.

The corresponding changes in the energy system in the DAO scenario lead to considerable savings in control costs for air pollutants: 7 % or EUR 6.6 billion per year (in WE only). The substantial changes in WE energy system reduce the need to use relatively high-cost emission reduction measures to meet the strict air pollution control targets of this region. The TNS and TWS scenarios involve somewhat lower savings: 5 % (EUR 4.1 billion per year) and 3 % (EUR 2.5 billion per year), respectively. In these scenarios, air pollution control cost savings for WE are reduced by EUR 3–5 billion per year. At the same time, savings in CEE and RF & EE now amount to EUR 0.2 to 0.9 billion per year. The savings in per cent compared to baseline control costs for CEE and RF & EE are substantial, ranging from 5–9 % (Figure II). Thus, similar to emission reduction, the use of Kyoto mechanisms also shifts some of the air pollution control cost savings from WE to CEE, and RF & EE.

This analysis indicates that a substantial part of the control costs of CO_2 reduction can actually be recovered from reduced costs of controlling air pollution. Quantitatively, this saving could amount to 50 % of the costs to implement the Kyoto Protocol. However, it should be noted that more research is needed to further harmonise cost estimates of different models used in this analysis. Clearly, while flexible mechanisms in our scenarios reduce the costs to meet the Kyoto targets, they also reduce the savings in air pollution control costs. From a purely financial perspective, the resulting total cost savings may still favour the scenarios including the use of Kyoto mechanisms.

Change in annual control costs for air pollutant emission in 2010 compared to the baseline scenario (%) Figure II



Impacts on ecosystem and human health
The air pollutant emission reductions resulting from climate policies also increase ecosystem protection against acidification and eutrophication throughout Europe. These reductions will also lead to reduced ambient concentration of ground-level ozone and therefore reduced exposure of vegetation and population.

Our results showed earlier that the trading scenarios (in particular, the TNS scenarios) lead to the largest emission reduction of air pollutants for Europe as a whole. This result is reflected in our results for environmental impacts. However, in addition to this, due to the transboundary nature of air pollution the trading scenarios (TNS and TWS) also lead to substantial improvements in environmental impacts in WE even compared to the DAO scenario.

Qualitative conclusions

- Implementation of climate change policies to comply with the Kyoto Protocol is likely to yield substantial ancillary benefits for air pollution in Europe.
    - The ancillary benefits are expected to result not only in a decrease in air pollution emissions and control costs but an increase in environmental protection.
- The realisation of ancillary benefits depends on how the flexible mechanisms and surplus emission allowances are used in meeting the Kyoto targets.
    - For Europe as a whole, the use of Kyoto mechanisms for meeting WE's Kyoto target (JI, emission trading) can increase the ancillary benefits in terms of reductions of regional air pollutants and related environmental impacts.
    - Using surplus emission allowances will reduce these ancillary benefits, in particular for CEE and Russia, and western NIS.
    - Using flexible mechanisms will shift ancillary benefits in terms of emission reductions of air pollutants from WE to CEE, and RF & EE.

- The use of flexible mechanisms and surplus emission allowance is intended to, and will, reduce the costs of implementing the Kyoto Protocol. However, using flexible mechanisms will also reduce the ancillary benefits in terms of control cost for air pollution in Europe.

- An integrated approach to climate change and regional air pollution policies could be important to harvesting potential ancillary benefits in the future.

1. Introduction

Environmental policies aimed at mitigation of environmental impacts in one area can have significant effects on other aspects of environmental quality. Therefore, policies need to look at cost-effectiveness and environmental effectiveness of proposed solutions in an integrated way, taking into account the effects on different environmental issues and sectors. Such integration prevents inefficient use of resources and implementation of sub-optimal solutions.

The Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-level Ozone, the so-called Gothenburg Protocol (UN/ECE, 1999), is a good example of how several environmental problems can be examined in an integrated way. Emission ceilings adopted by the protocol can realise important efficiency gains for simultaneously controlling acidification and eutrophication risks, and ground-level ozone concentrations.

Important links have been established between regional air pollution and climate change, although these are currently hardly considered in policy-making (e.g. RIVM, EFTEC *et al.,* 2001; Syri, Amann *et al.,* 2001; Mayerhofer, de Vries *et al.,* 2002; Van Harmelen, Bakker *et al.,* 2002). First, some substances directly influence both climate change and regional air pollution, for instance, sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Second, the emissions of greenhouse gases and regional air pollutants originate to a large extent from the same activity, i.e. fossil fuel consumption. Third, technologies for the abatement of one pollutant may also affect the emissions of other pollutants, either beneficially or adversely (e.g. the use of car catalytic converters decreases the nitrogen oxide (NO_x) emissions but increases emission of the greenhouse gas nitrous oxide (N_2O)). Fourth, environmental effects may influence one another. Climate change, for instance, changes the weather patterns and thus the transport of pollutants and the buffering capacity of soils (Posch, 2002) (2). At the same time, SO_2 emissions are important for climate change due to their cooling effect. Despite these linkages, both types of problems have, to date, usually been explored separately using different tools and models, concentrating on different technical solutions. For instance, while greenhouse gases analysis focuses on changes in the energy system, the analysis of atmospheric pollutants concentrates mostly on end-of-pipe technologies.

Recently, several studies have been published on the linkages between (policies for) climate change and regional air pollution in Europe. Van Harmelen *et al.* (2002) concluded that a considerable share of the investments in climate policies throughout the 21st century will be recovered by lower costs on pollution control for sulphur dioxide and nitrogen oxides. Brink (2002) indicated that strategies aiming at simultaneous reduction of greenhouse gases and regional air pollutants in the agricultural sector may differ significantly from strategies aimed at only one of the problems. In the European Environmental Priority Study for western Europe (RIVM, EFTEC *et al.,* 2001), addressing ancillary benefits between implementing the Kyoto Protocol and regional air pollution, it was found that reducing the western European emissions by 8 % from 1990 levels would reduce costs for regional air pollution control by almost 10 %. Similar (but more qualitative) results have been found for the whole of Europe (including central and eastern Europe) in an assessment looking into targets significantly more ambitious than the Kyoto targets (Van Vuuren and Bakkes, 1999).

The Kyoto Protocol and the Marrakech Accords provide for three mechanisms, known as the Kyoto mechanisms and cited below. Parties may use these mechanisms in addition to domestic implementation to facilitate compliance with their commitments.

- **Joint Implementation** (JI) allows Annex-1 countries to conduct emission reduction projects jointly. The mechanism invites

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(2) The typology of the different linkages is based on Brink (2002).

parties to invest in projects to reduce GHG emissions in other Annex-1 countries. The achieved emission reduction units can be used to fulfil the reduction commitments of the investing party.

- **The clean development mechanism** (CDM) invites Annex-1 countries to invest in projects to reduce GHG emissions in non-Annex-1 countries. According to the reduction achieved, certified emission reduction units are issued that Annex-1 countries can use to fulfil their commitments.
- **Emission trading** (ET) allows Annex-1 countries to trade emission allowances among themselves.

Current emission projections suggest that implementation of the Kyoto Protocol will require a significant abatement effort by the western European countries (EEA, 2002). For most central and eastern European countries, the Kyoto target is higher than or close to the level of emissions that will be reached without policies, mainly as a result of the economic restructuring in these countries following the transition process. Since the Kyoto Protocol allows all Annex-1 parties to fulfil their obligations, partly, by means of the Kyoto mechanisms, emission reduction required to reach the target for western Europe may also take place in other countries, especially in central and eastern Europe and in Russia.

A special feature here is the possibility for trade in so-called 'surplus emission allowances' (see also Elzen and Moor, 2002). The emissions for most countries with economies in transition have declined substantially since 1990 and, as a result, the expected baseline emissions (without additional climate policies) of several of these countries in the first commitment period (CP) are significantly lower than the Kyoto targets. According to the provisions of the Kyoto Protocol, this surplus can be traded to other parties. Countries with the largest surplus of emission allowances are Russia and Ukraine. The difference between the Kyoto target and the baseline emissions is referred to as 'surplus emission allowances' throughout this report.

Clearly, differences in the way the Kyoto targets are implemented (in terms of use of Kyoto mechanisms) also affect the potential ancillary benefits for air pollution in terms of emissions, control costs and environmental impact. In principle, shifting some of the emission reductions in greenhouse gases from western Europe to central and eastern European countries also shifts the ancillary benefits. However, there are no ancillary benefits from meeting climate targets by using surplus emission allowances. To date, studies have not addressed how implementation of the Kyoto targets in the whole of Europe will affect regional air pollution in terms of emissions, control costs and environmental impact.

2. Objective and scope

The objective of this report is to explore the emission reductions of air pollutants and change in control costs and environmental impacts forthcoming from different ways in which the Kyoto Protocol is implemented in Europe, in particular with regard to the use of Kyoto mechanisms. It should, however, be noted that, given the stage of this type of research, quantitative results should be seen as indicative. In particular, this refers to assessing the costs of individual policies. The results presented are of a descriptive 'what-if' character and do not intend to be prescriptive for any future implementation of the Kyoto Protocol and air pollution policies.

As this technical report underpins the pan-European environment report produced by the European Environment Agency for the ministerial conference to be held in Kiev in May 2003, the discussion will focus primarily on three country grouping/regions. These are western Europe (3) (WE), central and eastern Europe (4) (CEE), Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries (RF & EE) (5). Results for individual countries, shown in the annexes, are mainly included for illustrative purposes since the analysis of climate policies has been performed at the large region level. At this stage, the study is restricted to carbon dioxide (CO_2), leaving the remaining five greenhouse gases covered by the Kyoto Protocol unaddressed.

The analysis was performed using a set of linked models that collectively simulate different ways of achieving the Kyoto targets for climate change and targets for controlling regional air pollution. The impacts of climate change scenarios are explored by comparing emission control costs and environmental impact indicators. Chapter 3 will describe the methodology and the models used in the analysis, while Chapter 4 will discuss the baseline scenario and demonstrate the corresponding emissions and their impacts on regional air pollution. The results of three mitigation scenarios are introduced and their effects compared with the results of the baseline scenario. The remainder of the report is devoted to the interpretation of the results and discussion of the conclusions.

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(3) WE includes: EU15+Norway and Switzerland. In this study: WE excludes Iceland, Liechtenstein, Andorra, Monaco and San Marino.

(4) CEE includes: Albania, Bosnia-Herzegovina, Bulgaria, Czech Republic, Croatia, Estonia, FYR Macedonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia and Montenegro, Slovak Republic, Slovenia. In this study CEE does not include Cyprus, Malta and Turkey.

(5) RF & EE includes: Belarus, Republic of Moldova, Russian Federation and Ukraine. Only the part of Russia west of the Urals is included in this study (corresponding to the part covered by the EMEP region (www.emep.int)).

3. Methodology

As already indicated in the previous section, this report explores the effects of implementing the Kyoto Protocol in Europe on the basis of different assumptions for using the Kyoto mechanisms. So as to cover a range of potential ancillary benefits for the main region investigated, this study explores three mitigation scenarios in which Kyoto mechanisms are used in different ways to reach the Kyoto targets.

The scenarios explored are:

- pure domestic implementation, allowing only internal emission trading within the three European sub-regions;
- full use of Kyoto mechanisms, but without use of 'surplus emission allowances'; and
- full use of Kyoto mechanisms, however, assuming that a large share of the 'surplus emission allowances' will be banked to optimise the revenues of the selling parties (6).

These scenarios are elaborated upon in detail in Chapter 5. In this chapter, the ancillary benefits from the mitigation scenarios are derived by comparison with a baseline scenario that does not include any explicit climate change policies. The results included in the analysis are concerned with trends in emissions, the parts of ecosystems not protected against damage from acidification and eutrophication and air quality exceedance targets for ozone. Control costs for different scenarios are also addressed, both for the policies to reduce greenhouse gases and for emission control costs of regional air pollution.

We should note here that the results of the study should be seen as explorative in ascertaining the ancillary benefits in the larger European regions, emission control costs, climate policies and air pollution control. The costs calculated by different models should be compared with caution since they stem from different modelling traditions (in fact, even within the two research areas cost estimate ranges are considerable).

3.1. Model framework used

Assessment models to study climate change and regional air pollution have often been developed independently. This study integrates the different research areas by linking models that address climate change issues (FAIR and the energy model IMAGE/TIMER) (7) and regional air pollution (RAINS) (8) (Figure 3.1). Within the total framework:

- The FAIR model is used to calculate the use of Kyoto mechanisms and domestic action to achieve the Kyoto targets given a certain trading regime.
- The TIMER model is used to develop a baseline scenario for the study and to implement the outcomes of FAIR in terms of changes in the energy system (mitigation scenarios).
- The RAINS model is used to calculate emissions of air pollutants for the scenarios and to explore their environmental impacts. Indicators used to address environmental impacts are ecosystem protection against acidification and eutrophication, and the exceedances of critical thresholds for ozone. The costs of emission control policies are determined and compared as well.

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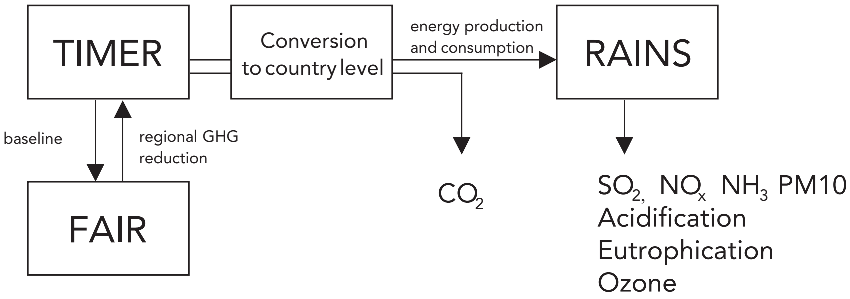
(6) Banking is used here in a catch-all. A promising area for further research would be to examine the options for permit suppliers to curtail supply and analyse strategies for exercising market power. A policy of optimal banking would, ideally, also have to consider permit prices in future period commitments to be inter-temporally optimal. As targets for the second commitment period and beyond are as yet unknown and uncertain, optimal banking is interpreted as maximising revenues in the first commitment period.

(7) Both FAIR and TIMER constitute part of the IMAGE 2.2 framework (integrated model to assess the global environment) — a modelling framework to study global change issues

(8) For western Europe, earlier links were made between the Primes energy model and the RAINS model to bridge these two different areas of policy-making. The Primes model, however, only encompasses western European countries, which was the reason for choosing the global energy model TIMER for this study.

Overview of the models used in this study Figure 3.1



3.2. Description of the models used

3.2.1. The FAIR model

The FAIR model (Framework to Assess International Regimes for differentiation of future commitments) was designed to quantitatively explore the outcomes of different burden sharing and trading regimes in terms of possible environmental and economic impacts. FAIR is a decision-support tool that uses expert information from more complex models (in particular, IMAGE), such as emission baselines and marginal abatement costs curves. In this study FAIR was used to determine the results of different assumptions on the use of Kyoto mechanisms. The basic assumption of the model is that regions will reach their emission reduction commitments on the basis of least cost. Extensive documentation of the FAIR model can be found in Elzen and Both (2002). Previous analysis assessments performed using FAIR evaluating different trading regimes under the Kyoto Protocol have been described in Elzen and Moor (2002).

The basis of the FAIR calculations is formed by marginal abatement cost (MAC) curves, which reflect the additional costs of reducing the last unit of carbon and differ per region. The MAC curve-based calculations allow an assessment of the willingness of any party to import permits or to abate more than is required to meet the Kyoto commitment and sell permits. The calculations can simulate a fully open permit market but also include constraints on buying and selling emission permits, for example, by only allowing domestic actions. Calculations can also account for non-competitive behaviour (restraining the number of permits based on the surplus emission allowances) and limit the implementation of some cost-efficient measures. The last option is used particularly for the clean development mechanism (CDM), in which the supply of CDM is set at 10 % of the theoretical maximum to reflect the limited operational availability of viable CDM projects. In other words, not all cost-effective projects in non-Annex-A countries (according to the MACs) will be available for use as CDM projects.

The Kyoto targets are calculated per region on the basis of the Marrakech Agreements and the 1990 CO_2 emission estimates. Each region is assumed to fully use the carbon credits granted to it on the basis of Articles 3.3 and 3.4 (forest and agricultural management activities) of the Kyoto Protocol, as estimated by FAO (see Elzen and Both, 2002). The reason for this is that sink credits are assumed to be more cost-effective than credits from emission reduction. In addition, each country is assumed to use its maximum-allowed credits from sink projects via CDM (a maximum of 1 % of the assigned amounts).

3.2.2. The TIMER model

The energy system model, TIMER (Targets IMage Energy Regional Model), has been developed to simulate long-term energy baseline and mitigation scenarios and explore the long-term dynamics of the energy system. The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and depletion. Inputs to the model are macroeconomic scenarios and assumptions on technology development, preference levels and fuel trade. The output of the model demonstrates how energy intensity, fuel costs and competing non-fossil supply technologies develop over time. The model recognises 17 world regions, 5 different end-use sectors, several different energy-producing sectors and about 10 energy carriers. The electricity generation sub-model includes production options based on hydropower, nuclear energy, renewables and different fossil fuels. The model is linked to an emission module that relates energy use to emissions of various greenhouse gases. The TIMER model has been described in detail in Vries *et al.* (2001). TIMER is incorporated into the IMAGE integrated assessment framework to study global change. An important reason to use the TIMER model in this research is that it is a global energy model: i.e. it covers the whole of Europe, in contrast to the more detailed energy models used in earlier exercises that only covered part of the region.

Implementation of CO_2 mitigation is generally modelled on the basis of price signals. A tax on carbon dioxide (carbon tax) is applied to bring down carbon emissions from the energy system. It should be noted that TIMER does not account for any feedback from the energy system to economic drivers. In response to the carbon tax, the model generates several responses:

1. price-induced investments in energy-efficiency, which, in turn, affect the energy-efficiency supply cost curve as a result of learning-by-doing (economies of scale, innovation);
2. price-induced fossil fuel substitution;
3. changes in the trade patterns of (fossil) fuels as a consequence of changing demand patterns and regional fuel prices;
4. price-induced acceleration of investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels, bringing down their specific investment costs in the process of learning-by-doing;
5. a decrease in the use of fossil fuels (as a result of the responses discussed above), leading to slower depletion rates and consequently lowers prices but also to a lower rate of innovation in the production of these fuels (slowing down learning-by-doing).

TIMER simulates a variety of technological and economic changes in the energy system in response to the requirement to reduce CO_2 emissions. Differences in energy system costs between scenarios are used as a measure for costs of CO_2 mitigation, defined as the product of energy consumption, and the costs of energy production and consumption, plus the annuitised expenditures for energy efficiency. Costs of (aggregated) energy technologies used by the model are calibrated for the base year using historical data (see Vries *et al.*, 2001). It should be stressed that total system costs are not directly related to the costs of a single measure because each option induces changes in the costs of other parts of the system. Investing in energy efficiency, for instance, reduces the costs of energy production and also accelerates the learning of energy-efficiency technology. Costs of air pollution control equipment are not included in the energy system costs of TIMER.

TIMER is an energy system model, focusing on the supply and demand of energy, but not on feedbacks to the general economy. In this sense, the model is similar to the Primes model. Important differences between the Primes and TIMER models are the levels of scale and time period for which the models are usually run. While TIMER is a long-term, worldwide energy model focusing on 17 global regions, the Primes model focuses on medium-term projections for individual countries within the European Union. Related to this, the level of detail in Primes is significantly larger than in TIMER (e.g. 10 versus 24 fuel types, and there are larger differences for the number of technologies considered in the electricity sector). Another difference between the two models is the data used for model calibration (EuroStat for Primes versus International Energy Agency for TIMER). The two models report generally on the same output variables. As this study not only encompasses the western European region, but also the other European regions, the global energy model TIMER was chosen for this study.

3.2.3. The RAINS model

The Regional Air Pollution Information and Simulation (RAINS) model provides a consistent framework for the analysis of emission reduction strategies within Europe (Amann, Cofala *et al.*, 1999). The model makes it possible — for a given scenario of economic development — to estimate the costs and environmental effects of emission control policies. A non-linear optimisation mode is used to identify the cost-minimal combination of measures, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. The model covers all pollutants relevant for acidification, eutrophication and formation of ground-level ozone (sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (VOC)). Recently, a module that estimates the emissions of particulate matter (PM) from anthropogenic sources was added to the model (compare Klimont, Cofala *et al.,* 2002). PM is estimated separately for the fine fraction ($PM_{2.5}$ — particles with aerodynamic diameter smaller than 2.5 m), coarse fraction particles (between 2.5 and 10 m) and total suspended particles (TSP). The sum of emissions of fine and coarse fractions (PM_{10}) is also calculated.

The model covers almost all European countries, including the western part of Russia. RAINS incorporates data on energy consumption for 42 regions in Europe, distinguishing 22 categories of fuel use in six economic sectors. The RAINS database also covers scenarios of non-energy economic activities responsible for air pollution (agricultural production, industrial processes, solvent use etc.). Scenarios for energy development form exogenous input to the model. The model was calibrated using the results from the European emission database compiled by the EMEP (compare http://webdab.emep.int). Data on emission factors from the Corinair inventory of the European Environment Agency (EEA, 2001) were also used. For PM, the Cepmeip inventory (Cepmeip, 2002) developed by the TNO was used as one of the important information sources to determine emission factors and activity levels for some of non-energy related emission sources.

RAINS calculates emission reductions for control strategies reflecting the current pollution control legislation in Europe. Emission reductions are assumed to be achieved exclusively by technical measures; any feedback of emission controls on economic and energy system is not included. Options and costs for controlling emissions for the various substances are represented in the model by reflecting characteristic technical and economic features of the most important emission control technologies. Current implementation of the model covers more than 300 technologies. For example, emissions of SO_2 can be controlled through the use of fuels with lower sulphur content or through desulphurisation of flue gases. Reduction of the emissions from transport can be achieved through implementation of catalytic converters, engine modifications, particulate traps etc. A wide range of measures (for instance, recovery of gasoline vapours, use of water-based paints, incineration or recovery of solvents) is available for the reduction of NMVOC.

Atmospheric dispersion processes for all pollutants are modelled on the basis of results of the EMEP models for acidifying and eutrophying compounds, photo-oxidants and fine particles. Next, the impacts of the scenarios are evaluated using a set of indicators reflecting sensitivities of ecosystems to pollution (critical loads), as well as effects on agricultural crops and human health. For acidification and eutrophication, the model estimates the area of ecosystems not protected for each country by comparing deposition on a grid-level against critical loads. For ozone, an estimate is made of the exceedance of critical (damage) thresholds for agricultural crops (AOT40) and human health (AOT60). More details about the indicators used can be found in Cofala *et al.* (2002). Recently, a methodology was developed to link air pollution scenarios with changes in statistical life expectancy (Mechler, Amann *et al.,* 2002). The first quantitative results for individual countries are now also available. However, because of resource and time constraints, the effect of the scenarios described in this report on life expectancy was not assessed.

All emission control costs in RAINS are calculated in fixed prices for 1995. Following the recommendations of the UN/ECE Task Force on 'Economic Aspects of Abatement Strategies' a uniform interest rate of 4 % was applied to all countries.

3.3. Linking the different models

3.3.1. TIMER and FAIR

In principle, the TIMER and FAIR models use a similar regional breakdown and data can be easily transferred between them. For the RF & EE however, FAIR recognises two different categories: (1) the countries that have emission obligations under the Kyoto Protocol, in particular the Russian Federation and Ukraine and (2) the countries that have not yet adopted emission obligations (most of the other countries). In TIMER, this division does not exist. As the first category contributes the lion's share of the emissions in the region, we have simply assumed the same relative reduction of CO_2 in TIMER as in FAIR. A second limitation in the transfer of data is FAIR's use of historical data from CDIAC for base year emissions (CDIAC, 1999; Elzen and Both, 2002), that may be somewhat different from the TIMER modelling results for 1990. Therefore relative changes compared to 1990 were used in the data transfer between these models.

3.3.2. TIMER to RAINS

For RAINS, country-level energy scenarios are necessary as inputs for emissions calculations. The TIMER model, however, calculates energy use for three large regions in Europe. In terms of fuel types too, the RAINS model is more detailed than TIMER. Finally, the data sources used to calibrate the model for the base year were also different (TIMER is calibrated against IEA data, RAINS uses data from national sources). Thus it was necessary to develop a methodology that translates the TIMER results into more detailed RAINS input.

Equation 1 indicates the basic procedure. It consists of several steps. In the first step, RAINS data for each fuel/sector combination are aggregated into the TIMER level. This aggregation is done for the base year (1995) and for the target year (2010) using one of the previous scenarios available in RAINS. The assumptions of the RAINS scenario used are in fact very similar to the assumptions of the TIMER baseline. Second, for each country, fuel type and sector, the original RAINS data are scaled to the new TIMER value using Equation 1. This routine is also robust for regions where the geographic coverage of RAINS and TIMER is not identical (9).

Equation 1 **Basic procedure for translating TIMER results into RAINS input**

$$\begin{aligned} En\_R_{c,s,f,2010} = {} & En\_R_{old,c,s,f,1995} * (En\_T_{R,s,f,2010} / En\_T_{R,s,f,1995}) * \\ & (En\_R_{old,c,s,f,2010} / En\_R_{old,c,s,f,1995}) / (En\_R_{old,R,s,f,2010} / En\_R_{old,R,s,f,1995}) \end{aligned}$$

Where:

— *En_R* is the energy scenario used by RAINS;
— *old* refers to the data of an earlier RAINS run;
— *En_T* is the scenario in the TIMER format;
— the prefixes *c* and *R* refer to country and region level;
— the prefixes *s* and *f* are used for sector and fuel type.

In addition, some further assumptions and/or data transformations had to be made. First of all, RAINS uses several data for emission calculations on activities not directly related to energy consumption (e.g. production of industrial products causing process emissions, livestock farming, use of solvents in industry and by households etc.). Data from a previous RAINS scenario were used for such a case. This has also been done for specific energy sources for which TIMER did not include specific information (the use of solid waste as a fuel). Secondly, Equation 1 cannot be applied to fuels with very small (or even zero) consumption in the base year. This is particularly important for 'new' renewable energy sources such as solar and wind in power generation and for natural gas use in transport. In these cases, the TIMER output has been scaled down to the country level on the basis of a constant percentage, reflecting the contribution of a given country to regional total. In case of renewables, the share of individual countries in total power generation was used. Data on natural gas use in transport was distributed on the basis of total national demand for transport fuels. Finally, using the scaling method of Equation 1 does not necessarily result in supply meeting demand on a country level. Therefore, for district heat, we have introduced a correction in which demand was scaled back per country to its production level.

In general, the final results on a country level show very good correspondence to country-based projections (e.g. EEA, 2002) indicating that our method for downscaling TIMER results to country level was functioning well (see also Annex B).

3.4. Comparing control costs from TIMER and RAINS: compatibility of costs calculated by different models

There are considerable differences in the methodologies and databases used for control cost calculations in climate change and transboundary air pollution.

In climate change in general, two types of estimates are used to assess the costs of implementation of CO_2 control policies: welfare loss and the change in energy system

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(9) This is the case for Russia, because RAINS includes only the part of Russia west of the Urals.

costs (compare RIVM, EFTEC *et al.*, 2001; Syri *et al.*, 2001). The welfare loss is usually lower than the increase in the costs of the energy system because extra expenditures on energy induced by carbon constraint are recycled within the economy and generate incomes in other sectors. In addition to this fundamental difference in cost concepts, there may be a large number of other factors that can influence cost calculations such as assumptions about substitutability of fuels and technologies, technology development, the coverage of the study etc. As a result, cost estimates for implementing the Kyoto Protocol in western Europe range from several billions to even more than EUR 100 billion (IPCC, 2001). Some of these differences can be understood in terms of the methodological differences mentioned; others simply reflect the uncertainty we are still facing (see also IPCC, 2001). Here, the TIMER model was used to estimate the costs of different climate policies, while RAINS was used to calculate air pollution emission control costs. One should bear in mind that the cost items included in the two models are different.

TIMER uses several cost concepts. The first concept, net implementation costs, calculates the costs on the basis of the carbon tax that is required to reach the specific reduction target in each region. Costs in this case can be calculated by determining the integral of emission reductions and the carbon tax. The second concept is the difference in energy system costs for a mitigation scenario compared to the baseline scenario. These costs are defined as the product of energy consumption, and the costs of energy production and consumption, plus the annuitised expenditures for energy efficiency. A final cost concept which may be used, is additional investment in the energy system. The latter, however, would not include the impacts on fuel trade. None of the three measures is directly related to the costs of a single measure, because each option induces changes in the costs of other parts of the system. Investing in energy efficiency for instance, reduces the costs of energy production. The costs of technologies in TIMER include the effect of learning, i.e. costs change, depending on the pace of implementation of a given option. The underlying information on costs supplied by TIMER and the different cost calculations have been documented (Vries, van Vuuren *et al.*, 2001). It should be noted that TIMER does not account for the costs of controlling the emissions of air pollutants (which prevents double counting these costs if combined with RAINS calculations). In this study, the net implementation costs will be used as the central costs concept.

RAINS calculates for a given energy scenario, the costs of implementing technologies that limit the emissions of air pollutants. These technologies include fuel quality improvement (e.g. low sulphur fuels) and add-on controls like flue gas filters, scrubbers, catalytic converters etc. The assumptions used for cost calculations in RAINS and the appropriate databases are described (Cofala and Syri, 1998; Cofala and Syri, 1998; Klimont, 1998; Klimont, Amann *et al.*, 2000; Klimont, Cofala *et al.*, 2002). In RAINS, no effect of technology development has been accounted for.

Theoretically, adding the control costs, as estimated by TIMER and RAINS, should yield total technical costs of an integrated CO_2 and air pollution control policy. However, as seen above, the two models use different databases and cost concepts. The influence of the two factors has not been explored in detail as yet. Also the models use different interest rates. Thus at the current stage of research we do not recommend that the costs calculated by the two models be simply added up. Instead, we are of the opinion that the models will generate a valuable input for quantitative assessment and identification of the directions of changes in costs of policies when looking at the problem of emissions of greenhouse gases and air pollution separately and in an integrated manner. Comparing the control costs calculated using the two models will indicate the possible orders of magnitude of ancillary benefits.

4. The baseline scenario for carbon dioxide emissions and air pollution in Europe for 2010

A baseline scenario for the year 2010 was developed to assess trends in carbon dioxide emissions in the absence of explicit policies to control greenhouse gas emissions and to assess the effect of control measures on future emissions of air pollutants and ecosystem protection that had already been decided. The baseline scenario includes emission and fuel standards in each country according to the current legislation (CLE) (10) as well as emission ceilings from the National Emission Ceilings Directive of the EU and the Gothenburg Protocol to the CLRTAP. The more stringent value from CLE and the national ceiling was used for each country. The baseline scenario covers three country groupings/regions: western Europe (WE), central and eastern Europe (CEE) and Russian Federation, and western countries of eastern Europe, Caucasus and central Asia countries (RF & EE).

4.1. Main assumptions

The baseline is characterised by a continuation of trends that were dominant during the 1990s: increasing globalisation, further liberalisation and average assumptions for population growth, economic growth and technology development. The baseline is consistent with several other scenarios currently used for European assessments (Capros, 1999; Criqui and Kouvaritakis, 2000; IMAGE-team, 2001; EEA, 2002). Table 4.1 shows the main assumptions on population, economic growth and energy use.

Figure 4.1 shows the resulting total primary energy demand per capita, by fuel type. In western Europe, the scenario results in a slow, continuous increase of absolute and per capita energy use. Natural gas shows by far the fastest growth rates — but oil remains the most important energy carrier. The share of coal further declines, marking a continuation of the 1990–2000 trend. In central Europe, coal has historically been the most important energy carrier. However, in our scenario the position of coal is challenged, both by natural gas (increased use in the residential and commercial sectors as well as for electricity generation) and oil (due to fast growth of private transport). Total energy use is expected to grow considerably from 1995 levels but will not reach the level of the late 1980s. In RF & EE natural gas has become by far the most important energy carrier, certainly after the economic crises in the early 1990s. In our scenario, coal use declines further and natural gas and oil grow modestly after 2000. Total energy use in 2010 remains more than a third below 1990 level.

The baseline assumptions for emission control legislation in individual regions are as follows:

WE:

- Countries in WE adopt emission standards from the large combustion plant and national emission ceilings directives as well as legislation on mobile sources resulting from the auto oil programme.

Table 4.1 **Major baseline assumptions**

Source: RIVM, TIMER model calculations after disaggregating to country level.

	Population (mlns)			GDP (1995 euro/cap)			Share services in GDP (%)		Primary energy use (EJ)		
	1995	2010	AAGR	1995	2010	AAGR	1995	2010	1995	2010	AAGR
WE	384	396	0.2 %	16 250	22 771	2.3 %	69 %	71 %	58.2	66.7	0.9 %
CEE	121	121	0.0 %	2 120	4 195	4.7 %	56 %	57 %	12.9	15.4	1.2 %
RF & EE	293	298	0.1 %	1 312	1 851	2.3 %	51 %	55 %	23.8	23.5	– 0.1 %
World	5 706	6 891	1.3 %	3 704	4 940	1.9 %	63 %	63 %	371	492	1.9 %

(AAGR = annual average growth)

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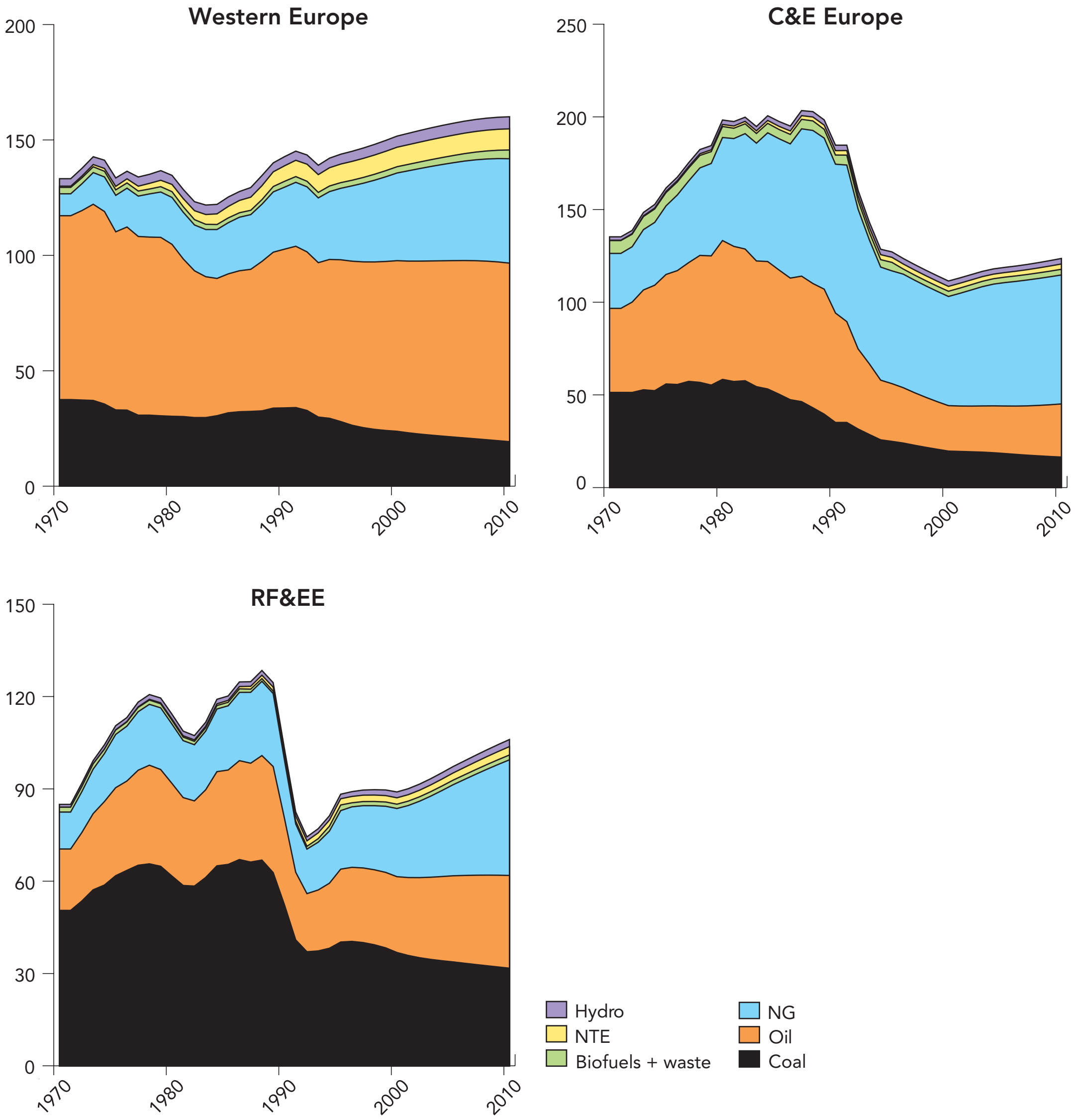
(10) The impacts are assessed for the year 2010 and include policies as decided per December 2001.

Per capita primary energy consumption by fuel in the European sub regions (GJ/cap-year) Figure 4.1



Note: NG = natural gas, NTE = Renewable electricity and nuclear power.

- In addition, national emission standards are implemented (if stricter from the EU-wide).

CEE:

- All candidate countries adopt the EU emission and fuel standards for mobile and stationary sources between 2006 and 2008 at the latest.

- Other CEE countries control emissions according to the provisions of the second sulphur protocol and the Gothenburg Protocol to the CLRTAP (if applicable).

RF & EE:

- Countries from RF & EE comply to the provisions of the second sulphur protocol and the Gothenburg Protocol. For SO_2, the controls include emission standards for new sources and low sulphur gas oil (second sulphur protocol). The Gothenburg Protocol does not specify any national emission ceilings for Russia but only requires implementation of controls in the so-called pollution emissions management areas (PEMA).

- Emissions from transport remain uncontrolled.

4.2. Baseline results

4.2.1. Carbon dioxide and air pollutant emissions

The baseline scenario indicates a significant reduction in the emissions of air pollutants throughout Europe (compare Table 4.2 and Table 4.3), a continuation of the trend that has been seen in the recent past. Figure 4.2 shows the trends for individual pollutants

Table 4.2 **Air emissions in the 2010 baseline scenario**

Source: CO_2 emissions: FAIR/TIMER; other pollutants: RAINS.

	CO_2 (Mton)	SO_2 (kton)	NO_x (kton)	NH_3 (kton)	VOC (kton)	PM_{10} (kton)
WE	3 565	3 153	6 617	3 177	6 697	1 197
CEE	1 008	3 785	2 256	1 367	2 289	768
RF & EE	1 284	2 833	4 001	1 686	3 778	1 276
Total	**5 852**	**9 771**	**12 874**	**6 260**	**12 764**	**3 241**

Table 4.3 **Emissions changes in 2010 as compared with 1990 (%)**

Source: CO_2 emissions: FAIR/TIMER; other pollutants: RAINS.

	CO_2	SO_2	NO_x	NH_3	VOC	PM_{10}
WE	+ 8	– 81	– 52	– 15	– 54	– 56
CEE	– 10	– 68	– 42	– 15	– 22	– 67
RF & EE	– 2	– 71	– 32	– 36	– 26	– 68
Total	– 7	– 74	– 45	– 18	– 44	– 64

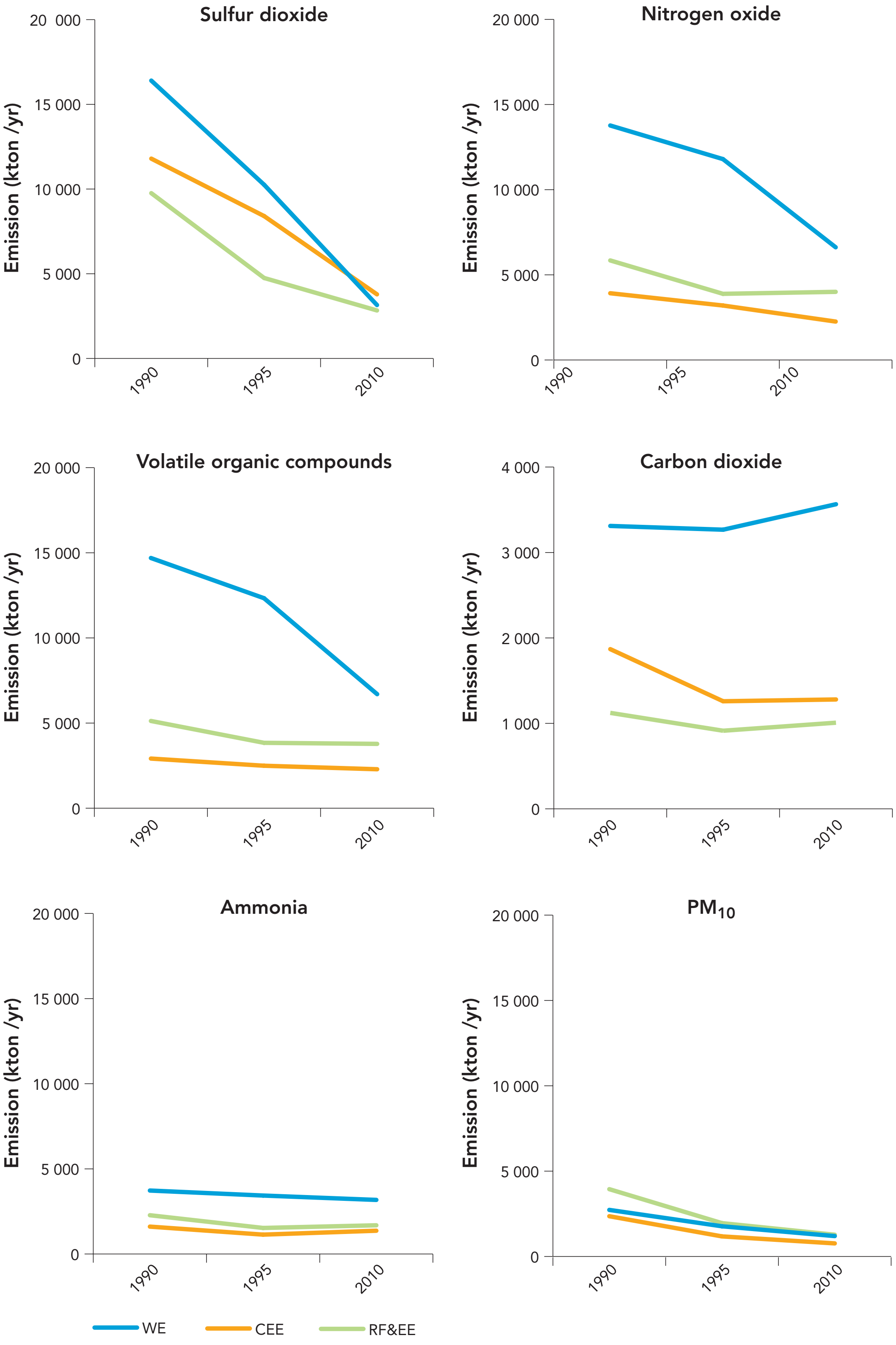
under the baseline scenario. Between 1990 and 1995, the emissions of all pollutants in all three regions considerably decreased. For the whole of Europe, this decrease was approximately 20 % for NO_x and NH_3, 18 % for VOC, 38 % for SO_2 and even 46 % for PM_{10}. In the case of the EU countries the main driver for the decrease of energy-related emissions was the implementation of add-on control technologies and low sulphur fuels, and to a lesser extent, structural changes in the energy system. For PM_{10} in particular, the changes in the eastern parts of Germany were very important too. These are changes in fuel, upgrade to western German emission standards, closing of obsolete plants. In the case of EU candidate — and other east European countries — a large proportion of emission reduction was achieved through reduction in energy demand and agricultural production, which was due to economic restructuring. However, in some candidate countries (Czech Republic, Hungary, Poland and Slovenia) add-on controls on SO_2 sources played an important role in emission reduction.

Under the baseline, the stringent policies for regional air pollution adopted recently in Europe have been assumed to be implemented. As a result, the total European emissions of SO_2 decrease up to 2010 by 74 % compared with 1990. The corresponding reductions of NO_x and VOC are 45 and 44 %. Ammonia emissions are only 18 % lower than the emissions in 1990. The decrease results mainly from the decrease in livestock farming. Finally, PM_{10} emissions are reduced by 34 % from 1995 to 2010.

It should be noted that for WE and CEE, the main part of emissions reductions is achieved as a result of implementing emission and fuel standards according to EU legislation. In Russia and western NIS the emission ceilings will be reached mainly through economic restructuring and a switch to cleaner fuels. Abatement measures play a less important role in these countries. For Europe as a whole, implementation of national emission ceilings (in addition to the emission standards) decreases the emissions of NO_x and SO_2 by 2 % and the emissions of VOC by 7 %. For WE, implementing standards from the recently amended Large Combustion Plant Directive allows the region to reach the national emission ceilings for SO_2. In the case of other pollutants (NO_X, VOC and NH_3), additional measures, on top of the standards, are needed in some of the countries with the most stringent ceilings.

Between 1990 and 1995 the CO_2 emissions in Europe decreased by 10 % (from 6.3 Gtons to 5.4 Gtons CO_2). The trend in the different European regions differs significantly. In the WE regions, emissions decreased slightly by about 1 %. The emissions in CEE and RF & EE fell by almost 20 and more than 30 %, respectively. In contrast to these historical decline trends, emissions are expected to grow in the baseline in all regions between 1995 and 2010 (EEA, 2002). Following the baseline, emissions in WE will be 8 % above 1990 level by 2010. This compares relatively well to several other projections. The differences between these emissions and the national projections submitted to the EU are, for most countries, Emissions of air pollutants under baseline assumptions

Figure 4.2



Source: CO_2 emissions: FAIR/TIMER; other pollutants: RAINS.

also relatively small, as indicated in Annex B. It should be noted that the projections used here only contain the impacts of climate policies formulated before 1998. The emissions in CEE and RF & EE, although higher than in 1995, will remain below the 1990 values (by 10 and 32 %), consistent with the EEA projections (EEA, 2002).

4.2.2. Emission control costs

The emission control costs Table 4.4 include, for each region, the costs of measures necessary to reach the emission reductions discussed in the previous section. The cost of controlling all air pollutants in the baseline scenario for the whole of Europe will increase to about EUR 89 billion per year in 2010. About 57 % of the total costs are the costs of controlling emissions from mobile sources (road and off-road transport). Costs of PM controls from stationary sources contribute about 11 % and the costs of SO_2, 21 % to the total. Since the current policies and emission ceilings for ammonia are still relatively liberal, the costs of controlling ammonia emissions contribute only 2 % of the total cost.

Table 4.4 **Annual control costs and distribution per pollutant for the baseline scenario (1995 prices)**

Source: IIASA (RAINS model).

	Cost, billion	**Distribution of control costs (%)**				
Region	**Euro/year**	**SO_2**	**NO_x+VOC*)**	**NH_3**	**PM_{10}*)**	**Mobile sources**
WE	72	22	11	1	8	59
CEE	14	14	2	7	15	61
RF & EE	3	35	2	1	63	0
TOTAL	**89**	**21**	**9**	**2**	**11**	**57**

Note: *) Only stationary sources.

Table 4.5 **Ecosystem protection against acidification and eutrophication and change in ground level ozone 1990–2010**

Source: RAINS calculations.

	Ecosystems protected (% of ecosystems' area)				**Ozone exposure, change relative to 1990 (%)**	
Region	**Acidification**		**Eutrophication**		**Population (AOT60 (11))**	**Vegetation (AOT40 (12))**
	1990	**2010**	**1990**	**2010**		
WE	76.2	96.2	47.9	64.8	– 72	– 48
CEE	62.2	98.7	20.1	42.4	– 79	– 52
RF & EE	91	99.6	84.4	92.6	– 86	– 53
Total	**83.9**	**98.5**	**69.5**	**82.2**	**– 74**	**– 50**

Western Europe bears 81 % of total European costs, the reasons being the large contribution of the region to total European emissions in the base year and the more stringent emission control compared to other parts of Europe. Thus the marginal reduction costs in WE are higher than in the CEE and Russia, and western NIS.

Implementing the EU legislation by the candidate countries will increase the control costs in CEE. As for WE, compliance with the standards for mobile sources will be particularly costly. Compared with the legislation from the mid-nineties (i.e. with emission and fuel standards adopted before the accession negotiations begun), the costs for candidate countries have more than doubled. About 63 % of (rather low) air-pollution control costs in Russia and western NIS are the costs of dust control equipment (cyclones, electrostatic precipitators) used on larger stationary sources. Other costs for RF & EE result from the necessity to comply with the emission and fuel standards, as specified in the second sulphur protocol.

4.2.3. Regional environmental impacts

Implementation of emission controls will significantly increase the area of ecosystems protected against acidification and eutrophication. For acidification, protection in 2010 will be high throughout Europe (see Table 4.5). The share of unprotected ecosystems decreases in the whole of Europe from 16.1 % in 1990 to as low as 1.5 % in 2010. However, in spite of such impressive improvement there will be still countries where most of their ecosystems are subject to atmospheric deposition above the critical loads. Country level details can be found in Annex A. The areas with excess deposition of

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(11) The AOT60 index is used to quantify health-related ozone levels. It represents the cumulative excess exposure over 60 ppb (parts per billion), for practical reasons over a six-month period.

(12) The AOT40 is the cumulative exposure index over a threshold of 40 ppb. It is calculated using hourly concentrations during daylight hours over a three-month period (growing season). The critical level for agricultural crops (relating to a 5 % crop loss) has been set at an AOT40 of 3 ppm.hours (ppm=parts per million), averaged over a five-year period.

nutrient nitrogen (which is responsible for eutrophication of ecosystems) decrease for Europe as a whole from 30.5 % in 1990 to 18.8 % in 2010. Nevertheless, relatively large areas will remain unprotected from eutrophication, in particular, those in the CEE region (more than 57 %). Substantial reductions of nitrogen emissions would be needed beyond 2010 — especially from the agriculture sector — to further improve the level of protection.

Developments according to the baseline scenario will also substantially reduce population exposure to elevated ozone levels (compare the second part of Table 4.5). The average exposure of a person in Europe (AOT60) will decrease from 2.3 ppm.hours in 1990 to 0.6 ppm.hours in 2010, i.e. by 74 %. However, this also means that in 2010 the WHO guidelines will still be exceeded, in particular in some countries in western Europe (country details can be found in Annex A). Similarly, just as for health effects, the situation will also improve for vegetation. Here, the improvement is significantly less — a 50 % decrease of the exposure index for the whole Europe (AOT40) — from 4.1 excess ppm.hours in 1990 to 2.0 excess ppm.hours in 2010.

5. Kyoto scenarios and ancillary benefits for regional air pollution

This section illustrates the potential ancillary benefits of climate policies for regional air pollution in Europe in 2010. Particularly the reduction of CO_2 emissions through structural changes in the energy sector, or through energy efficiency improvement, also reduces the emissions of air pollutants. Different ways to implement the Kyoto targets (in terms of the use of Kyoto mechanisms) affect the potential for these ancillary benefits. Three scenarios have been developed and compared for exploring this potential.

There are important differences between abatement strategies for climate change and regional air pollution. The effects of climate-change policies on global temperature and other climate indicators are independent of the place where the emissions are reduced. Therefore, climate change policies can aim at the most cost-effective reduction worldwide. Policies to combat regional/local air pollution have to address the location of emission sources. In the European context, it is mainly western Europe (WE) that needs to implement policies to meet the Kyoto targets. The other two regions already meet their target under the baseline. There are several options for WE to meet the target. First, reduction measures can be implemented domestically, i.e. within the WE. Second, WE can use the so-called Kyoto mechanisms of emission trading (ET), joint implementation (JI) and clean development mechanism (CDM), as described in Section 1. The use of Kyoto mechanisms requires interaction with countries from other regions — either with industrialised countries, in the case of ET and JI or with developing countries (CDM).

An important factor in this context is the role of so-called 'surplus emission allowances' (SEA). After the rejection of the Kyoto Protocol by the USA in 2001, the existence of these 'surplus emission allowances' became an even more relevant factor (see Elzen and de Moor, 2002). The total required reduction by the Annex-1 countries under most business-as-usual scenarios (including the baseline in this study) is smaller than the total available surplus emission allowances in central and eastern Europe, the NIS and Russia, so theoretically, only trading these allowances would be enough to implement the Protocol. In reality, however, this would not be an attractive strategy for the countries selling emission credits, as this would drive the carbon price to zero. According to the provisions of the Kyoto Protocol, the surplus emission allowances can be traded to other parties but can also be banked i.e. held for use in the years subsequent to the first commitment period (2008–12).

The following policy scenarios that assume meeting the Kyoto commitments are explored and compared with the baseline (13):

1. **Domestic action only (DAO).** All Annex-1 parties (countries from western Europe, Central Europe as well as Russia, newly independent States, Canada, Australia, New Zealand and Japan) implement their Kyoto targets domestically i.e. without use of the Kyoto mechanisms. The exception is the trade within the regions considered, in particular among the current EU member countries (14).
2. **Trade — no use of surplus emission allowances (TNS).** This scenario assumes full use of the Kyoto mechanisms among Annex-1 parties, but without any use of the 'surplus emission allowances' (SEA). This scenario explores the maximum ancillary benefits that can be obtained under a trade case.
3. **Trade with surplus emission allowances (TWS).** This scenario assumes full use of Kyoto mechanisms among Annex-1 parties and includes the use of 'surplus emission allowances' (SEA). However, the supply of these allowances is limited to the level that

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(13) In all scenarios (including DAO) we assume full use of land use, land-use change and forestry activities and CDM for achieving carbon credits for sinks, as agreed in Marrakech in 2001. The amount of CDM sinks that the European regions can use amounts to 95 Mt CO_2.

(14) We have assumed that the USA will implement the targets indicated in the Bush Climate Change initiative (see Van Vuuren, D. P., den Elzen, M. J. E. *et al.*, 2002. 'An evaluation of the level of ambition and implications of the Bush Climate Change Initiative.' *Climate Policy 2: 293–301.*), which does not result in any improvement over our baseline scenario. At the time of the analysis, Australia had not indicated that it was not going to implement the Kyoto Protocol. The rejection of the Kyoto Protocol by Australia, however, has only a very small impact on the international permit market and thus on the analysis presented here (see Lucas, P., den Elzen, M. G. J. *et al.*, 2002. *Multi-gas abatement analysis of the Marrakech Accords*).

maximises the profits of Russia and Ukraine from selling the emission permits. According to calculations performed by FAIR, the supply of tradable permits on the basis of the 'surplus emission allowances' of some of the central and eastern European countries, the NIS and Russia is 20 % of total available potential (15).

In addition, a sensitivity case (S10) was developed, in which all regions in Europe reduce their CO_2 emissions by 10 %. The purpose of this run is to explore the relationship for similar stricter climate policies.

It needs to be stressed that the results for all the scenarios are of a 'what-if' character and do not intend to be prescriptive for any future implementation of the Kyoto Protocol and air pollution policies. Furthermore, we need to emphasise that all our scenarios concentrate exclusively on the reduction of CO_2 emissions, CO_2 being by far the most important greenhouse gas. Possibilities of reducing other gases (CH_4, N_2O, HFCs, PFCs and SF_6) are not considered. The Kyoto Protocol, however, refers to this total set of six greenhouse gases, and allows for substitution among these.

There are indications that reduction control costs for non-CO_2 gases could be lower than those for CO_2 (see e.g. Lucas, Den Elzen *et al.*, 2002). As a result, in an optimal reduction strategy for all greenhouse gases, reduction rates for CO_2 might be (somewhat) lower than the overall reduction targets. As a result, the actual reduction of CO_2 and the ancillary benefits between climate change policies and regional air pollution can change when the other GHGs are also considered (16).

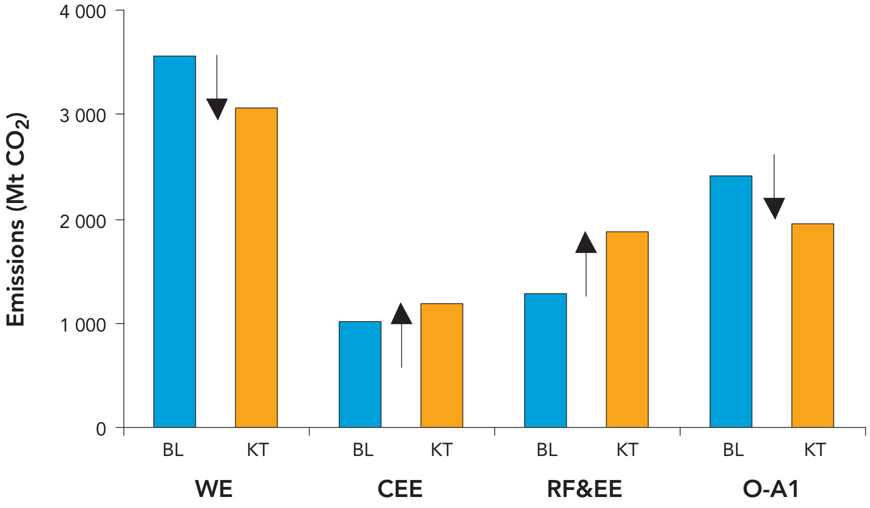
In our scenarios we included the provisions of the Marrakech Accords on carbon sinks. We assumed that the Annex-1 countries could use a total of sinks credits (17) of 440 Mt CO_2, of which 270 Mt CO_2 could be used by the regions included in our study. As shown further in this report, the remaining total emission reduction obligation in Europe, after taking into account these sinks credits, is about 500 Mt CO_2 (see also Elzen and Both, 2002).

5.1. Kyoto scenario results

5.1.1. CO_2 emissions

Figure 5.1 compares the baseline emissions and the reduction target for the different European regions and the group of other

Emissions in the European sub-regions and other Annex-1 countries the baseline (BL) compared to Kyoto targets (KT) according to the Marrakech accords Figure 5.1



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(15) It should be noted that as the total available 'surplus emission allowances' is larger than the required emissions reductions by Annex-1 parties (from the baseline), a scenario that would assume trade with full use of 'surplus emission allowances' would simply equal the baseline.

(16) The consequence could be that there will be fewer changes in the energy system, and therefore less impact on sulphur and nitrogen oxide emissions. At the same time, the increased reductions in CH_4 (as a greenhouse gas) will impact the levels of tropospheric ozone.

(17) Activities covered by Articles 3.3 and 3.4 of the Kyoto Protocol and agricultural management and sinks under the Clean Development Mechanism; for details see Elzen, M. G. J., den and S. Both, 2002. *Modelling emissions trading and abatement costs in FAIR 1.1.* Bilthoven, The Netherlands, National Institute for Public Health and the Environment.

Table 5.1 **Emissions and mitigation actions (% of 1990 emissions)**

	WE			CEE			RF & EE			Europe		
	DAO	TNS	TWS	DAO	TNS	TWS	DAO	TNS	TWS	DAO	TNS	TWS
Baseline	108	108	108	90	90	90	68	68	68	93	93	93
Assigned amounts	93	93	93	106	106	106	100	100	100	97	97	97
Reduction measures												
— Sinks	– 2	– 2	– 2							– 1	– 1	– 1
— Domestic mitigation (energy system)	– 13	– 5	– 3	0	– 7	– 5	0	– 7	– 5	– 7	– 6	– 4
— ET/JI — SEA	0	0	– 5							0	0	– 2
— Other	0	– 5	– 3							0	– 3	– 2
— CDM	0	– 3	– 2							0	– 2	– 1
Actual emissions	93	101	103	90	83	85	68	61	63	85	86	88
Sales of A.A.U.												
ET/JI — SEA	—	—	—	0	0	– 3	0	0	– 7	0	0	0
— Other	—	—	—	0	– 7	– 5	0	– 7	– 5	0	– 1	0
Available for banking	0	0	0	17	17	14	36	36	29	14	14	11

Abbreviations:
ET/JI: emission trading and joint implementation.
SEA: surplus emission allowances.
Other: use of ET/JI leading to actual physical emission reductions.
CDM: clean development mechanism.
A.A.U: assigned amount units.

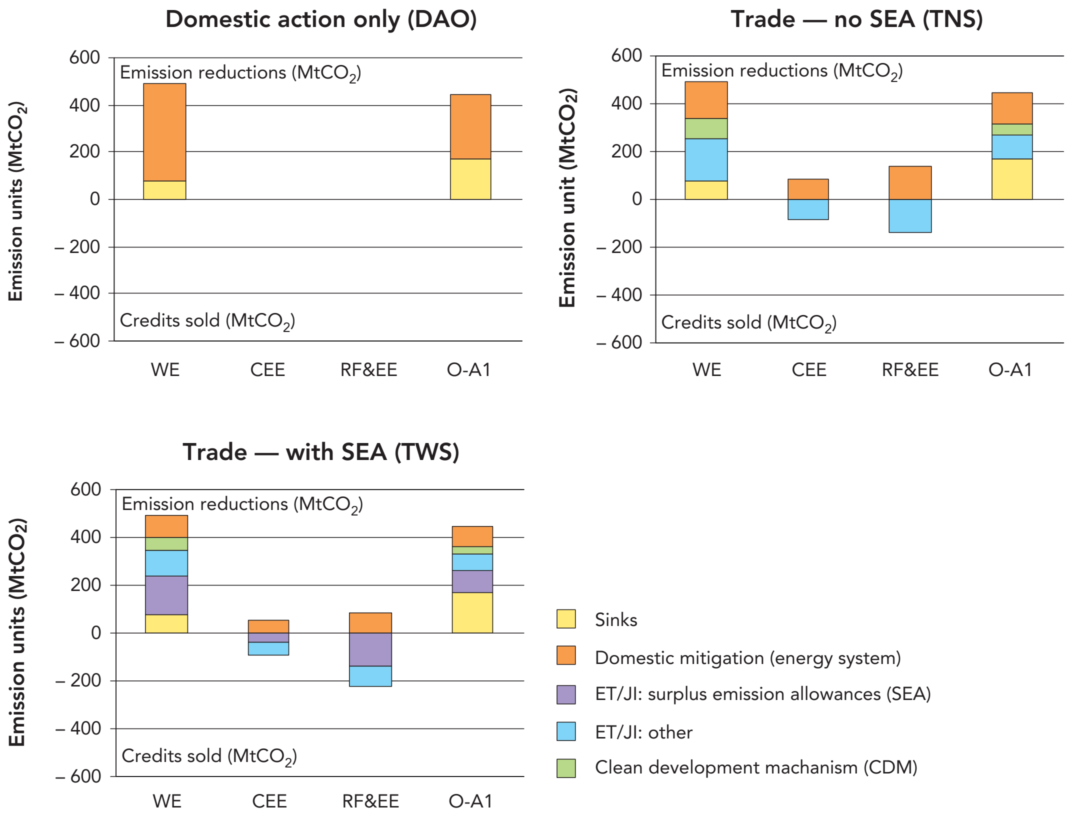
Note: The Kyoto targets are formulated as percentage reductions from base year. For some sources, the base year can be different from the 1990 level. As a result, the assigned amount, expressed as a percentage of 1990 emissions, can differ from those expressed as a percentage of base year emissions. In particular this is the case in the CEE region (6 % increase versus a 7 % reduction). In the WE region, the difference between 1990 and base year emissions and the higher assigned amounts (as percentage) of Switzerland, Norway and Iceland result in an assigned amount of 93 % of 1990 emissions (instead of 92 % for the EU compared to base year). The columns for the total European regions indicate under sales, the trade in assigned amount units with Annex-1 regions outside the European region. Rounding may cause small deviations in sums.

Annex-1 countries (other A-1). The difference between the baseline and the target indicates the reduction burden for western Europe and the other Annex-1 countries (Japan, Canada, Australia and New Zealand), and the 'surplus of emission allowances' (SEA) of CEE and RF & EE.

Emission reduction for each scenario is shown in Figure 5.2. Table 5.1 also demonstrates the reductions in Europe relative to 1990 emissions by country group and measure taken. Of the European regions, only western Europe (WE) reduces its CO_2 emissions in the case of DAO. The reduction from the energy system is about 13 % of 1990 emissions. The balance (2 %) is achieved by carbon sinks. Reduction in emissions from the energy system is achieved through enhanced energy efficiency and changes in the electricity production structure. In the latter case a switch from coal to less carbon-intensive generation options occurs. In addition, some fuel substitution also takes place in the end-use sectors. The total response in the transport sector is small.

In the TWS scenario, we first needed to determine how much of the surplus emission allowances (SEA) would be supplied by the Russian Federation and Ukraine in order to maximise their revenues. The calculations have shown that under the baseline conditions (assuming that the USA does not re-enter the Kyoto Protocol) it is optimal for the Russian Federation and Ukraine to supply only 20 % of the SEA and to 'bank' the rest. In such a case, the use of Kyoto mechanisms further limits the necessity to reduce the emissions from the domestic energy systems of the Annex A countries. In the TWS scenario the contribution of energy-system measures is 3 % in WE, 5 % in CEE and 5 % in the RF & EE of their respective 1990 emissions. This implies that about 80 % of the necessary reductions in WE is achieved by the Kyoto mechanisms. The overall reduction of European emissions compared to 1990 is less than in the domestic action (DAO) case, i.e. 89 % instead of 86 %, which is mainly due to the use of 'surplus emission allowances'.

Figure 5.2 Implementation of the Kyoto targets in the three European regions and other Annex-1 countries according to (a) the domestic implementation scenario, (b) trade without the use of surplus emissions allowances and (c) trade with optimal banking



Note: SEA indicates the use of 'surplus emission allowances', and energy system means reduction of (domestic) energy-related CO_2 emissions.

In the TNS scenario (trade without the use of surplus emission allowances — SEA), the WE and 'Other A-1' countries (Canada, Japan, Australia and New Zealand) use the Kyoto mechanisms to implement their targets. CO_2 reduction in WE, achieved with domestic energy system measures, is now 60 % lower and replaced by the use of CDM and emission trading. The latter induces the reductions in CEE and RF & EE (by 7 % and 8 % of their 1990 emissions, respectively). Total reductions in Europe in this scenario are approximately the same as in the DAO case. This is the net result of a decrease in European emission reductions as a result of CDM use by western Europe, and an increase in reductions in CEE and RF & EE as a result of emission trading with the group of other Annex-1 countries.

Table 5.2 shows the changes in the demand for primary energy. In the case of the DAO (domestic action only), the necessity of reducing carbon emissions in western Europe causes a 38 % decrease in the use of coal. The consumption of oil and gas decreases by 9 % and 2 %, respectively, compared with the baseline. This results in a 7 % decrease in the total demand for primary energy.

Since in the trading scenarios, less CO_2 needs to be reduced through domestic action, the changes in the west European energy system do not need to go so far. In the TNS case (trading, no use of available 'surplus emission allowances') the total energy demand decreases by 2 % and coal use decreases 21 % from the baseline. Consumption of oil decreases by 3 % but the use of gas at the same time increases by the same percentage. Measures that need to be implemented in CEE and in RF & EE cause the drop in the primary energy demand by 4 and 9 %, respectively. This is largely due to a lower use of coal (23 % less in CEE and 32 % less in RF & EE). In the scenario with full use of Kyoto mechanisms, including the 'surplus emission allowances' (TWS), less CO_2 needs to be reduced from the energy system, and therefore the level and structures of fuel use in all regions are closer to the baseline. Nevertheless, also for that scenario the demand for coal substantially decreases

Table 5.2 **Changes in the primary energy demand induced by the CO_2 control compared to the baseline scenario (%)**

Region	DAO	TNS	TWS	S10
WE:				
Total, of which:	**– 7**	**– 2**	**– 1**	**– 6**
Coal	38	– 21	– 14	– 33
Oil	– 9	– 3	– 2	– 7
Gas	– 2	3	3	1
CEE:				
Total, of which:	**0**	**– 4**	**– 2**	**– 6**
Coal	0	– 23	– 17	– 28
Oil	0	– 2	0	– 3
Gas	0	7	6	6
RF & EE:				
Total, of which:	**0**	**– 9**	**– 5**	**– 7**
Coal	0	– 32	– 26	– 30
Oil	0	– 9	– 6	– 7
Gas	0	– 7	– 3	– 5

Table 5.3 **Change in 2010 emissions compared to the baseline scenario (%)**

Scenario	Region	CO_2	SO_2	NO_x	VOC	PM_{10}
DAO	WE	– 12	– 15	– 7	– 1	– 5
	CEE	0	0	0	0	0
	RF & EE	0	0	0	0	0
	Total	**– 7**	**– 5**	**– 4**	**– 1**	**– 2**
TNS	WE	– 4	– 7	– 3	0	– 3
	CEE	– 8	– 16	– 7	– 2	– 9
	RF & EE	– 11	– 19	– 12	– 6	– 7
	Total	**– 6**	**– 14**	**– 6**	**– 2**	**– 6**
TWS	WE	– 3	– 4	– 1	0	– 2
	CEE	– 5	– 11	– 4	– 1	– 7
	RF & EE	– 5	– 15	– 8	– 4	– 6
	Total	**– 4**	**– 10**	**– 4**	**– 2**	**– 4**
S10	WE	– 9	– 12	– 6	– 1	– 5
	CEE	– 10	– 20	– 9	– 2	– 11
	RF & EE	– 9	– 17	– 10	– 5	– 7
	Total	**– 9**	**– 17**	**– 8**	**– 3**	**– 7**

Source: RIVM, IIASA.

(14 % in WE, 17 % in CEE, and 26 % in RF & EE).

Finally, the S10 scenario, with a flat rate reduction of CO_2 emissions, generates fairly similar changes in relative energy demand and its structure in each of the regions (decrease in primary energy demand by 6 to 7 %, decrease of the demand for coal by 28 to 33 %, depending on the region).

5.1.2. Air emissions

Table 5.3 clearly shows that the implementation of the Kyoto Protocol can have important ancillary benefits by reducing emissions of air pollutants in Europe. At the same time, the actual size of these ancillary benefits does strongly depend on the climate policies assumed. In the DAO scenario, CO_2 emission reductions are only implemented in western Europe. Therefore, all ancillary benefits in terms of emissions are restricted to that region. The emissions of SO_2 decrease by 15 % below the baseline levels. The corresponding reductions of NO_x and PM_{10} are 7 and 5 %, respectively.

Compared with the unilateral case (DAO), the European ancillary benefits are higher in the trading scenarios (TNS, TWS). However, since the CO_2 reductions in those scenarios are to a large extent achieved through implementation of cheaper measures in eastern Europe (CEE and RF & EE regions), the ancillary benefits are shifted to those regions.

In particular, CO_2 trading has a strong effect on SO_2 emissions in eastern Europe. This is because a large share of the CO_2 reduction is achieved through the switch from coal to gas, which eliminates the emissions of SO_2. Reductions of NO_x emissions occur mainly in sectors where energy efficiency options are implemented. Thus the effect of trading on NO_x is smaller. Trading also decreases the emissions of PM_{10}. The European emissions are reduced by 4 to 6 %, depending on the scenario. Ancillary benefits for VOC emissions are relatively low (about 2 % reduction from the baseline).

The introduction of surplus emission allowances on the market (scenario TWS) has an important effect on ancillary benefits. Since, in this case, part of the reduction does not require any physical action, fewer changes in the European energy system are necessary. This results in lower reductions of air pollutants. For instance, the reduction of SO_2 emissions is only 10 % instead of 14 % in the TNS scenario.

The sensitivity case (S10), with a 10 % reduction of energy-related CO_2 in each region, demonstrates the effects of more ambitious European CO_2 targets. Stricter targets generate higher ancillary benefits. The emissions of SO_2 are reduced by 17 % from the baseline. The reductions of other pollutants are 8 % (NO_x), 3 % (VOC) and 7 % (PM_{10}).

The TIMER model does not separately specify different categories of biomass for energy (e.g. waste, modern biomass, wood). Therefore, the assumptions on the use of wood for heat generation have been taken from the RAINS database and are identical in all scenarios. Since the use of wood is an important source of PM emissions from the residential sector, the estimates of the changes in PM emission levels would be different if the increased direct burning of wood were included in the CO_2 control scenarios.

5.1.3. Emission control costs

CO_2 emissions

Table 5.4 shows the net implementation costs of CO_2 reduction measures in western Europe. In the DAO scenario, the costs are about EUR 12 billion per year in 2010. This is the net result of additional investments into energy efficiency and the use of low-carbon or zero-carbon supply options and cost reductions for other conventional power supply, reduced oil imports and reduced production of fossil fuels. If only the increased investments into energy efficiency and zero-carbon supply options were accounted for, the costs increase would be EUR 30 billion per year.

The trade scenarios show that the total costs of reducing CO_2 emissions can be more than halved through the use of flexible mechanisms. In the TNS scenario the costs of domestic energy system measures in western Europe decrease to EUR 2 billion. However, at the same time about EUR 5 billion would be needed to be spent on permits, so that the total cost of meeting the Kyoto target for this scenario is EUR 7 billion. In the scenario with 'surplus emission allowances' (TWS), the expenditures on domestic measures decrease to EUR 1 billion and the cost of permits also decreases to slightly above EUR 3 billion.

The results relate well to several other recent European studies. A detailed European study (Blok, De Jager *et al.*, 2001) looking into the costs of domestic implementation of the Kyoto Protocol found costs to vary between EUR 4 and 8 billion, depending on whether EU-wide trading was assumed. This study also covered the non-CO_2 greenhouse gases. Generally, including non-CO_2 gasses in the Kyoto Protocol analysis leads to a limited overall decrease in implementation costs,

Total annual costs in 2010 for reducing CO_2 emissions in western Europe in line with the Kyoto targets (EUR 1995 billion)

Table 5.4

	DAO	TNS	TWS
Domestic measures	12	2	1
Permits	0	5	3
Total	12	7	4

Source: TIMER model calculations.

Table 5.5 **Change in air pollutant emission control costs in 2010 compared to the baseline scenario**

Source: IIASA.

	EUR Bln/year				% of baseline cost (%)			
Region	**DAO**	**TNS**	**TWS**	**S10**	**DAO**	**TNS**	**TWS**	**S10**
WE	– 6.6	– 2.9	– 1.7	– 5.4	– 9	– 4	– 2	– 7
CEE	0.0	– 0.9	– 0.6	– 1.2	0	– 7	– 5	– 8
RF & EE	0.0	– 0.2	– 0.2	– 0.2	0	– 9	– 7	– 8
Total	**– 6.6**	**– 4.1**	**– 2.5**	**– 6.8**	**– 7**	**– 5**	**– 3**	**– 8**

which means that the costs estimated by Blok *et al.* (2001) could even be more consistent with the costs calculated here. The European Environmental Priorities study using the Primes model also found almost similar costs for domestic implementation of the Kyoto Protocol as this study, that is if a similar costs concept is used, i.e. EUR 13.5 billion. According to this study, however, the total energy system costs as an alternative indicator increases by EUR 92 billion (probably not taking reduced energy imports into consideration). The European Environmental Priorities study also includes an estimate of the net implementation costs taking into account trade, which is again close to those found here, i.e. EUR 6.3 billion versus EUR 4–7 billion for the two trade scenarios explored here.

Air pollutants

The ancillary benefits of CO_2 control policies also occur in terms of reduced costs of regional air pollution. The effects for individual scenarios are shown in Table 5.5. In the DAO scenario (requiring strong domestic action in western Europe), the expenditures on regional air pollution mitigation in the western European countries decrease by EUR 6.6 billion (or about 9 %) from the baseline level. In relative terms, the ancillary benefits calculated in this study are similar to the ancillary benefits identified by Syri *et al.* (2001).

The air pollution control costs are also lower in the trading scenarios. However, the cost savings are not as high as in the domestic action case. For instance, in the TNS scenario the saving for the WE region decreases to EUR 2.9 billion per year. Characteristically, there are important cost reductions in the trading scenarios in the CEE and RF & EE regions. For the whole of Europe, the reduction in annual expenditures on air pollution control is about EUR 4.1 billion per year in the TNS scenario. Inclusion of surplus emission allowances reduces the European ancillary benefits to only EUR 2.5 billion per year. The reduction in the cost of the S10 scenario equals to about 8 % of the total baseline cost.

Analysis presented in this section demonstrates that a substantial part of extra expenditures on CO_2 reduction can be recovered in the form of reduced costs of controlling air pollution. Although the use of flexible mechanisms reduces the ancillary benefits, the resulting total cost savings still favour the scenarios with emissions trading. However, as already mentioned in Section 3.4, the cost estimates in TIMER and RAINS are not fully comparable and thus should be treated as an indication of possible synergies rather than the quantitative assessment of the costs of integrated CO_2 and regional air pollution control policies.

5.1.4. Ecosystem protection

In line with the results of Table 5.6, the trading scenarios increase the ecosystem protection against acidification and eutrophication throughout Europe. Although the absolute values of that increase are not high, we should compare them with the protection level already achieved in the baseline. For acidification, only 1.5 % of total European ecosystem area will remain unprotected under the baseline conditions (compare Section 5.5). Thus an additional 0.3 % of ecosystem area protected in the S10 scenario contributes one-fifth of the total distance to sustainable conditions. For eutrophication, (35 % of ecosystems not protected in WE and 18.8 % in the whole of Europe) the climate change policies induce a 'gap closure' (between the baseline and sustainable conditions) of up to 3 % (WE) and 5 % (total Europe). An interesting aspect is the transboundary effects of regional air pollution — which means that the trading scenarios that reduce regional air pollutants in other parts of Europe, may indirectly also reduce environmental impacts in WE. This can be seen by comparing the DAO and TNS scenarios. In the latter, only a third of the action is taken in WE of that of the former;

Improvement in ecosystem protection from acidification (Acid.) and eutrophication (Eutr.) compared to the baseline scenario (% of ecosystem area) Table 5.6

Region	DAO		TNS		TWS		S10	
	Acid.	*Eutr.*	Acid.	*Eutr.*	Acid.	*Eutr.*	Acid.	*Eutr.*
WE	+ 0.4	*+ 1.1*	+ 0.3	*+ 0.7*	+ 0.2	*+ 0.5*	+ 0.5	*+ 1.1*
CEE	+ 0.1	*+ 0.8*	+ 0.4	*+ 1.5*	+ 0.3	*+ 1.0*	+ 0.4	*+ 1.9*
RF & EE	0.0	*+ 0.1*	+ 0.2	*+ 0.6*	+ 0.1	*+ 0.4*	+ 0.2	*+ 0.6*
Total	+ 0.1	*+ 0.3*	+ 0.2	*0.7*	+ 0.1	*+ 0.5*	+ 0.3	*+ 0.8*

still the improvement in acidification impacts is almost similar. By the same token, the DAO scenario also improves the environmental impact indicators in CEE even if no action is taken in this region. For Europe as a whole, the largest ancillary benefits are found for the trading scenarios.

Also for ground level ozone, the CO_2 mitigation scenarios reduce impact indicators (Table 5.7 and Table 5.8). In relative terms, these ancillary benefits can be very substantial. The S10 scenario (in all regions 10 % reduction of CO_2 emissions) reduces the AOT60 impact indicator in Central Europe by 20 % and in Russia and western NIS, by more than 40 %. However, in the second case the reduction occurs from already low levels. Since AOT60 indicator is based on peak concentrations, it can be very responsive to small changes in emissions. In the case of western Europe, the highest reductions are for the S10 scenario (5 %), which includes the positive effects of reducing emissions in other parts of Europe on ozone exceedance in western Europe. For Europe as a whole, the reduction in AOT60 is about 8 %. The effects for the vegetation exposure index (AOT40) are somewhat smaller (less than 7 % reduction for the S10 case, and 5 % reduction for the TNS case).

Population exposure indices for the policy scenarios (AOT60), average index and ppm.hours Table 5.7

Region	BL	DAO	TNS	TWS	S10
WE	0.95	0.92	0.93	0.94	0.90
CEE	0.34	0.32	0.29	0.30	0.27
RF & EE	0.05	0.05	0.03	0.04	0.03
Total	0.60	0.57	0.57	0.58	0.55

Vegetation exposure indices for the policy scenarios (AOT40), average index, excess ppm.hours Table 5.8

Region	BL	DAO	TNS	TWS	S10
WE	3.26	3.15	3.20	3.23	3.15
CEE	2.85	2.77	2.67	2.74	2.61
RF & EE	0.74	0.73	0.61	0.65	0.62
Total	2.04	1.98	1.93	1.97	1.90

6. Discussion

In this report, we have explored the potential ancillary benefits of different ways to implement the Kyoto Protocol in Europe by linking several models that had previously been used to study the impacts of climate change and regional air pollution policies. Within the analysis, five different cases were used (baseline, three Kyoto cases and a sensitivity case). The analysis concentrated, in particular, on the use of Kyoto mechanisms to meet the western European emission target. The energy scenarios were prepared by using the TIMER and FAIR models, and implemented in the integrated assessment framework RAINS to calculate the effects on regional air pollution.

A few remarks should be made on the interpretation of our results. First, no attempt has been made to fully optimise climate change and regional air pollution policies in one integrated framework at this stage. Before this can be done it is necessary to harmonise the costs concepts used by the different models. Second, given the preliminary stage of this type of research, climate policies in the analysis concentrated solely on carbon dioxide. In a multi-gas strategy, reduction rates for non-CO_2 gases are likely to be higher than the average, which implies smaller reductions for carbon dioxide. In this case, both the costs of climate policies and those for ancillary benefits could be somewhat lower.

Overall, the study clearly shows that climate policies and, in particular, implementation of the Kyoto Protocol, will have important ancillary-benefits in reducing regional air pollution. This was found earlier in studies focusing on western Europe. The results of the Domestic Action scenario can be compared with those studies. The European Environmental Priority study (RIVM, EFTEC *et al.,* 2001) and a related study (Syri, Amann *et al.,* 2001) found that reducing the western European CO_2 emissions by 15 % compared to the baseline (– 8 % if related to 1990 emissions) would reduce SO_2 emissions by 24 % and NO_x emissions by 8 %. In our study, the ancillary benefits in terms of emissions reductions are somewhat lower (15 % for SO_2 and 7 % for NO_x resulting from a 12 % reduction of CO_2 emissions) which is due to the inclusion of carbon sinks in the reduction target and different assumptions adopted in the baseline (higher fuel efficiency of cars according to the ACEA agreement, stricter emission control legislation resulting from the Gothenburg Protocol and the National Emission Ceilings and Large Combustion Plants Directives). A study for western Europe using the E3ME model, also estimated the possible ancillary benefits after domestic implementation of the Kyoto Protocol (in this case a 10 % reduction from baseline for CO_2), to find comparable numbers: 12–14 % for SO_2, 7–8 % for NOx and 4 % for PM_{10} (Barker, 2000). The reduction for PM_{10} emissions found in this study is 5 % (again 12 % reduction of CO_2). Differences between the E3ME study and this study can be explained by different CO_2 baseline projections and the assumed policies for regional air pollutants.

An important finding of our study is that the link between the reduction in CO_2 emissions and regional air pollution is stronger in Central Europe and in Russia/western NIS than in western Europe. This is caused by heavy reliance on coal in eastern Europe and by less stringent emission control legislation. Thus a switch to cleaner fuels in this region has, as a side effect, higher reduction in emissions of sulphur and PM compared with the reductions achievable in western Europe.

Implementation costs of the Kyoto target vary; according to this study, these are between EUR 12 billion per year for the domestic action case and EUR 4–7 billion for the trading scenarios. Thus, the trading scenarios result in significantly lower costs. This general observation is also found in other studies looking at the costs of the Kyoto Protocol. Overall, the costs calculated in this study seem to be within the broad range of different cost estimates. This in particular holds for comparison with the Sectoral Objectives Study, a detailed technology oriented study on domestic implementation of the Kyoto Protocol and the European Environment Objective study, as indicated in Section 5.1.3.

Our study shows that implementation of the Kyoto Protocol will lead to lower costs for regional air pollution control. For the domestic implementation of Kyoto targets in western Europe, the changes in the energy system result in a decrease of air pollution control expenditures by 9 % or EUR 6.6 billion per year. This result suggests that for the domestic action scenario, about half of the total costs to implement the Kyoto target are regained in terms of reduced costs for air pollution control. A set of other studies that looked into the potential reduction of regional air pollution control *vis-à-vis* climate control costs also found significant cost reductions, although these were generally lower (around 20–30 %). These studies cover the EU (Syri, Amann *et al.,* 2001), Netherlands (Smeets and Wijngaart, 2002), and the USA (Burtraw and Toman, 2000).

Finally, an alternative set of literature sources on ancillary benefits focuses on benefits in terms of avoided 'externality damage', i.e. reductions in impact on health and ecosystems expressed in monetary terms. Barker and Rosendahl (2000) specifically looked at the gains of implementing the Kyoto Protocol in western Europe by means of domestic action, and found results of avoided externality damage that have a similar order of magnitude, i.e. EUR 9 billion as the avoided air pollution control costs calculated here. Other ancillary-benefit studies, almost all at a country level, have found a somewhat higher relative reduction of environmental damage. However, most of the studies cover a much wider range of environmental parameters and often calculate impacts for 1990, with much higher emissions of air pollutants.

7. Conclusions

From this explorative study on the potential ancillary benefits for air pollution in Europe of implementing the Kyoto Protocol, several general conclusions can be drawn as presented below. These are accompanied by a brief explanation and examples underpinning the conclusions with quantitative results.

- **Implementation of climate change policies to comply with the Kyoto Protocol is likely to yield substantial ancillary benefits for air pollution in Europe. These ancillary benefits are expected to result in a decrease in air pollution emissions and control costs but also in increased environmental protection.**

  Implementing the Kyoto Protocol in Europe reduces the emissions of SO_2 and NO_x by 5–14 % and 4–6 %, respectively, depending on the scenario. Similarly, PM_{10} and VOC emissions are reduced by 2–6 % and 1–2 %, respectively. The improvement of ground-level ozone exposure of population and vegetation is 3–5 %. The reduced emissions also increase the protection of ecosystems in terms of reduced exceedance above critical thresholds throughout Europe.

  Implementation of the Kyoto Protocol in Europe also reduces the control costs for air pollutants. This is caused by structural changes in energy systems induced by climate change policies. The results indicate reduction in control costs of 3–7 % (EUR 2.5–7 billion). The scenarios where the Kyoto flexible mechanisms are used result in savings in control costs of 5–9 % for central and eastern Europe, and for Russia and the western New Independent States.

- **The type and size of ancillary benefits depend on how the flexible mechanisms and surplus emission allowances are used to meet the Kyoto targets.**

  The links between the CO_2 and air pollutant emissions are weaker in western Europe (WE) than they are in central and eastern Europe (CEE), and Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries (here denoted RF & EE). This is due to more stringent air pollution control legislation and less use of coal (only in comparison with CEE). Therefore the ancillary benefits in terms of emission reductions for Europe as a whole may be higher in the scenarios that involve the Kyoto flexible mechanisms than in the domestic action scenario. Similarly, savings in control costs are dominated by abatement measures in WE due to the relatively high marginal control costs there, which will be reduced by required structural changes in the energy system to comply with the Kyoto targets.

— **The use of flexible mechanisms will shift ancillary benefits in terms of reduction in air pollutant emissions from WE to CEE and Russia, and western NIS. For Europe as a whole, ancillary benefits increase in the trading scenarios but not in the domestic action scenario.**

In meeting the Kyoto targets through domestic actions only, ancillary benefits are limited to western Europe (as only this region needs to take additional action). Since emission trading and joint implementation will result in changes in the energy system in the other European regions also the ancillary benefits will be partially shifted to the other European regions.

The ancillary benefits for Europe as a whole are higher in the trading scenarios than in the domestic action case, due to the stronger link between sulphur and carbon dioxide emissions in these regions than in western Europe.

For western Europe the domestic action scenario yield a somewhat higher ecosystem protection against further acidification and eutrophication as well as reduced concentrations of ground level ozone compared to the trading scenarios. However, due to the transboundary nature of air pollution, the absolute differences in ecosystem protection are relatively small.

- **Using surplus emission allowances will reduce ancillary benefits, in particular for CEE and Russia and western NIS.**

  Introduction of the available surplus emission allowances on the carbon market of the future reduces the need for actual physical emission reductions through emissions trading and joint implementation. Consequently, reduction in air pollutant emissions and savings in control cost will drop, particularly in CEE and Russia, and the western NIS. Reduction in SO_2 and NO_x emissions drop by 4 % and 2 %, respectively, when surplus emission allowances are put on the carbon market. Corresponding savings in control cost for air pollution drop by about 2 % (EUR 1.5 billion).

  Joint implementation and emission trading bring about substantial reduction in control costs for air pollution in CEE and RF & EE. As expected, both emission reductions in air pollutants and associated control costs are reduced when surplus emission allowances are put on the carbon market, thus offsetting the need for actual physical abatement strategies.

- **Climate policies can lead to large cost savings in reducing air pollution emissions. Results may be important in designing climate policies.**

  Thus the exact implementation of the Kyoto Protocol (with regard to the use of Kyoto mechanisms) strongly impacts the ancillary benefits for regional air pollution. For Europe as a whole, and more specifically for western Europe, the use of Kyoto mechanisms reduces not only direct climate policy costs but also the savings in control cost for air pollution. At the same time, this use increases ancillary benefits in terms of reduction in European air pollution emissions. Comparison of climate control costs and air pollution control still has to be carried out carefully in this study, as these cost assessments are performed using different methods. Still, results indicate substantial savings for ancillary benefits compared to climate control costs (around 50 %). For this reason, the exact design of climate policy should take care of ancillary benefits.

According to the costs concept used in the climate policy evaluation, the implementation costs of meeting the Kyoto target vary from EUR 4 to 12 billion per year in 2010, with the trading scenarios resulting in significantly lower costs than the domestic action case. For domestic implementation of the Kyoto targets in western Europe, air pollution control expenditures decrease 7 % from the baseline, or by EUR 6.6 billion. Emissions trading results in a smaller reduction of air pollution control costs in western Europe (EUR 1.7 to 2.9 billion) but is compensated by a higher reduction in climate policy costs.

The results of our explorative study suggest that a proportion of the implementation costs of the Kyoto policies can be re-gained in terms of reduced costs of air pollution.

The scenarios considered in this study demonstrate that both financial and air-pollution benefits might justify the limitation on the use of 'surplus emission allowances' (SEA) in climate policies from the perspective from countries in the CEE and RF & EE regions. The financial benefits occur as by limiting supply, countries with SEA can maximise revenues by raising the permit price. The second category, which can be seen from comparing the trade scenario with and without the use of SEA occur as physical measures in CEE and RF & EE have ancillary benefits in reducing air pollution and its control costs, while SEA has not. Both effects are very substantial. From the perspective of WE, limiting use of SEA raises the effectiveness and credibility of the Kyoto Protocol (but also its costs). The scenarios also show that the use of flexible instruments for western Europe, leading to real emission reductions in central and eastern Europe, may have several attractive side effects. Examples are greater improvement in the overall environmental situation in Europe and even some improvement in the western European environment (due to transboundary nature of regional air pollution). When CDM is used with developing countries these benefits in Europe are relinquished.

- **An integrated approach to climate change and regional air pollution policies could be important for harvesting potential ancillary benefits in the future**

  The results of this study suggest that integrating future developments on climate change and regional air pollution policies may lead to important efficiency gains. Still, further development of tools and analysis is necessary. In particular, the assessment models need to be extended so that not only CO_2 but also other greenhouse gases are included. In addition, the costing methodologies need to be unified. This will help in defining the strategies that fully harvest the potential synergies between air pollution and climate change.

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Annex 1: Country level results

CO$_2$ emissions for the five scenarios (in million tons)

Table A1.1

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	57	59	61	56	60	60	58
Belgium	108	115	126	114	123	124	117
Denmark	54	61	60	51	56	57	53
Finland	59	66	82	68	75	77	70
France	378	367	419	379	405	412	388
Germany	991	888	839	702	777	800	728
Greece	76	82	112	91	102	106	95
Ireland	31	33	45	40	43	44	41
Italy	428	434	474	432	463	469	445
Luxembourg	9	7	8	7	7	7	7
Netherlands	160	172	205	189	202	204	195
Portugal	42	52	73	63	69	70	65
Spain	222	242	305	267	290	296	275
Sweden	54	73	84	76	81	82	78
United Kingdom	572	540	584	529	569	576	546
Total EU-15	*3 242*	*3 190*	*3 477*	*3 063*	*3 323*	*3 386*	*3 162*
Norway	27	33	41	40	42	42	41
Switzerland	42	43	47	42	45	46	43
Total western Europe	***3 311***	***3 267***	***3 565***	***3 145***	***3 409***	***3 473***	***3 246***
Bulgaria	86	61	81	81	75	77	74
Czech Republic	157	126	134	134	120	125	116
Estonia	33.6	18	12	12	9	10	9
Hungary	67	61	70	70	71	71	70
Latvia	24	10	11	11	10	10	10
Lithuania	38	16	18	18	16	17	17
Poland	364	348	347	347	305	319	294
Romania	152	125	154	154	152	154	149
Slovakia	63	44	54	54	51	52	50
Slovenia	15	14	17	17	17	17	16
Total candidate countries	*999*	*822*	*896*	*896*	*826*	*852*	*804*
Albania	6	5	8	8	7	7	7
Bosnia-Herzegovina	23	16	20	20	18	19	17
Croatia	21	16	24	24	24	25	24
FYR Macedonia	12	10	10	10	9	9	8
Yugoslavia	62	44	50	50	44	46	42
Total central and eastern Europe	***1 123***	***914***	***1 008***	***1 008***	***927***	***957***	***903***
Belarus	115	70	76	76	70	72	71
Moldova	29	11	16	16	14	15	14
Russia	1 046	747	756	756	684	715	697
Ukraine	679	431	432	432	372	391	380
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***1 869***	***1 259***	***1 280***	***1 280***	***1 140***	***1 193***	***1 162***
Total	**6 303**	**5 439**	**5 852**	**5 433**	**5 477**	**5 624**	**5 312**

Note: Russia contains only the European part within the EMEP region.

Table A1.2 **SO$_2$ emissions (in kilotonnes)**

Country	**1990**	**1995**	**2010**				
			BL	**DAO**	**TNS**	**TWS**	**S10**
Austria	93	56	33	30	32	33	31
Belgium	370	246	99	97	99	99	99
Denmark	182	149	48	39	44	45	41
Finland	242	98	87	73	81	83	76
France	1 256	932	375	375	375	375	375
Germany	5 291	2 000	519	409	464	483	426
Greece	492	548	219	170	195	203	178
Ireland	178	165	42	42	42	42	42
Italy	1 651	1 363	328	280	311	318	291
Luxembourg	21	8	4	4	4	4	4
Netherlands	200	144	50	50	50	50	50
Portugal	342	367	131	110	122	125	113
Spain	2 062	1 731	518	431	477	491	446
Sweden	117	81	67	59	64	65	61
United Kingdom	3 812	2 298	585	475	541	563	496
Total EU-15	*16 308*	*10 186*	*3 105*	*2 645*	*2 899*	*2 979*	*2 728*
Norway	52	34	22	21	22	22	21
Switzerland	42	34	26	24	26	26	24
Total western Europe	***16 402***	***10 254***	***3 153***	***2 689***	***2 947***	***3 027***	***2 774***
Bulgaria	1 842	1 483	733	733	606	644	576
Czech Republic	1 873	1 112	213	213	175	187	166
Estonia	261.4	118	58	58	42	45	43
Hungary	966	705	174	174	144	153	137
Latvia	121	59	27	27	24	24	24
Lithuania	222	95	47	47	42	44	43
Poland	3 001	2 363	1 059	1 059	875	932	832
Romania	1 331	1 104	546	546	474	498	454
Slovakia	548	234	95	95	83	87	79
Slovenia	200	129	27	27	27	27	27
Total candidate countries	*10 364*	*7 403*	*2 979*	*2 979*	*2 491*	*2 640*	*2 381*
Albania	72	51	56	56	53	54	51
Bosnia-Herzegovina	487	364	361	361	285	307	269
Croatia	180	69	70	70	66	68	65
FYR Macedonia	107	94	73	73	61	64	58
Yugoslavia	585	423	246	246	205	217	195
Total central and eastern Europe	***11 796***	***8 404***	***3 784***	***3 785***	***3 160***	***3 350***	***3 019***
Belarus	843	279	324	324	289	300	294
Moldova	197	43	72	72	57	60	58
Russia	5 012	2 607	1 509	1 509	1 247	1 313	1 273
Ukraine	3 706	1 822	928	928	702	748	719
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***9 758***	***4 751***	***2 833***	***2 834***	***2 294***	***2 421***	***2 344***
Total	**37 956**	**23 409**	**9 771**	**9 308**	**8 401**	**8 798**	**8 136**

Note: Russia contains only the European part within the EMEP region.

NO_x emissions (in kilotonnes) Table A1.3

Country	**1990**	**1995**	**2010**				
			BL	**DAO**	**TNS**	**TWS**	**S10**
Austria	192	171	98	92	96	97	94
Belgium	344	341	176	165	176	176	169
Denmark	274	260	127	127	127	127	127
Finland	280	224	150	132	141	145	135
France	1 867	1 669	810	810	810	810	810
Germany	2 717	1 974	970	849	915	936	871
Greece	331	336	336	292	316	323	300
Ireland	113	124	65	64	65	65	65
Italy	2 037	1 751	985	908	960	972	927
Luxembourg	22	21	10	9	10	10	9
Netherlands	571	495	260	255	260	260	260
Portugal	303	361	249	221	237	242	227
Spain	1 166	1 244	831	745	794	808	761
Sweden	338	313	148	148	148	148	148
United Kingdom	2 839	2 178	1 167	1 073	1 150	1 167	1 101
Total EU-15	*13 394*	*11 462*	*6 382*	*5 890*	*6 205*	*6 286*	*6 002*
Norway	220	211	156	156	156	156	156
Switzerland	155	123	79	79	79	79	79
Total western Europe	***13 769***	***11 796***	***6 617***	***6 125***	***6 440***	***6 521***	***6 237***
Bulgaria	355	249	246	246	234	239	230
Czech Republic	546	424	245	245	223	230	217
Estonia	83.3	42	40	40	34	36	35
Hungary	219	195	113	113	112	113	110
Latvia	116	48	38	38	35	36	35
Lithuania	151	84	73	73	65	67	66
Poland	1 217	1 145	604	604	535	557	517
Romania	518	435	378	378	370	375	364
Slovakia	219	175	110	110	105	107	103
Slovenia	60	70	37	37	35	36	35
Total candidate countries	*3 485*	*2 867*	*1 885*	*1 885*	*1 748*	*1 796*	*1 713*
Albania	24	24	41	41	39	40	38
Bosnia-Herzegovina	80	54	61	61	57	59	56
Croatia	80	69	87	87	87	87	87
FYR Macedonia	39	30	29	29	27	28	27
Yugoslavia	211	155	153	153	142	146	139
Total central and eastern Europe	***3 919***	***3 199***	***2 256***	***2 256***	***2 101***	***2 155***	***2 060***
Belarus	385	219	252	253	226	236	230
Moldova	87	41	53	53	46	48	47
Russia	3 486	2 411	2 474	2 475	2 212	2 303	2 250
Ukraine	1 888	1 215	1 222	1 204	1 049	1 097	1 069
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***5 846***	***3 885***	***4 001***	***3 984***	***3 533***	***3 684***	***3 595***
Total	**23 534**	**18 880**	**12 874**	**12 364**	**12 074**	**12 360**	**11 893**

Note: Russia contains only the European part within the EMEP region.

Table A1.4 **NH_3 emissions (in kilotonnes)**

Country	1990	1995	2010
Austria	77	71	66
Belgium	97	100	74
Denmark	122	76	69
Finland	40	36	31
France	810	782	780
Germany	757	655	550
Greece	80	75	73
Ireland	127	121	116
Italy	462	435	419
Luxembourg	7	7	7
Netherlands	233	164	128
Portugal	77	73	73
Spain	352	366	353
Sweden	61	60	57
United Kingdom	329	320	297
Total EU-15	*3 631*	*3 341*	*3 093*
Norway	23	22	21
Switzerland	72	70	63
Total western Europe	***3 727***	***3 433***	***3 177***
Bulgaria	141	81	108
Czech Republic	107	76	101
Estonia	28.9	14	29
Hungary	120	65	90
Latvia	43	16	35
Lithuania	80	41	81
Poland	505	424	468
Romania	292	192	210
Slovakia	60	35	39
Slovenia	23	18	21
Total candidate countries	*1 398*	*961*	*1 181*
Albania	32	28	35
Bosnia-Herzegovina	31	23	23
Croatia	40	33	30
FYR Macedonia	17	16	16
Yugoslavia	90	77	82
Total central and eastern Europe	***1 608***	***1 138***	***1 367***
Belarus	219	150	158
Moldova	47	34	42
Russia	1 282	831	894
Ukraine	729	515	592
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***2 277***	***1 530***	***1 686***
Total	**7 611**	**6 100**	**6 230**

Note: Russia contains only the European part within the EMEP region.

VOC emissions (in kilotonnes) Table A1.5

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	352	271	159	159	159	159	159
Belgium	376	298	139	139	139	139	139
Denmark	182	154	80	78	79	80	78
Finland	213	188	121	118	120	120	119
France	2 382	1 968	1 050	1 050	1 050	1 050	1 050
Germany	3 122	2 205	995	995	995	995	995
Greece	336	312	204	196	201	202	198
Ireland	110	102	48	46	47	47	46
Italy	2 055	2 103	1 113	1 080	1 099	1 105	1 085
Luxembourg	19	18	7	7	7	7	7
Netherlands	490	374	185	185	185	185	185
Portugal	294	310	180	180	180	180	180
Spain	1 008	972	636	617	627	631	620
Sweden	511	420	241	241	241	241	241
United Kingdom	2 672	2 048	1 200	1 200	1 200	1 200	1 200
Total EU-15	*14 120*	*11 743*	*6 358*	*6 291*	*6 329*	*6 342*	*6 302*
Norway	297	365	195	195	195	195	195
Switzerland	278	224	144	142	143	143	142
Total western Europe	***14 695***	***12 333***	***6 697***	***6 627***	***6 667***	***6 680***	***6 639***
Bulgaria	195	159	165	165	162	163	161
Czech Republic	442	310	220	220	220	220	220
Estonia	45.4	36	39	39	37	38	38
Hungary	204	170	132	132	129	130	128
Latvia	63	43	41	41	38	39	38
Lithuania	111	100	77	77	71	73	72
Poland	800	723	636	636	621	626	616
Romania	504	479	481	481	476	478	474
Slovakia	151	116	111	111	109	110	108
Slovenia	55	72	40	40	40	40	40
Total candidate countries	*2 570*	*2 208*	*1 941*	*1941*	*1 903*	*1 917*	*1 895*
Albania	31	28	43	43	42	42	42
Bosnia-Herzegovina	51	39	50	50	48	49	48
Croatia	103	87	90	90	90	90	90
FYR Macedonia	19	14	20	20	19	19	19
Yugoslavia	142	118	145	145	140	142	139
Total central and eastern Europe	***2 915***	***2 494***	***2 288***	***2 288***	***2 243***	***2 259***	***2 232***
Belarus	371	256	308	308	287	294	289
Moldova	50	34	42	42	38	40	39
Russia	3 542	2 727	2 631	2 631	2 465	2 517	2 486
Ukraine	1 161	823	797	797	749	771	758
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***5 124***	***3 840***	***3 778***	***3 778***	***3 539***	***3 621***	***3 572***
Total	**22 734**	**18 667**	**12 763**	**12 694**	**12 449**	**12 560**	**12 444**

Note: Russia contains only the European part within the EMEP region.

Table A1.6 **PM_{10} emissions (in kilotonnes)**

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	54	44	31	31	31	31	31
Belgium	92	78	42	40	41	41	41
Denmark	33	31	23	22	23	23	22
Finland	38	31	26	25	25	25	25
France	308	289	191	182	187	188	184
Germany	1 007	281	191	180	186	188	182
Greece	87	57	60	53	56	58	54
Ireland	30	21	15	14	14	14	14
Italy	273	244	152	146	149	150	147
Luxembourg	6	5	2	2	2	2	2
Netherlands	75	62	51	50	50	51	50
Portugal	43	43	33	31	32	32	31
Spain	218	216	148	138	143	144	140
Sweden	60	38	32	31	32	32	31
United Kingdom	330	261	141	129	135	137	131
Total EU-15	*2 655*	*1 701*	*1 137*	*1 074*	*1 107*	*1 118*	*1 084*
Norway	55	50	44	44	44	44	44
Switzerland	20	18	15	15	15	15	15
Total western Europe	***2730***	***1 770***	***1 197***	***1 132***	***1 166***	***1 177***	***1 143***
Bulgaria	286	107	114	114	100	104	96
Czech Republic	349	142	61	61	55	57	54
Estonia	101.5	55	14	14	11	11	11
Hungary	142	63	32	32	31	32	31
Latvia	22	13	7	7	7	7	7
Lithuania	33	15	12	12	12	12	12
Poland	624	340	189	189	177	181	173
Romania	374	192	162	162	150	154	148
Slovakia	98	45	30	30	28	29	27
Slovenia	32	15	10	10	9	9	8
Total candidate countries	*2 060*	*987*	*632*	*632*	*579*	*595*	*568*
Albania	18	8	9	9	8	8	8
Bosnia-Herzegovina	63	45	31	31	25	26	23
Croatia	45	18	19	19	18	18	18
FYR Macedonia	32	25	14	14	12	12	11
Yugoslavia	142	94	64	64	54	57	52
Total central and eastern Europe	***2 360***	***1 177***	***768***	***768***	***696***	***717***	***681***
Belarus	119	61	55	55	53	53	53
Moldova	45	15	16	16	14	15	14
Russia	2 567	1 267	826	826	776	789	781
Ukraine	1 213	611	379	379	339	348	343
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***3 945***	***1 954***	***1 276***	***1 276***	***1 183***	***1 206***	***1 192***
Total	**9 035**	**4 901**	**3 241**	**3 176**	**3 044**	**3 100**	**3 015**

Note: Russia contains only the European part within the EMEP region.

Emission control costs in 2010 (million EUR/year) Table A1.7

Country	**BL**	**DAO**	**TNS**	**TWS**	**S10**
Austria	1 492	1 407	1 456	1 472	1 422
Belgium	2314	2 143	2 239	2 271	2 171
Denmark	984	870	929	949	888
Finland	1 262	1 119	1 191	1 216	1 141
France	9 488	8 689	9 142	9 288	8 825
Germany	17 077	15 323	16 269	16 572	15 627
Greece	1 757	1 506	1 634	1 678	1 546
Ireland	841	770	809	822	782
Italy	10 787	9 968	10 441	10 589	10 115
Luxembourg	106	99	103	104	100
Netherlands	3 522	3 243	3 400	3 450	3 290
Portugal	1 313	1 193	1 259	1 281	1 213
Spain	5 833	5 312	5 602	5 695	5 403
Sweden	2 236	2 005	2 133	2 176	2 044
United Kingdom	11 037	9 964	10 620	10 793	10 199
Total EU-15	*70 050*	*63 611*	*67 228*	*68 355*	*64 765*
Norway	813	756	789	799	766
Switzerland	1 340	1 244	1 295	1 315	1 258
Total western Europe	***72 204***	***65 611***	***69 312***	***70 469***	***66 790***
Bulgaria	774	774	704	726	686
Czech Republic	2 223	2 223	2 035	2 095	1 987
Hungary	56	56	39	41	40
Estonia	1 306	1 306	1 262	1280	1 246
Latvia	127	127	113	117	115
Lithuania	209	209	187	194	190
Poland	5 657	5 657	5 280	5403	5 177
Romania	1 550	1 550	1 490	1509	1 473
Slovakia	901	901	857	873	843
Slovenia	722	722	682	695	670
Total candidate countries	*13 527*	*13 527*	*12 648*	*12 933*	*1 2429*
Albania	14	14	13	14	13
Bosnia-Herzegovina	57	57	46	49	43
Croatia	94	94	89	91	86
FYR Macedonia	24	24	20	21	19
Yugoslavia	204	204	165	176	157
Total central and eastern Europe	***13 920***	***13 920***	***12 982***	***13 284***	***12 748***
Belarus	55	55	53	53	53
Moldova	22	22	19	20	19
Russia	1 682	1 682	1 568	1 597	1 580
Ukraine	852	852	746	767	754
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***2 611***	***2 611***	***2 386***	***2 437***	***2 406***
Total	**88 734**	**82 142**	**84 679**	**86 190**	**81 944**

Note: Russia contains only the European part within the EMEP region.

Table A1.8 **Ecosystems with deposition exceeding critical loads for acidification (% of ecosystem area)**

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	47.6	23.9	2.1	2.0	2.0	2.0	1.9
Belgium	58.4	39.6	15.3	14.0	15.0	15.1	14.4
Denmark	20.0	5.4	1.7	1.5	1.5	1.6	1.5
Finland	17.2	5.0	2.4	2.3	2.0	2.2	2.0
France	25.8	11.1	0.4	0.3	0.4	0.4	0.3
Germany	79.6	57.3	10.0	8.3	8.9	9.3	8.2
Greece	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	10.7	5.4	1.0	1.0	1.0	1.0	1.0
Italy	19.5	8.3	0.5	0.5	0.5	0.5	0.5
Luxembourg	66.8	16.3	4.6	4.4	4.5	4.5	4.4
Netherlands	89.3	84.2	48.8	42.8	46.9	47.6	44.2
Portugal	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Spain	0.9	0.6	0.1	0.1	0.1	0.1	0.1
Sweden	16.5	9.1	3.2	2.9	2.9	3.0	2.8
United Kingdom	43.0	29.6	9.1	7.7	8.5	8.8	7.9
Total EU-15	*24.8*	*13.3*	*2.9*	*2.6*	*2.6*	*2.8*	*2.5*
Norway	24.1	17.8	9.7	9.0	9.2	9.4	8.8
Switzerland	41.1	25.9	3.6	3.3	3.5	3.5	3.3
Total western Europe	***24.8***	***14.0***	***3.8***	***3.4***	***3.5***	***3.6***	***3.3***
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	90.1	75.2	3.8	3.0	2.8	3.0	2.5
Estonia	16.6	0.7	0.2	0.2	0.2	0.2	0.2
Hungary	50.8	26.6	12.8	12.8	12.4	12.6	12.3
Latvia	4.7	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	43.1	4.4	0.0	0.0	0.0	0.0	0.0
Poland	72.9	37.9	1.8	1.5	1.0	1.2	0.9
Romania	3.7	0.9	0.3	0.3	0.3	0.3	0.3
Slovakia	51.5	25.7	7.4	7.2	6.6	6.8	6.5
Slovenia	40.1	3.4	0.5	0.5	0.5	0.5	0.4
Total candidate countries	*44.2*	*22.9*	*1.5*	*1.4*	*1.1*	*1.2*	*1.0*
Albania	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bosnia-Herzegovina	9.1	9.0	0.0	0.0	0.0	0.0	0.0
Croatia	2.7	0.0	0.0	0.0	0.0	0.0	0.0
Macedonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yugoslavia	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Total central and eastern Europe	***37.8***	***19.7***	***1.3***	***1.1***	***0.9***	***1.0***	***0.8***
Belarus	53.9	21.7	3.2	3.1	1.2	1.4	0.9
Moldova	7.0	2.6	1.1	1.1	0.9	0.9	0.9
Russia	7.8	1.1	0.3	0.3	0.2	0.3	0.2
Ukraine	29.1	8.9	3.6	3.5	2.3	2.7	1.8
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***9.0***	***1.6***	***0.4***	***0.4***	***0.3***	***0.3***	***0.3***
Total	**16.1**	**6.8**	**1.5**	**1.4**	**1.3**	**1.4**	**1.2**

Note: Russia contains only the European part within the EMEP region.

Ecosystems with deposition exceeding critical loads for eutrophication (% of ecosystem area) Table A1.9

Country	**1990**	**2010**					
		1995	**BL**	**DAO**	**TNS**	**TWS**	**S10**
Austria	90.4	75.6	50.6	48.8	49.4	49.9	48.7
Belgium	99.6	99.4	92.9	91.8	92.4	92.6	91.9
Denmark	71.2	55.9	31.1	29.5	30.2	30.5	29.6
Finland	44.9	26.4	9.5	9.0	8.7	9.1	8.5
France	92.3	87.3	78.2	77.0	77.2	77.2	77.1
Germany	99.0	97.8	84.9	83.0	84.0	84.4	83.1
Greece	12.1	7.3	3.7	3.3	3.3	3.6	3.2
Ireland	10.0	8.7	5.5	3.3	5.5	5.5	3.7
Italy	49.4	45.5	29.5	29.0	29.3	29.4	29.1
Luxembourg	100.0	100.0	88.5	87.0	87.9	88.2	87.2
Netherlands	97.8	95.6	89.7	89.2	89.5	89.6	89.3
Portugal	37.4	38.0	35.3	30.5	34.2	34.7	31.0
Spain	29.7	32.4	16.0	13.3	14.8	15.3	13.6
Sweden	14.4	8.6	4.2	4.0	4.1	4.1	4.0
United Kingdom	11.2	8.6	1.3	1.0	1.3	1.3	1.0
Total EU-15	*55.7*	*49.6*	*38.3*	*37.2*	*37.6*	*37.8*	*37.2*
Norway	14.8	12.3	1.3	0.4	0.4	0.4	0.4
Switzerland	92.4	90.0	76.6	75.8	76.3	76.4	76.0
Total western Europe	***52.1***	***46.5***	***35.2***	***34.1***	***34.5***	***34.6***	***34.1***
Bulgaria	80.2	26.9	38.5	36.6	33.1	34.1	32.9
Czech Republic	98.2	90.9	80.0	78.3	78.2	78.9	77.2
Estonia	68.6	33.8	31.1	30.8	30.7	30.8	30.6
Hungary	58.3	47.5	45.1	44.9	44.8	44.9	44.6
Latvia	83.2	51.6	53.1	51.3	51.0	51.3	50.7
Lithuania	77.8	45.6	47.8	47.5	47.3	47.5	47.2
Poland	97.3	93.8	86.8	86.1	85.6	86.1	85.1
Romania	55.4	28.3	28.0	28.0	27.8	27.9	27.8
Slovakia	93.5	70.6	49.7	48.6	47.6	48.4	46.8
Slovenia	54.0	30.7	11.7	10.6	10.8	11.4	10.5
Total candidate countries	*84.3*	*64.9*	*61.1*	*60.3*	*59.5*	*60.0*	*59.2*
Albania	22.6	17.3	17.8	17.2	17.3	17.5	17.0
Bosnia-Herzegovina	76.2	59.8	38.5	37.3	37.1	37.7	36.4
Croatia	25.9	11.7	6.1	4.0	4.0	6.0	3.9
Macedonia	22.8	11.8	12.5	12.2	11.8	12.3	11.6
Yugoslavia	67.7	58.6	53.6	53.3	52.7	53.3	52.4
Total central and eastern Europe	***79.9***	***61.7***	***57.6***	***56.8***	***56.1***	***56.6***	***55.7***
Belarus	40.8	21.2	19.0	18.9	18.4	18.7	18.3
Moldova	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Russia	13.9	6.4	6.4	6.3	5.7	5.9	5.8
Ukraine	75.0	49.9	47.0	46.8	46.3	46.6	46.2
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***15.6***	***7.5***	***7.4***	***7.4***	***6.8***	***7.0***	***6.9***
Total	**30.5**	**22.1**	**18.8**	**18.5**	**18.1**	**18.3**	**18.0**

Note: Russia contains only the European part within the EMEP region.

Table A1.10 **Population exposure ozone indicator (AOT60), ppm.hours**

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	2.00	1.40	0.20	0.20	0.20	0.20	0.20
Belgium	6.50	5.10	2.40	2.40	2.40	2.40	2.40
Denmark	1.80	1.20	0.30	0.30	0.30	0.30	0.30
Finland	0.10	0.00	0.00	0.00	0.00	0.00	0.00
France	5.50	4.00	1.20	1.10	1.20	1.20	1.10
Germany	5.10	3.60	1.30	1.20	1.30	1.30	1.20
Greece	0.70	0.60	0.20	0.20	0.20	0.20	0.20
Ireland	0.80	0.60	0.10	0.10	0.10	0.10	0.10
Italy	3.20	2.80	0.90	0.80	0.80	0.80	0.80
Luxembourg	8.50	6.40	2.40	2.20	2.30	2.30	2.30
Netherlands	4.90	3.90	2.00	2.00	2.00	2.00	2.00
Portugal	1.80	1.40	0.70	0.80	0.80	0.80	0.80
Spain	1.00	0.90	0.20	0.10	0.20	0.20	0.10
Sweden	0.40	0.20	0.00	0.00	0.00	0.00	0.00
United Kingdom	2.20	2.00	1.00	1.00	1.00	1.00	1.00
Total EU-15	*3.50*	*2.70*	*1.00*	*0.90*	*1.00*	*1.00*	*0.90*
Norway	0.10	0.10	0.00	0.00	0.00	0.00	0.00
Switzerland	2.10	1.40	0.10	0.10	0.10	0.10	0.10
Total western Europe	***3.42***	***2.63***	***0.95***	***0.92***	***0.93***	***0.94***	***0.90***
Bulgaria	0.40	0.10	0.00	0.00	0.00	0.00	0.00
Czech Republic	3.30	2.10	0.70	0.60	0.60	0.60	0.50
Estonia	0.20	0.10	0.00	0.00	0.00	0.00	0.00
Hungary	2.60	1.80	0.60	0.60	0.60	0.60	0.50
Latvia	0.40	0.20	0.00	0.00	0.00	0.00	0.00
Lithuania	0.60	0.30	0.00	0.00	0.00	0.00	0.00
Poland	2.40	1.60	0.50	0.50	0.50	0.50	0.40
Romania	0.80	0.40	0.10	0.10	0.10	0.10	0.00
Slovakia	2.80	1.90	0.70	0.70	0.60	0.60	0.60
Slovenia	2.20	1.80	0.40	0.40	0.40	0.40	0.40
Total candidate countries	*1.84*	*1.19*	*0.39*	*0.37*	*0.33*	*0.35*	*0.31*
Albania	0.40	0.30	0.00	0.00	0.00	0.00	0.00
Bosnia-Herzegovina	0.70	0.40	0.00	0.00	0.00	0.00	0.00
Croatia	1.70	1.30	0.40	0.30	0.30	0.40	0.30
Macedonia	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Yugoslavia	0.70	0.40	0.10	0.10	0.10	0.10	0.10
Total central and eastern Europe	***1.64***	***1.07***	***0.34***	***0.32***	***0.29***	***0.30***	***0.27***
Belarus	0.40	0.20	0.00	0.00	0.00	0.00	0.00
Moldova	0.70	0.30	0.10	0.00	0.00	0.00	0.00
Russia	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Ukraine	0.90	0.30	0.10	0.10	0.10	0.10	0.10
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***0.40***	***0.12***	***0.05***	***0.05***	***0.03***	***0.04***	***0.03***
Total	**2.28**	**1.67**	**0.60**	**0.57**	**0.57**	**0.58**	**0.55**

Note: Russia contains only the European part within the EMEP region.

Vegetation exposure ozone indicator (AOT40), excess ppm.hours Table A1.11

Country	1990	1995	2010				
			BL	DAO	TNS	TWS	S10
Austria	9.00	7.80	4.00	3.80	3.80	3.90	3.70
Belgium	11.50	10.70	8.00	8.10	8.00	8.00	8.00
Denmark	4.70	3.60	1.20	1.10	1.10	1.10	1.10
Finland	0.00	0.00	0.00	0.00	0.00	0.00	0.00
France	12.90	11.50	6.50	6.40	6.40	6.40	6.40
Germany	11.10	9.00	4.50	4.40	4.40	4.50	4.30
Greece	4.30	3.60	2.60	2.40	2.50	2.50	2.40
Ireland	1.10	0.90	0.20	0.20	0.20	0.20	0.20
Italy	11.30	10.90	6.80	6.50	6.70	6.70	6.50
Luxembourg	16.60	14.50	8.10	8.00	8.10	8.10	8.00
Netherlands	8.40	7.40	5.20	5.30	5.20	5.20	5.20
Portugal	6.70	5.60	4.80	4.80	4.80	4.80	4.80
Spain	6.90	6.60	4.10	3.80	4.00	4.10	3.90
Sweden	0.40	0.30	0.00	0.00	0.00	0.00	0.00
United Kingdom	2.30	2.40	1.60	1.60	1.60	1.50	1.60
Total EU-15	*6.60*	*5.90*	*3.40*	*3.30*	*3.40*	*3.40*	*3.30*
Norway	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Switzerland	8.70	7.90	4.30	4.10	4.20	4.20	4.20
Total western Europe	***6.27***	***5.61***	***3.26***	***3.15***	***3.20***	***3.23***	***3.15***
Bulgaria	4.60	3.80	3.00	2.90	2.80	2.90	2.80
Czech Republic	10.30	8.30	4.30	4.10	4.10	4.20	4.00
Estonia	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Hungary	9.70	8.00	4.50	4.40	4.30	4.40	4.20
Latvia	1.00	0.30	0.00	0.00	0.00	0.00	0.00
Lithuania	1.80	0.70	0.00	0.00	0.00	0.00	0.00
Poland	6.60	5.10	2.40	2.30	2.10	2.20	2.10
Romania	5.40	4.40	3.00	3.00	2.80	2.90	2.80
Slovakia	9.60	7.70	4.40	4.30	4.10	4.20	4.00
Slovenia	10.70	9.90	6.30	6.10	6.10	6.20	6.00
Total candidate countries	*6.06*	*4.78*	*2.72*	*2.65*	*2.52*	*2.60*	*2.46*
Albania	4.80	4.10	2.80	2.70	2.70	2.80	2.60
Bosnia-Herzegovina	6.40	5.60	3.50	3.40	3.40	3.50	3.40
Croatia	8.60	7.80	5.10	5.00	5.00	5.00	4.90
Macedonia	3.30	2.90	2.10	2.00	2.00	2.00	2.00
Yugoslavia	4.80	4.40	2.90	2.80	2.80	2.90	2.80
Total central and eastern Europe	***6.01***	***4.86***	***2.85***	***2.77***	***2.67***	***2.74***	***2.61***
Belarus	2.10	0.70	0.30	0.30	0.20	0.30	0.20
Moldova	4.90	3.10	2.50	2.50	2.10	2.30	2.10
Russia	0.90	0.50	0.40	0.40	0.30	0.30	0.30
Ukraine	4.50	3.00	2.40	2.40	2.10	2.20	2.10
Russian Federation and western countries of eastern Europe, Caucasus and central Asia countries	***1.55***	***0.89***	***0.74***	***0.73***	***0.61***	***0.65***	***0.62***
Total	**4.07**	**3.33**	**2.04**	**1.98**	**1.93**	**1.97**	**1.90**

Note: Russia contains only the European part within the EMEP region.

Annex 2: Comparison of projected CO_2 baseline emissions with other recent studies

Table A2.1 **Emissions of CO_2 (in billion tonnes)**

	1990				2010				Ratio 2010/1990			
	1	2	3	This study	1	2	3	This study	1	2	3	This study
Austria	62	55	55	57	73	55	61	61	1.17	1.00	1.10	1.06
Belgium	114	105	106	108	129	124	112	126	1.13	1.18	1.06	1.17
Denmark	53	53	53	54	43	55	47	60	0.81	1.04	0.88	1.10
Finland	62	51	53	59	73	74	51	82	1.17	1.45	0,97	1.40
France	385	352	354	378	459	389	406	419	1.19	1.11	1.15	1.11
Germany	1 015	952	943	991	852	821	824	839	0.84	0.86	0.87	0.85
Greece	84	71	71	76	113	108	106	112	1.34	1.52	1.49	1.47
Ireland	32	30	30	31	51	43	47	45	1.63	1.43	1.57	1.47
Italy	438	388	391	428	447	429	422	474	1.02	1.11	1.08	1.11
Luxembourg	10	0	11	9	8	0	12	8	0.74		1.10	0.91
Netherlands	161	153	153	160	208	205	174	205	1.29	1.34	1.14	1.28
Portugal	44	39	39	42	75	66	68	73	1.69	1.69	1.74	1.73
Spain	226	202	204	222	283	273	303	305	1.25	1.35	1.48	1.38
Sweden	55	57	51	54	66	63	54	84	1.19	1.11	1.07	1.56
United Kingdom	583	536	569	572	548	571	519	584	0.94	1.07	0.91	1.02
EU-15	**3 325**	**3 044**	**3 082**	**3 242**	**3 426**	**3 276**	**3 205**	**3 477**	**1.03**	**1.08**	**1.04**	**1.07**
Norway			29	27			39	41			1,34	1.50
Switzerland			43	42			48	47			1,12	1.11
western Europe			**3 154**	**3 311**			**3 292**	**3 565**			**1.04**	**1.08**
Where of non energy related CO_2 emissions:	164			164				183				
EU/western Europe energy related CO_2 emissions:	**3 161**	**3 044**	**3 082**	**3 147**		**3 276**	**3 292**	**3 382**	**1.03**	**1.08**	**1.04**	**1.08**

1) National emission projections as compiled in EEA (2002). Cames, M., Garber, W., Gardiner, A., van Minnen, J., Strobl, B., Taylor, P. and van Vuuren, D. Analysis and Comparison of national and EU-Wide projections of greenhouse gas emissions. European Environment Agency. Copenhagen.

2) Shair — projections as in EEA (2002). Albers, R., F. de Leeuw, J. Van Woerden and J. Bakkes (2002). *The ShAir scenario. Towards air and climate change outlooks, integrated assessment methodologies and tools applied to air pollution and greenhouse gases.* European Environment Agency, Copenhagen.

3) Primes LREM (2003).

It should be noted that the projections of this study are developed at the level of larger European regions and scaled down to countries. In general, the results comply very well with recent projections for individual countries. The growth of western European emissions in this study is 8 %, consistent with the ShAir scenario (on which it was based).

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