9. EXPLORING THE ANCILLARY BENEFITS OF THE KYOTO PROTOCOL FOR AIR POLLUTION IN EUROPE

Abstract. An integrated approach to climate change and regional air pollution can harvest considerable ancillary benefits in terms of environmental impacts and costs. This is because both problems are caused to a large extent by the same activity (fossil fuel consumption). Substantial ancillary benefits were found for regional air pollution (SO_2, NO_x, VOC and particulate matter) of implementing the Kyoto Protocol (greenhouse gas emissions) in Europe. The benefits apply both to mitigation costs and to emissions. For instance, while three different scenarios on Kyoto implementation showed reduction of European CO_2 emissions by 4-7%, they also showed reduction of European emissions of SO_2 by 5-14% compared with a no Kyoto policies case. The total cost savings for implementing current policies for regional air pollution stated in the Kyoto Protocol are in the order of 2.5-7 billion Euro. In all cases, this is in the order of half the costs of the climate policy (4-12 billion Euro). The magnitude of ancillary benefits depends on how flexible mechanisms and surplus emission allowances are used in meeting the Kyoto targets. Using flexible mechanisms reduces emissions of air pollutants for Europe as a whole even further than domestic implementation (e.g. 10-14% versus 5% for SO_2 emissions), but the reductions have shifted from Western Europe to Central and Eastern Europe and Russia. The use of surplus emission allowances (so-called “hot air”) to achieve the Kyoto targets decreases the ancillary benefits, in particular, for the latter group of countries.

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9.1 Introduction

Policies aimed at mitigation of environmental impacts in one area can have significant effects on other aspects of environmental quality. Control strategies that consider cost-effectiveness and environmental effectiveness of proposed solutions in an integrated fashion can therefore often prevent inefficient use of resources and implementation of sub-optimal solutions. The Protocol to the Convention on Long-range Transboundary Air Pollution (CLRTAP) to Abate Acidification, Eutrophication and Ground-level Ozone (the so-called Gothenburg Protocol), (UN/ECE, 1999), is an example of how several environmental problems can be examined in an integrated way. The emission ceilings adopted in this Protocol were designed to realize important efficiency gains by simultaneously controling acidification and eutrophication risks, along with ground-level ozone concentrations.

Important links have also been identified between regional air pollution and climate change, although these are currently still hardly considered in policy-making (e.g., (RIVM et al., 2001; Syri et al., 2001; Alcomo et al., 2002; Mayerhofer et al., 2002; Van Harmelen et al., 2002)). Links exist because greenhouse gases and regional air pollutants originate to a large extent from the same activity, i.e. fossil fuel consumption. Moreover, reduction options for each of the gases can affect the emissions of other pollutants, either beneficially or adversely. Finally, the pollutants interact within the environmental system. Some substances directly influence both climate change and regional air pollution, for instance, sulfur dioxide (SO_2) and nitrogen oxides (NO_x). There are also more indirect effects such as the impacts of climate change on weather patterns, which cause impacts on the atmospheric transport and deposition of pollutants and the buffering capacity of soils (Posch, 2002). Despite these linkages, both types of problems have, to date, usually been explored separately using different tools and models, concentrating on different technical solutions. While analysis of greenhouse gas mitigation focuses generally on changes in the energy system, analyzing mitigation of atmospheric pollutants concentrates mostly on end-of-pipe technologies.

Recently, several studies have been published on the linkages between climate change and regional air pollution in Europe. All those studies indicated that a considerable share of investments in climate policies can be recovered through lower costs of air pollution control (generally in the order of 20-30% or higher; see also discussion) (van Vuuren and Bakkes, 1999; RIVM et al., 2001; Brink, 2002; Van Harmelen et al., 2002). The reason is that the reduction of CO_2 emissions through structural changes in the energy sector also brings about a decrease in the emissions of air pollutants. Of these studies, only the RIVM et al.(2001) study looked specifically into the consequences of implementing the Kyoto Protocol – but for Western Europe only and without properly accounting for emission trading. In reality, there are several ways the protocol can be implemented, one crucial difference in these has to do with whether the target is achieved through domestic measures only or (partly) through the so-called Kyoto Mechanisms (i.e. Joint Implementation, Clean Development Mechanism and Emission Trading). Clearly, this also affects the potential ancillary benefits for air pollution (emissions, control costs and environmental impacts). To date, studies have not addressed this important issue.

The objective of this chapter is to explore the emission reductions of air pollutants and change in control costs and environmental impacts resulting from different ways in which the Kyoto Protocol is implemented in Europe, in particular, with regard to the use of Kyoto Mechanisms. The results presented are of a descriptive "what-if" character and do not pretend to be prescriptive for any future implementation of the Protocol and air pollution policies. The discussion will focus primarily on three country group-

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[i] The actual calculations for the climate policies are made using global models based on 17 world regions. The WE region includes EU15, Switzerland, Norway and Iceland. The CE region includes the new EU member states (except Cyprus and Malta), Bulgaria and Romania, and the Balkan countries. Finally, the EE region includes Belarus, Moldova, Russian Federation and Ukraine. For Russia, energy consumption and emissions are reported only for the European part (west of the Urals) as covered by the EMEP region.

ings/regions. These are: Western Europe (WE), Central Europe (CE) and Eastern Europe (Ukraine, Moldova, Belarus and Russia, west of the Ural and EE)[i]. Calculations for climate policy are done at the levels of these regions. The calculations on air pollution policies, in contrast, are done at the national level and aggregated to the regional level. The study is restricted to carbon dioxide (CO_2), leaving the remaining five greenhouse gases covered by the Kyoto Protocol un-addressed.

The analysis was performed using three linked models that collectively simulate different ways of achieving the Kyoto targets for climate change and targets for controlling regional air pollution. Section 9.2 describes the methodology, scenarios and the models used, while Section 9.3 discusses the baseline scenario. Section 9.4 presents the results of three mitigation scenarios. Finally, sections 9.5 and 9.6 discuss the results and draw conclusions. More details of this study can be found in Van Vuuren et al. (2003).

9.2 Methodology

Three climate policy scenarios have been developed to assess the potential impacts of the different ways to implement the Kyoto Protocol in Europe,. The scenarios are compared to a baseline scenario, which assumes no new climate policies. For this analysis, several models that have so far been used have been independently linked. The results of the study are intended to be explorative in ascertaining the ancillary benefits in larger European regions.

The changes in the energy system induced by climate policies will (in most cases) have a downward impact on emission of air pollutants (e.g. SO_2). This “ancillary benefit” (or co-benefit) can be captured in theory in three different ways.

- *Reduced air pollution control costs:* Emissions of air pollutants are held at the same level as the original baseline. In such a case, less air pollution control is needed and ancillary benefits are substantiated in terms of reduced costs of achieving these air pollutant emission levels.
- *Reduced emissions:* The technologies introduced to control air pollution levels are held at the level as the baseline scenario. In such a case, ancillary benefits exist in terms of emissions reductions.
- *Both:* The ancillary benefits are determined on the basis of existing policies. For European countries, the most relevant policies are the air pollution emission targets under the Gothenburg Protocol and the EU National Emission Ceilings Directive. In our baseline, we have assume these targets to be achieved, i.e. if required by additional investments into air pollution control. In this case, introduction of climate policies results in: a) cost savings as long as meeting the targets still required additional investments and b) additional environmental benefits if the targets have already been met through existing policies and the induced changes through climate policies alone. This situation differs from country to country.

The third case is explored in this study as it is the most policy-relevant for the European situation. Analytically, the disadvantage is that ancillary benefits are obtained along two different axes – mostly, in terms of reduced costs for air pollution control, but partly also in terms of reduced emission of air pollutants.

9.2.1 Scenarios explored

The Kyoto Protocol and the Marrakesh Accords provide for three mechanisms that parties may use in addition to domestic implementation to facilitate compliance with their commitments. These mechanisms are: *Joint Implementation* (JI), *Clean Development Mechanism* (CDM) and *Emission Trading* (ET)[ii]. Current emission projections suggest that implementation of the Kyoto Protocol within Europe will require significantly more abatement effort by the countries in Western European region than in the Central and Eastern European regions (EEA, 2002a). As a result, the Western European region may use the Kyoto Mechanisms to benefit from low-cost reduction options in other European regions. A special issue here is the possibility for trade in so-called "surplus emission allowances" [the term "surplus (emission) allowances" is used throughout this study; a more common but somewhat value-laden term is "hot-air")] (see also den Elzen and de Moor (2002)). The emissions for most countries with economies in transition have substantially declined since 1990 and, as a result, the expected baseline emissions (without additional climate policies) of several of these countries in the First Commitment Period (2008-2012) are significantly lower than the Kyoto targets. According to the provisions of the Kyoto Protocol, these surplus allowances can be traded to other parties. In fact, after the rejection of the Protocol by the USA in 2001, the total required reduction of participating countries under most conceivable baseline scenarios is smaller than the total available surplus allowances in Central Europe and Eastern Europe. In such a case, only trading these allowances would, theoretically, 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 down to zero. According to the provisions of the Kyoto Protocol, the surplus 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. Several studies have indicated that banking of surplus allowances could be an attractive strategy for selling countries in order to maximize their revenues (den Elzen and de Moor, 2002).

Obviously, the use of Kyoto Mechanisms will not only have important implications for the total costs of implementing the Kyoto Protocol, but also for the ancillary benefits. In principle, the use Kyoto Mechanisms will not only shift greenhouse gas reductions, but also the ancillary benefits to those regions were measures are implemented. The

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[ii] *Joint Implementation* (JI) allows Annex-1 countries to invest in projects to reduce GHG emissions in other Annex-1 countries. The achieved emission reduction units can be used to meet the reduction commitments of the investing Party. *The Clean Development Mechanism* (CDM) does the same, but now between Annex-1 countries and non-Annex-1 countries. Finally, Emission trading (ET) allows Annex-1 countries to trade emission allowances among themselves. The conditions for using these instruments (i.e. criteria that need to be met) have been developed within the Kyoto Protocol and are available in the related documents.

use of surplus allowances, however, will not result in any ancillary benefits. This means that there are important trade-offs from the design of climate policies for the overall efficiency and effectiveness of Europe's environmental policies. In order assess these trade-offs, three different (hypothetical) climate policy scenarios are analyzed in this chapter.

(1) **Domestic Action:** assumes that Kyoto targets are met solely through domestic implementation, allowing only for internal emission trading (i.e. within each region, such as Western Europe).
(2) **Restricted Trade:** This case assumes full use of the Kyoto Mechanisms, but without using surplus allowances.
(3) **Normal Trade:** Also this case assumes full use of Kyoto Mechanisms, but allows trading of surplus allowances. The use of surplus allowances is chosen at a level that maximizes the revenues from their trade for the Central and Eastern European regions. This "optimal" level of trading has been determined by model analysis (compare den Elzen and de Moor (2002).

In the first scenario, ancillary benefits are expected to occur mainly in the Western European region, the region that also experiences the highest costs of climate policies. In the second and third scenarios, some of the ancillary benefits will have shifted to the other European regions, while ancillary benefits in the Western European region are expected to be less. As the second scenario does not allow for the use of surplus allowances, this scenario could be indicative of the maximum amount of ancillary benefits under trading assumptions. The third scenario is a more cost-optimal scenario (and arguably more realistic). Comparing the results of this scenario against those of the second allows us to assess the consequences of including surplus allowances in climate policies in terms of abatement costs and ancillary benefits. It should be noted that the reduction of CO_2 emissions is not the same in all scenarios as a result of CDM and use of surplus allowances (see Section 9.4).

In all scenarios we included the provisions of the Marrakesh Accords on carbon sinks. Based on a separate analysis, we assumed that the Annex-I countries could use a total of sinks credits[iii] coming to 440 Mt CO_2, of which 270 Mt CO_2 is used by the regions included in our study (see den Elzen and de Moor (2002). Our analysis concentrates exclusively on the reduction of CO_2 emissions, CO_2 being the most important greenhouse gas. The Kyoto Protocol, however, refers to the total set of six greenhouse gases (also CH_4, N_2O, HFCs, PFCs and SF_6), and allows for substitution among them. Other studies, e.g. Lucas et al. (2002), indicate that control costs for non-CO_2 gases for moderate reductions could be lower than those for CO_2. Thus, under an optimal reduction strategy, reduction rates for CO_2 might be lower than the overall reduction targets. In

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[iii] 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 (den Elzen and Lucas, 2003a)

[iv] The consequence could be that there will be fewer changes in the energy system, and therefore less impact on sulfur and nitrogen oxide emissions. At the same time, the increased reductions in CH4 (as a greenhouse gas) will impact the levels of tropospheric ozone.

such a case the ancillary benefits could be somewhat different from those presented here[iv]. However, it is not expected that this will change the qualitative conclusions of our research.

9.2.2 Model framework used

This study integrates the different research areas by linking models that address climate change issues: the climate policy model FAIR (den Elzen and Lucas, 2003b), the energy model TIMER[v] (de Vries et al., 2001) and regional air pollution model RAINS (Amann et al., 1999) (Figure 9.1). Appendix 9.1 provides some description of each of the models and their linkages – while additional information on TIMER can be found in Chapter 2).

Within the total framework, the first step was to use the global energy system model TIMER (de Vries et al., 2001) to determine the changes in energy (and thus CO_2 emissions) under the baseline scenario (see Section 9.3). Next, on the basis of these emissions and a set of marginal abatement costs curves for CO_2 per region, the reduction and abatement costs sub-model of FAIR was used to determine the level of (domestic) action and use of Kyoto Mechanisms required in each region to meet the Kyoto targets under each scenario [see, for a description of this model, the marginal abatement curves and a detailed description of results under comparable scenarios (den Elzen and de Moor, 2002)]. The fundamental assumption here is that on the basis of the marginal abatement curves, regions will implement a least-cost approach, choosing to use Kyoto Mechanisms if costs outside their region are lower, unless constrained by specific rules on emission trading.

Next, the TIMER model implements the outcomes of FAIR in terms of regional emissions by introducing price signals (a tax on carbon dioxide). In response to the carbon tax, the model generates several changes: investments in energy efficiency, fossil fuel

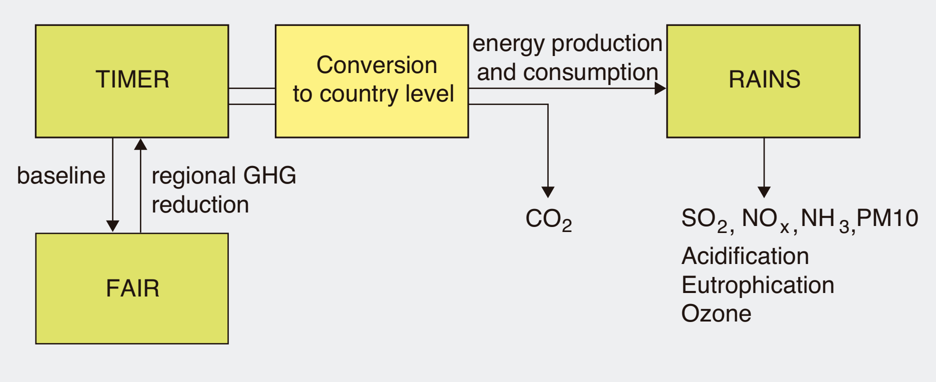

Figure 9.1 Overview of the models used in this study.

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[v] Both FAIR and TIMER constitute part of the IMAGE 2.2 framework (Integrated Model to Assess the Global Environment) – a modeling framework to study global change issues.

substitution, and extra investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels. These lead to changes in the energy system (mitigation scenarios).

Finally, the RAINS model calculates emissions of air pollutants (SO_2, NO_x, VOC, PM10 and NH_3) for the scenarios based on the outputs of TIMER, and explores their environmental impacts and emission control costs. In these calculations RAINS optimizes air pollutant emissions for acidification, eutrophication and formation of ground-level ozone, while at same time emissions of particulate matter (PM) from anthropogenic sources are also estimated. In each scenario, the RAINS model meets the emission standards set under the Gothenburg Protocol and the EU National Emission Ceilings Directive, by means of a cost-minimal combination of measures. Here, regional differences are accounted for in emission control costs and atmospheric dispersion characteristics.

Some assumptions needed to be made to link inputs and outputs of these models. As TIMER and FAIR models make use of a similar regional breakdown, data could be easily transferred between these models. Some minor assumptions needed to be made to deal with the non-Annex I parts of the Former Soviet Union region of TIMER, as described in Appendix 9.1. The link between RAINS and TIMER requires a more elaborate procedure. While RAINS requires energy activity levels on a country basis, the TIMER model calculates energy use for three large regions in Europe. In terms of fuel types too, the RAINS model is more detailed than TIMER [RAINS recognizes various forms of solid (coal) and liquid fuels (oil-based)]. Finally, the data sources used to calibrate the model for the base year are different (TIMER is calibrated against IEA data,while RAINS uses in addition data from national sources). A downscaling method has been developed to translate the TIMER energy results into RAINS input, as described in Appendix 9.1. Use of this method leads to the results on a country level showing very good correspondence to country-based projections, indicating that the method for downscaling was functioning well (van Vuuren et al., 2003b).

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

Estimating costs of future policies is beset with uncertainties. This is already an important issue when comparing costs from different studies within one research domain, but this is even more so when comparing cost calculations from different areas. Some of the differences between several studies result from methodological differences; others simply reflect the uncertainties we are facing (see also IPCC (2001b)). A practical cause of differences is the use of different cost concepts (e.g. welfare loss and the change in energy system costs, compare Syri et al., 2001)). But in addition, there are a large number of other factors that can influence cost calculations such as assumptions about substitutability of fuels and technologies, assumptions on the use of Kyoto Mechanisms, technology development, and 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 a hundred billion Euro (IPCC, 2001a).

The cost estimates of CO_2 policies presented in this chapter are based on the results of the TIMER model. Costs are calculated using the carbon tax that is required to meet the specific reduction target in each region. Costs are calculated by determining the integral of emission reductions and the carbon tax. The cost is not directly related to the costs of a single measure, because each option induces changes in the costs of other parts of the system. In contrast, RAINS calculates, for a given energy scenario, the costs of implementing technologies that limit the emissions of air pollutants. The assumptions used for cost calculations in RAINS and the appropriate databases are described in various documents (see Cofala et al. (2002)). In RAINS, effect of technology development has not 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. It was not possible to do a full comparison of the cost calculations in the context of this study. This means that the costs calculated by the two models should not be simply added up. However, in the discussion section of this chapter, we will show that the cost calculations of each model do comply well to other estimates with their respective research domains (climate policy for TIMER and air pollution control policies for RAINS). Moreover, we will show that the TIMER calculations also compare well with those of Blok et al. (2001) a study that estimates costs in a similar, bottom-up manner as the RAINS model. We therefore conclude that the results can be used for qualitative assessment and identification of the directions of changes in costs of policies and indicate the possible order of magnitude of ancillary benefits. In the discussion section, we will pay more attention to this issue.

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

The baseline scenario of this study assumes no new policies to control greenhouse gas emissions but includes the emission ceilings for regional air pollutants that have already been decided upon (i.e. national legislation (CLE)[vi] and the emission ceilings from the EU National Emission Ceilings Directive and from the Gothenburg Protocol to the CLRTAP). In terms of socio-economic trends (compare Table 9.1), the baseline is characterized by a continuation of trends that were dominant during the 1990s: increasing globalization, further liberalization and average assumptions for population growth, economic growth and technology development. The baseline is in principle consistent

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[vi] The impacts are assessed for the year 2010 and include policies as decided per December 2001.

Table 9.1 Major baseline assumptions

	Population (mill.)			GDP (1995 Euro/cap)			Primary energy use (EJ)		
	1995	2010	AAGR	1995	2010	AAGR	1995	2010	AAGR
WE	384	396	0.2%	16250	22771	2.3%	57.8	66.7	0.9%
CE	121	121	0.0%	2120	4195	4.7%	12.8	15.4	1.2%
EE	293	298	0.1%	1312	1851	2.3%	22.6	23.5	0.3%
World	5706	6891	1.3%	3704	4940	1.9%	371	492	1.9%

Source: RIVM, TIMER model calculations after disaggregation to country level; WE = Western Europe, CE = Central Europe, EE = Eastern Europe (AAGR=Annual Average Growth).

Table 9.2: Changes in the primary energy demand, baseline and policy scenarios

			Baseline 2010		Policy scenarios 2010		
	1990	1995			DA	RT	NT
	EJ	EJ	EJ	Change from 1990, %	Change compared to Baseline, %		
WE:							
Total, of which:	*56.4*	*57.8*	*66.7*	*18%*	*-7%*	*-2%*	*-1%*
Coal	11.7	9.2	6.6	-43%	-38%	-21%	-14%
Oil	22.9	23.2	26.3	15%	-9%	-3%	-2%
Gas	10.8	13.1	19.3	78%	-2%	3%	3%
Other	11.1	12.4	14.5	31%	2%	0%	0%
CE:							
Total, of which:	*15.4*	*12.8*	*15.4*	*0%*	*0%*	*-4%*	*-2%*
Coal	6.6	5.4	4.2	-36%	0%	-23%	-17%
Oil	4.0	3.1	4.0	1%	0%	-2%	0%
Gas	3.5	2.9	5.4	53%	0%	7%	6%
Other	1.3	1.4	1.9	40%	0%	1%	0%
EE:							
Total, of which:	*30.3*	*22.6*	*23.5*	*-23%*	*0%*	*-9%*	*-5%*
Coal	4.9	3.0	1.9	-61%	0%	-32%	-26%
Oil	7.9	4.2	4.2	-47%	0%	-9%	-6%
Gas	14.5	12.6	14.2	-2%	0%	-7%	-3%
Other	3.0	2.8	3.1	6%	0%	-3%	-2%

Note: DA = Domestic Action, RT = Restricted Trade (no hot air) and NT = Normal Trade (i.e. including hot air; but based on optimizing revenues of supplying countries). WE = Western Europe, CE = Central Europe, EE = Eastern Europe.

with several other scenarios currently used for European assessments (Capros, 1999; Criqui and Kouvaritakis, 2000a; IMAGE-team, 2001; EEA, 2002b).

Table 9.2 shows the resulting total primary energy demand 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. In Central Europe and Eastern Europe the energy use changed drastically between 1990 and 1995. In Central Europe, under the baseline scenario the historically dominant position of coal is challenged, both by natural gas (increased use for heating and electricity generation) and oil (fast growth of private transport). Total energy use recovers from the low 1995 levels but will in 2010 only be slightly higher than in 1990. In Eastern Europe, natural gas continues to be the most important energy carrier. Coal use further declines, while natural gas and oil grow modestly after 2000 (but still show a decline over the whole period). Total 2010 energy use in this region remains almost a third below the 1990 level.

9.3.1 Carbon dioxide and air pollutant emissions

Between 1990 and 1995 the CO_2 emissions in Europe as a whole decreased by 10% (from 6.3 Gtons to 5.4 Gtons CO_2) with widely diverging trends in the different regions (Western Europe, a 1% decrease, Central Europe, about a 20% decrease and Eastern Europe, more than a 30% decrease). In contrast to these declining trends, emissions are expected to increase in the baseline in all regions between 1995 and 2010, driven by the growth in energy consumption discussed in the previous section. Under the baseline scenario, the 2010 emissions in Western Europe will be 8% above the 1990 level. The emissions in the Central and Eastern Europe regions, although higher than in 1995, will remain below the 1990 values (by 10 and 32%– compare Table 9.3). Emissions of CO_2 and air pollutants by country for the Baseline are to be found in the report (van Vuuren et al., 2003).

The baseline scenario at the same time indicates significant reductions in the emissions of regional air pollutants throughout Europe (Table 9.3), which is a continuation of the trend that has been seen in the recent past. 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}. The main driver of this decrease in Western Europe was the implementation of add-on control technologies and low sulfur fuels, and to a lesser extent, structural changes in the energy system (a further decline of coal use)[vii]. In the case of the Central and Eastern European regions, a large proportion of emission reduction was achieved through a decrease in energy demand and agricultural production due to economic restructuring. In addition, in some candidate countries (Czech Republic, Hungary, Poland and Slovenia) add-on controls on SO_2 and PM sources played an important role in emission reduction.

Under the baseline, total European emissions of SO_2 are expected to decrease up to 2010 by 74% compared with 1990 (given the implementation of the Gothenburg Protocol). The corresponding reductions of NO_x and VOC are 45% and 44%, respectively. Finally, PM_{10} emissions are reduced by 64%. It should be noted that, for Western Eu-

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[vii] The exception is the eastern part of Germany where closing down obsolete plants and economic reform played a major role in emissions reduction.

Table 9.3 Air emissions 1990 - 2010: baseline and climate policy scenarios (CO2 in 10-6 tons, other pollutants in kilotons)

					Policy scenarios 2010		
	1990	1995	Baseline 2010		DA	RT	NT
				Change from 1990, %	Change compared to baseline (%)		
WE:							
CO_2	3311	3267	3565	8%	-12%	-4%	-3%
SO_2	16402	10254	3153	-81%	-15%	-7%	-4%
NO_x	13769	11796	6617	-52%	-7%	-3%	-1%
VOC	14695	12332	6697	-54%	-1%	0%	0%
PM_{10}	2730	1770	1197	-56%	-5%	-3%	-2%
NH_3	3726	3433	3177	-15%	0%	0%	0%
CE:							
CO_2	1123	914	1008	-10%	0%	-8%	-5%
SO_2	11795	8404	3785	-68%	0%	-16%	-11%
NO_x	3919	3199	2256	-42%	0%	-7%	-4%
VOC	2916	2494	2289	-22%	0%	-2%	-1%
PM_{10}	2360	1177	768	-67%	0%	-9%	-7%
NH_3	1608	1137	1367	-15%	0%	0%	0%
EE:							
CO_2	1869	1259	1284	-32%	0%	-11%	-5%
SO_2	9758	4751	2833	-71%	0%	-19%	-15%
NO_x	5846	3886	4001	-32%	0%	-12%	-8%
VOC	5124	3840	3778	-26%	0%	-6%	-4%
PM_{10}	3945	1954	1276	-68%	0%	-7%	-6%
NH_3	2277	1530	1686	-36%	0%	0%	0%
Total Europe:							
CO_2	6303	5440	5852	-7%	-7%	-6%	-4%
SO_2	37955	23409	9771	-74%	-5%	-14%	-10%
NO_x	23534	18881	12874	-45%	-4%	-6%	-4%
VOC	22735	18666	12764	-44%	-1%	-2%	-2%
PM_{10}	9035	4901	3241	-64%	-2%	-6%	-4%
NH_3	7611	6100	6260	-18%	0%	0%	0%

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

Note: DA = Domestic Action, RT = Restricted Trade (no hot air) and NT = Normal Trade (i.e. including hot air; but based on optimizing revenues of supplying countries). WE = Western Europe, CE = Central Europe, EE = Eastern Europe.

rope and candidate countries belonging to the Central European region, most of the emission reductions is achieved as a result of implementing the revised EU legislation (standards on mobile sources, revised Large Combustion Plant Directive, Solvent Directive etc.). In Eastern Europe the reductions occur mainly through economic restructuring and a switch to cleaner fuels. Abatement measures play a less important role in these countries.

9.3.2 Emission control costs

The cost of controlling all air pollutants in the baseline scenario for the whole of Europe are expected to increase to about € 89 billion per year in 2010 (Table 9.4). About 57% of the total costs are the costs of controlling emissions from mobile sources (road and off-road transport). PM controls from stationary sources contribute about 11% of the costs to the total and SO_2, 21% of the costs. The Western European region 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 (and hence more costly) than in other parts of Europe. Implementing the EU legislation by the candidate countries is expected to lead to an increase in the control costs in Central Europe. Compared with the legislation from the mid-nineties, the costs for candidate countries will more than double. More than a half of (rather low) air-pollution control costs in Eastern Europe are the costs of dust control equipment (cyclones, electrostatic precipitators) used on larger stationary sources. Other costs for Eastern Europe result from the necessity to comply with the emission and fuel standards, as specified in the 2nd Sulphur Protocol to CLRTAP.

Regional environmental impacts

Implementation of emission controls as assumed in the baseline is expected to significantly increase the area of ecosystems protected against acidification and eutrophication[viii]. For acidification, the calculations indicate that the share of unprotected ecosystems (i.e. ecosystems exposed above critical loads) could decrease from 16.1% in 1990 (93.4 million ha) to 1.5% in 2010 (8.7 million ha) - see Table 9.5. However, in spite of

Table 9.4 Calculated annual air pollution control costs for the baseline scenario in 2010 (1995 prices)

Region	Cost, billion Euro/year	Distribution of control costs SO2	NOx+VOC(*)	NH3	PM10(*)	Mobile sources
WE	72	22%	11%	1%	8%	59%
CE	14	14%	2%	7%	15%	61%
EE	3	35%	2%	1%	63%	0%
TOTAL	**89**	**21%**	**9%**	**2%**	**11%**	**57%**

(*) Only stationary sources
Source: IIASA (RAINS)
Note: WE = Western Europe, CE = Central Europe, EE = Eastern Europe

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[viii] Ecosystems are assumed to be protected against acidification if the total acidifying deposition is below the critical load. A similar definition holds for eutrophication (Amann et al., 1999).

Table 9.5 Environmental impact, baseline and climate policy scenarios

		Baseline	Policy scenarios 2010		
Region	1990	2010	DA	RT	NT
Acidification (million ha unprotected)					
WE	42.9	6.5	5.9	6.0	6.2
CE	18.2	0.6	0.6	0.4	0.5
EE	32.3	1.6	1.6	0.9	1.2
Europe	93.4	8.7	8.1	7.3	7.9
Eutrophication (million ha unprotected)					
WE	71.4	48.2	46.7	47.2	47.4
CE	38.4	27.7	27.3	27.0	27.2
EE	56.2	26.8	26.5	24.4	25.2
Europe	166.0	102.7	100.5	98.6	99.8
Health-related ozone (AOT60, ppm.hours)					
WE	3.42	0.95	0.92	0.93	0.94
CE	1.64	0.34	0.32	0.29	0.30
EE	0.43	0.06	0.05	0.03	0.04
Europe	2.30	0.60	0.57	0.57	0.58
Vegetation-related ozone (AOT40, excess ppm.hours)					
WE	6.30	3.26	3.15	3.20	3.23
CE	6.00	2.85	2.77	2.67	2.74
EE	1.50	0.74	0.73	0.61	0.65
Europe	4.10	2.04	1.98	1.93	1.97

Source: IIASA (RAINS model)
Note: DA = Domestic Action, RT = Restricted Trade (no hot air) and NT = Normal Trade (i.e. including hot air; but based on optimising revenues of supplying countries). WE = Western Europe, CE = Central Europe, EE = Eastern Europe.

such an impressive improvement at a regional level there will be still countries where a high proportion of their ecosystems will achieve atmospheric depositions above their critical loads (compare van Vuuren et al., 2003). These countries comprise the Netherlands (49% of ecosystems unprotected), Belgium (15%), Hungary (13%); Germany, Norway and the UK (9 - 10% ecosystems not protected). The areas with excess deposition of nutrient nitrogen, which is responsible for eutrophication of ecosystems, is expected to decrease for Europe as a whole from 30.5% in 1990 (166 million ha) to 18.8% in 2010 (103 million ha). Nevertheless, relatively large areas remain without protection from eutrophication, in particular, those in the Central European region (more than 57% of ecosystems' area). Developments according to the baseline scenario will also substantially reduce population exposure to elevated ozone levels (Table 9.5). The average exposure of a person in Europe (as measured by the so-called AOT60 value) under these conditions is projected to decrease from 2.3 ppm.hours in 1990 to 0.6 ppm.hours

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[ix] The AOT60 value indicates a cumulative exceedance of ozone of the critical (damage) thresholds for human health (60 ppb). Similarly, the AOT40 value indicates a cumulative exceedance of the critical (damage) thresholds for terrestrial vegetation (40 ppb). More details about the indicators used can be found in Cofala et al. (2002).

in 2010[ix]. However, this also means that in 2010 the guidelines of the World Health Organization will still be exceeded. Just as for health effects, the situation will also improve for vegetation, although at a somewhat slower pace. The exposure index for the whole of Europe (as measured by the so-called AOT40 value) is projected to decrease from 4.1 excess ppm.hours in 1990 to 2.0 excess ppm.hours in 2010.

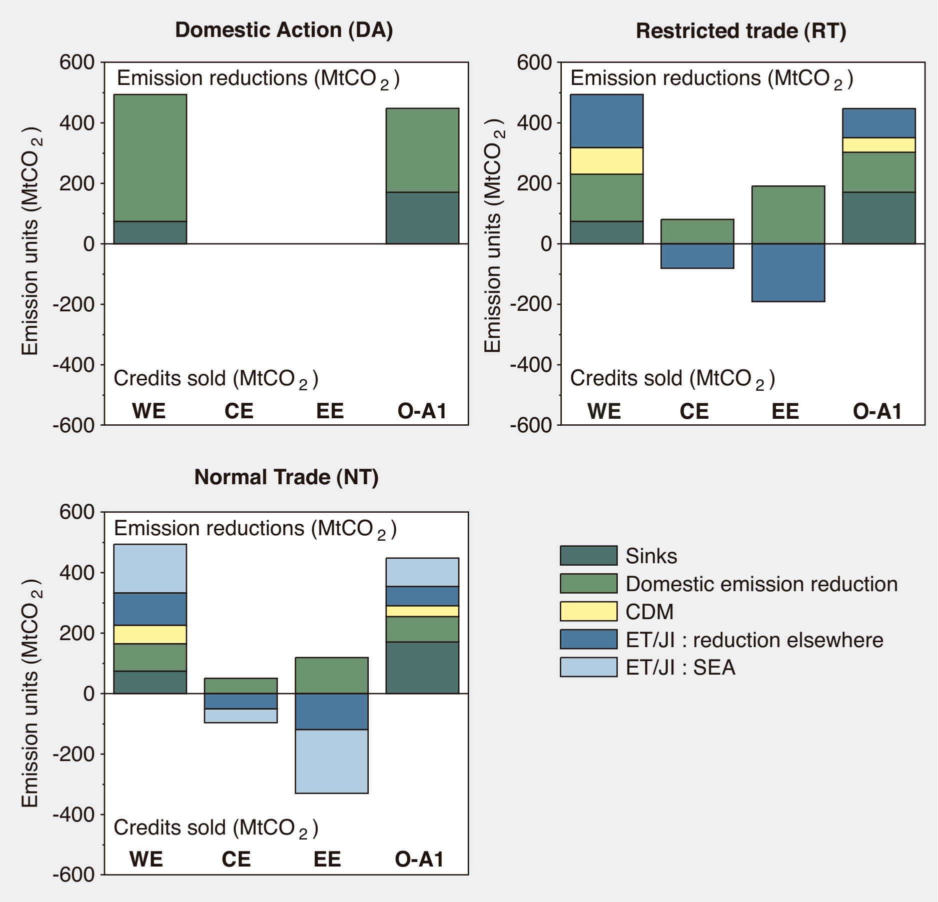

Figure 9.2 Implementation of the Kyoto targets in the three European regions and other Annex-1 countries according to: a) the Domestic Action scenario (DA); b) restricted trade (without the use of surplus emissions allowances, RT), and c) trade with optimal banking of sulfur emission allowances, NT).

Note:

- ET/JI: Emission trading and Joint Implementation. The study does not distinguish between these two instruments. The SEA category only refers to emission trading, as JI cannot lead to implementation of SEA. The category ET/JI (excl. SEA) refers to the use of Kyoto Mechanisms leading to actual physical emission reductions.

- Domestic mitigation refers to reduction of energy-related CO_2 emissions.

9.4 Kyoto scenarios and ancillary benefits for regional air pollution

Different ways of implementing the Kyoto Protocol result in different CO_2 reductions. Figure 9.2 and Table 9.6 illustrate these differences for three European regions (for the complete picture also the reductions of the other Annex-I countries are shown (OA-I = Canada, Japan, Australia and New Zealand[x]). In the *Domestic Action* scenario, of the European regions only Western Europe needs to reduce its CO_2 emissions. As a percentage of the 1990 emissions, the required reduction from baseline is 15 percent point (from 8% above the 1990 level to 7% below). About13 percent age points are achieved by domestic mitigation in the energy system. The balance (2 percentage points) is assumed to be achieved by carbon sinks, as indicated in Section 9.2 (den Elzen and Lucas, 2003b). Energy system CO_2 reduction measures are enhanced energy efficiency and changes in the electricity production structure. a switch from coal to less carbon-intensive generation options occurs in the latter case. Some fuel substitution also takes place in the end-use sectors. The total response in the transport sector is small.

In the *Restricted Trade* scenario (trade without the use of surplus allowances), the Western European and other Annex-I (OA-I) countries use the Kyoto Mechanisms to implement their targets. Domestic CO_2 reduction in Western Europe is reduced by 60% compared to the *Domestic Action* scenario, and replaced by the use of CDM and emission trading (ET). This leads to reductions in Central and Eastern Europe (by 7% and 8% of their 1990 emissions, respectively). Total reductions in Europe in this scenario are approximately the same as in the *Domestic Action* case. This is the net effect of a decrease in reductions as a result of CDM use by Western Europe, and an increase in reductions in Central and Eastern Europe due to emission trading with the group of other Annex-I (OA-I) countries.

The optimal level of surplus allowances had to be determined first for the *Normal Trade* scenario. This was done using a similar analysis as in den Elzen and de Moor (2002) applying the FAIR model. Countries having surplus allowances (mainly Russian Federation and Ukraine) have been estimated to maximise their revenues by supplying only 25% of the available surplus allowances in the First Commitment Period and to “bank” the rest. Compared with the *Restricted Trade* case, the use of surplus allowances increases emission trading and decreases the need for emission reductions from the energy system. In the *Normal Trade* scenario the contribution of the energy system measured is 3 percentage points (of 1990 emissions) in Western Europe, 5 percentage points in Central Europe and 5 percentage points in Eastern Europe. About 4/5 of the necessary reductions in Western Europe is achieved by the Kyoto Mechanisms.

The overall European emissions in this scenario (88% of 1990 level) are higher than in the *Domestic Action* case (85%), which is due to the use of surplus allowances. On

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[x] Only after these calculations were performed, did Australia decide not to ratify the Kyoto Protocol. As the group of Other Annex-I countries is dominated by Japan, this does not have consequences for the results presented in this paper.

Table 9.6 CO_2 emissions and mitigation action as a percentage of 1990 emissions

	WE			CE			EE			Total Europe		
	DA	RT	NT	DA	RT	NT	DA	RT	NT	DA	RT	NT
Baseline	108	108	108	90	90	90	68	68	68	93	93	93
Assigned amounts (Kyoto)	93	93	93	106	106	106	100	100	100	98	98	98
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
- SEA (ET)	0	0	-5							0	0	-2
- ET/JI (excl. SEA)	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.												
- SEA (ET)	-	-	-	0	0	-4	0	0	-8	0	0	-1
- ET/JI (excl. SEA)	-	-	-	0	-7	-5	0	-7	-5	0	-1	-1
Available for banking	0	0	0	17	17	13	32	32	24	13	13	10

Abbreviations:
DA = Domestic Action, RT = Restricted Trade (no hot air) and NT = Normal Trade (i.e. including hot air; but based on optimising revenues of supplying countries). WE = Western Europe, CE = Central Europe, EE = Eastern Europe. ET/JI: Emission trading and Joint Implementation. The study does not distinguish between these two instruments. The row on the use of Surplus Emission Allowances (SEA) only refers to emission trading, as JI cannot lead to implementation of SEA. The row ET/JI (excl. SEA) refers to the use of Kyoto Mechanisms, which leads 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 is not necessarily 1990. As a result, the assigned amount, expressed as a percentage of 1990 emissions, can differ from those expressed as a percentage of the base year emissions. This is particularly the case in the CE 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 European Union compared to base year). The columns for the total European regions indicate under “sales” the trade in A.A.U.’s with Annex-1 regions outside the European region. Rounding-off may cause small deviations in sums.

the scale of Europe as a whole, the emission reductions under the *Domestic Action* case amount to 420 Mton CO_2. In the *Restricted Trade* case, emissions are reduced to 377 Mton CO_2 (or 43 Mton less) as a result of the net balance of CDM use by Western Europe (lower reductions) and emission trading by other Annex-I countries (higher reductions). In the *Normal Trade* case, the net reduction on an European scale amounts to 229 Mton CO_2 (191 Mton less) as a result of both emission trading and the use of surplus emission allowances.

Table 9.2 shows the resulting changes in the demand for primary energy. In the *Domestic Action* case, 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. This results in a 7% decrease in the total demand for primary energy.

Since less CO_2 needs to be reduced through domestic action in the trading scenarios, the changes in the energy system of Western Europe do not need to go so far. In the *Restricted Trade* case, Western European energy demand decreases by 2% and coal use decreases 21% from the baseline. Consumption of oil decreases by 3% but - at the same time - the use of gas increases by the same percentage. Measures that need to be implemented in Central Europe and Eastern Europe cause a decline in the primary energy demand by 4% and 9%, respectively. This is largely due to a lower use of coal. In the scenario with full use of Kyoto Mechanisms, including surplus allowances (*Normal Trade*), the amount of CO_2 reductions from the energy system is smaller, 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.

9.4.1 Emissions of air pollutants

The right side of Table 9.3 and Figure 9.3 demonstrate how our scenarios of implementing the Kyoto Protocol reduce the emissions of air pollutants in Europe. The actual extent of these ancillary benefits highly depends on the climate policies assumed. In the *Domestic Action* scenario, CO_2 emission reductions are only implemented in the Western European region. Thus also the decline in air pollutant emissions is restricted to that region. The emissions of SO_2 decrease sharply as a result of climate policies: calculations show - to a value of 15% below the baseline levels - a similar reduction as that for CO_2, the primary target of the climate policies. In absolute terms, this amounts to more than 450 kilotons, which is comparable with the Gothenburg Protocol emission ceiling for Italy. The corresponding reductions of NO_x and PM_{10} are 7% and 5%, respectively.

Compared with the unilateral case (*Domestic Action*), the total European emission reductions (and thus ancillary benefits) are higher in the trading scenarios (*Restricted Trade*, *Normal Trade*) (see Figure 9.3). However, since the CO_2 reductions in those scenarios are to a large extent achieved in Central Europe and Eastern Europe, the benefits are shifted to these regions. The strongest impacts occur for SO_2 emissions as a result of switching from coal to gas in power generation and end-use sectors. Reductions in NO_x emissions are smaller because they occur mainly in sectors where energy efficiency options are implemented. Trading also decreases the emissions of particulate matter (PM_{10}, 6% reduction in the *Restricted Trade* scenario compared with 2% for the *Domestic Action* case) [xi], while the ancillary benefits for VOC emissions are relatively low (about 2% reduction from the baseline).

The introduction of surplus emission allowances on the market (*Normal Trade* scenario) results in less reduction of air pollutants. Because part of the reduction now does not require any physical action, fewer changes in the European energy system are nec-

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[xi] 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.

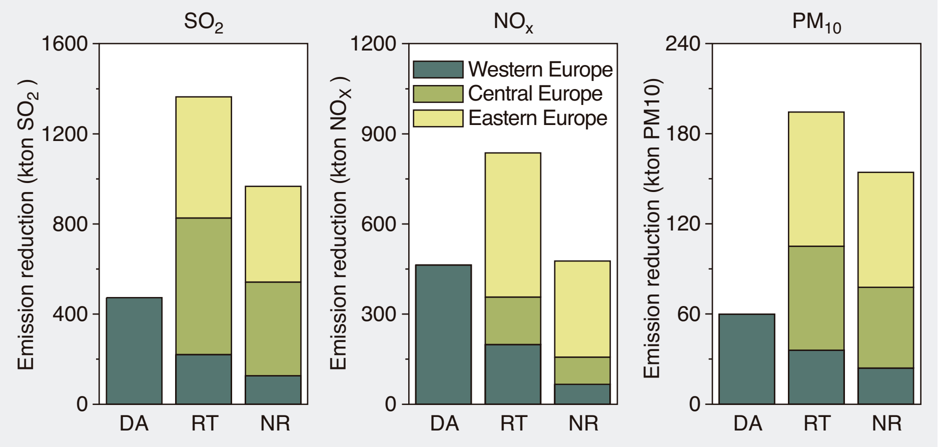

Figure 9.3 Emission reduction of regional air pollutants as a result of implementation of the Kyoto Protocol: a) the Domestic Action scenario (DAO), b) restricted trade (without the use of surplus emission allowances, TNS), and c) trade with optimal banking of sulfur emission allowances, TWS).

essary. For instance, the additional reduction of European SO_2 emissions is only 10% instead of 14% in the *Restricted Trade* scenario.

Emission control costs

Table 9.7 shows the net implementation costs of CO_2 reduction measures in Western Europe. In the *Domestic Action* scenario, the costs are about 12 billion Euro per year in 2010. This is the net result of additional investments in 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 cost increase would be 30 billion Euro per year.

Table 9.7 Total annual costs in 2010 for reducing CO_2 emissions in Western Europe in line with the Kyoto targets and change in air pollutant emission control costs (billion 1995 Euro/year)

Region	DA	RT	NT
Climate Policies (only WE)			
Domestic measures	12	2	1
Permits	0	5	3
Total	12	7	4
Change in air pollution control costs			
WE	-6.6	-2.9	-1.7
CE	0	-0.9	-0.6
EE	0	-0.2	-0.2
Total	-6.6	-4.1	-2.5

Note: DA = Domestic Action, RT = Restricted Trade (no hot air) and NT = Normal Trade (i.e. including hot air but based on optimising revenues of supplying countries). WE = Western Europe, CE = Central Europe, EE = Eastern Europe.

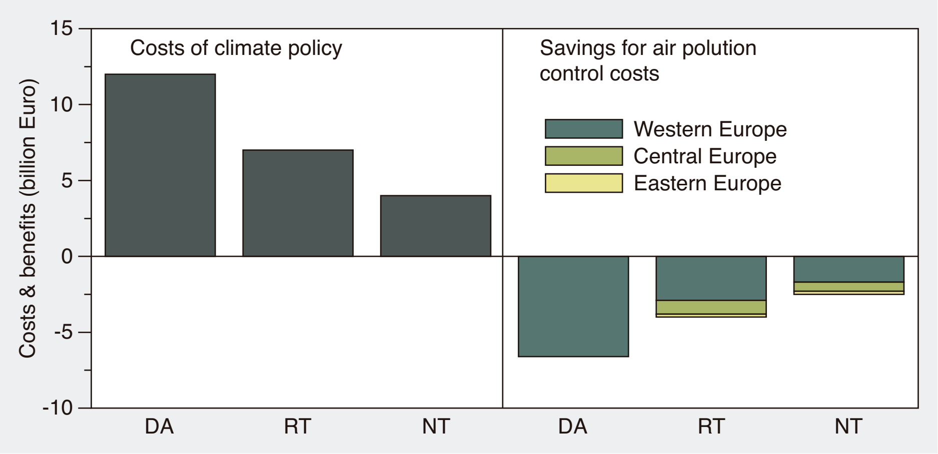

Figure 9.4 Costs of the different climate policy scenarios and their consequent savings for regional air pollution policies: a) the Domestic Action scenario (DA), b) restricted trade (without the use of surplus emissions allowances, RT), and c) trade with optimal banking of sulfur emission allowances, NT).

The trade scenarios show that the total costs of reducing CO_2 emissions can be more than halved through the use of flexible mechanisms (see also Figure 9.4). In the *Restricted Trade* scenario the costs of domestic energy system measures in Western Europe are projected to decrease to 2 billion Euro. However, at the same time about 5 billion Euro would be needed to be spent on permits, so that the total cost of meeting the Kyoto target for this scenario is 7 billion Euro. In the scenario with “Surplus Emission Allowances” (*Normal Trade*), the expenditures on domestic measures are expected to decrease further to 1 billion Euro; the same goes for the cost of permits to slightly above 3 billion Euro.

The ancillary benefits of CO_2 control policies also occur in terms of reduced costs of regional air pollution (compare the lower part of Table 9.7 and Figure 9.4). In the *Domestic Action* scenario, the expenditures on air pollution mitigation in Western Europe are projected to decrease by 6.6 billion Euro (or about 9%) from the baseline level. 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 *Restricted Trade* scenario, the savings for Western Europe are projected to decrease to 2.9 billion Euro per year. Characteristically, there are important cost reductions in the trading scenarios in the Central and Eastern European regions. The reduction for the whole of Europe,in annual expenditures on air pollution control is about 4.1 billion Euro per year in the *Restricted Trade* scenario. Inclusion of surplus emission allowances reduces the European ancillary benefits to only 2.5 billion Euros per year.

As mentioned earlier, the cost estimates for climate change and regional air pollution are not fully comparable and thus should be treated as an indication of possible synergies rather than the quantitative assessment. The results, however, clearly demonstrate that the gains in reducing air pollution control costs from climate policies can be very substantial. Although the use of flexible mechanisms reduces these ancillary benefits, the lowest total costs might still occur for the scenarios with emissions trading.

9.4.3 Regional environmental impacts

The absolute values of the changes in regional environmental impacts as a result of climate policies are not high, as substantial improvements are already achieved in the baseline (Table 9.5). For acidification, an additional 0.6 - 1.4 million ha of ecosystem area is protected in our scenarios. In case of eutrophication, 2.2 - 4.1 million ha of ecosystems are additionally protected. Nevertheless, about 100 million ha of yet European ecosystems remain threatened by eutrophication. Since our climate policies do not change ammonia emissions, achieving higher protection levels is not possible.

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 Western Europe. This can be seen by comparing the *Domestic Action* and *Restricted Trade* scenarios. In the latter, only a third of the action is taken in WE compared to what was formerly taken; yet the improvement in acidification impacts is almost similar. The stronger sulfur reductions in Central Europe per Mton CO_2 reduction (coming mostly from less stringent abatement levels) helps to achieve this result. By the same token, the *Domestic Action* scenario also improves the environmental impact indicators in Central Europe, even if no action is taken in this region. For Europe as a whole, the largest ancillary benefits are found for the trading scenarios.

The CO_2 mitigation scenarios reduce impact indicators for ground-level ozone too. For Western Europe, the highest reductions occur in the *Domestic Action* case – more than 3% reduction of the health-related (AOT60) and vegetation-related (AOT40) exposure indices compared with the baseline. For Europe as a whole, the highest effects are brought about by the *Restricted Trade* scenario (5% improvement of both indices). Just as for the Baseline, country-specific indicators can be found in the study by Van Vuuren et al. (2003).

9.5 Discussion

Our study has explored the potential ancillary benefits of different ways to implement the Kyoto Protocol in Europe by linking models that had previously been used separately to study the climate change and regional air pollution policies. A few remarks should be made on the interpretation of our results. First, no attempt has been made at this stage to optimize climate change and regional air pollution policies in one integrated framework. Before this can be done it is necessary to fully harmonize the costs concepts used by the different models. Moreover, optimization will not be straightforward, given the different trade-offs within the system. 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 CO_2 are likely to be smaller than the average reduction. In this case, both the costs of climate policies and the gains for ancillary benefits could be somewhat lower.

Overall, the study clearly shows that 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 only. The results of our Domestic Action (*Domestic Action*) scenario can be compared with those studies. The European Environmental Priority study (RIVM et al., 2001) and a related paper (Syri et al., 2001) found that reducing the CO_2 emissions in Western Europe by 15%, compared to the baseline (-8% from 1990 level), would reduce SO_2 emissions by 24% and NO_x emissions by 8%. In our study the emission reductions were 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). Another study for the Western European region used the E3ME model (Barker, 2000) to estimate the possible ancillary benefits of a 10% reduction of the baseline CO_2 emissions (domestic implementation of the Kyoto Protocol). The results (12-14% reduction for SO_2, 7-8% for NOx and 4% for PM_{10}) compare well with our results. The differences can be explained by different CO_2 baseline projections and the assumptions on policies for regional air pollutants.

In contrast to the earlier studies, this study also encompassed the Central and Eastern European regions – and the specific impacts of emission trading. An important finding is that the link between the reduction in CO_2 emissions and regional air pollution is stronger in these regions than in Western Europe. This is caused by heavy reliance on coal in Eastern Europe and by less stringent emission control legislation.

According to our calculations, implementation costs of the Kyoto target vary between 12 billion Euro per year for the domestic action case and 4-7 billion Euro for the trading scenarios. Overall, the costs presented here seem to be within the broad range of cost estimates used in other studies. For instance, a recent detailed European study (Blok et al., 2001) looking into the costs of domestic implementation of the Kyoto Protocol found costs to vary between 4 and 8 billion Euro, depending on the assumptions about EU-wide trading. Since the study also covered non-CO_2 greenhouse gases (leading to an overall decrease in implementation costs) the costs estimated by Blok et al. (2001) are consistent with those calculated here. The European Environmental Priorities study (RIVM et al., 2001) using the PRIMES model found costs very similar to our estimates for a similar cost concept (13.5 billion Euro for domestic implementation of the Kyoto Protocol). However, the total energy system cost calculated by PRIMES is much higher. This could be due to the sector-specific market interest rates used in PRIMES, which for some categories of energy consumers are quite high. The Priorities study also included an estimate of the net implementation costs, taking into account emissions trading, which is again close to those found here, i.e. 6.3 billion Euro versus 4-7 billion Euro for the two trade scenarios explored in this study.

The results indicate 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 6.6 billion Euro per year. This result suggests that for the domestic action scenario, about half the total costs for implementing the Kyoto target may be 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 generally somewhat lower (around 20-30%). These studies cover the EU (Syri et al., 2001), Netherlands (Smeets and Wijngaart, 2002) and the USA (Burtraw and Toman, 2000)

9.6 Conclusions

Our work resulted in several findings on ancillary benefits for air pollution in Europe by implementing the Kyoto Protocol. The most important conclusions are presented below in conjunction with brief explanations indicating the magnitude of potential benefits.

Implementation of the Kyoto Protocol yields substantial ancillary benefits for air pollution in Europe. The design of climate policies is important for obtaining ancillary benefits. Implementing the Kyoto Protocol in Europe reduces the emissions of air pollutants and results in lower exceedances of critical thresholds for ecosystems and human health throughout Europe. In fact, the additional emissions reductions (from baseline) for SO_2 are mostly larger than those for CO_2 (4 – 15 %). For NO_x and PM_{10}, somewhat smaller emission reductions are obtained (2 - 6 %), while the additional reductions are smallest for VOC (1-2 %).

Implementing the Kyoto Protocol also reduces the control costs for air pollutants. In spite of uncertainties in cost estimates and differences in cost calculation methodologies, the results suggest that about 50% of the costs of the Kyoto target can be re-gained in terms of reduced costs for air pollution control (i.e. air pollution control cost reductions of 2.5 to 6.6 billion Euro per year versus costs of climate policies of 4 to 12 billion Euro per year). Interestingly, the total annual air pollution control costs expected for 2010 (typically for emission control technology) are considerably higher than the expected costs for implementing the Kyoto Protocol (typical for changes within the energy system). As a result, even modest climate policies (in terms of costs) may have relatively large financial ancillary benefits in terms of avoiding the most expensive measures for air pollution control. It should be noted that the larger share of the measures taken for climate policies impact the industry and electric power sectors. In contrast, a very large share of the air pollution control costs (about 60%) occurs in the transport sector. This means that the relative reduction of air pollution control costs in the stationary sectors could, in fact, be much larger than the overall reduction. Moreover, the large potential financial co-benefits in the transport sector may allow for stricter climate policies in this sector than from a perspective of optimising climate control costs only.

The type and size of ancillary benefits depends on if - and how - CO_2 trading is used.
The links between the CO_2 and air pollutant emissions are weaker in Western Europe than in Central and Eastern Europe. This is mainly due to more stringent air pollution control legislation compared with the other two regions. As a result, total European air pollutant reductions can be higher in the scenarios that use the Kyoto flexible mechanisms compared to the domestic action scenario. In turn, savings on pollution control costs are the highest in the *Domestic Action* case, since structural changes in Western European energy system induced by the CO_2 constraint allow avoidance of high-cost air pollution abatement measures in this region.

Reaching the Kyoto targets through domestic action only limits the ancillary benefits to Western Europe (as only this region needs to reduce CO_2 emissions). Since emission trading and joint implementation induce changes in energy systems in other parts of Europe, trading scenarios shift (“trade”) ancillary benefits partly to European regions outside Western Europe. Interestingly, however, while in the trading scenarios most of the CO_2 emission reduction takes place outside Western Europe, the differences for environmental impacts (in particular acidification) are much smaller, as Western Europe can partly benefit from the transboundary effect of reducing the pollution levels in Central Europe.

Thus, the results indicate that the use of emission trading, provided that they lead to real emission reductions in Central and Eastern Europe, can lead to a sharper reduction of regional air pollution in Europe. Using CDM with developing countries foregoes these benefits.

Using surplus emission allowances reduces ancillary benefits, in particular, for the Central and Eastern Europe regions.
Introducing available surplus allowances on the carbon market reduces the need for physical action to reduce CO_2 emissions in those regions and, consequently, the emissions of air pollutants and their control costs are higher. In our scenario with surplus allowances, the SO_2 and NO_x emissions in Central Europe and Eastern Europe are 2-4% higher and the control costs are 1.5 billion Euro/year higher than in the scenario that excludes surplus allowances. This might be a further important reason for the Central European and Eastern European countries (in addition to the direct impacts on the price of CO_2 emission permits) to restrict the amount of surplus allowances put on the market.

Integrated approach to climate change and regional air pollution policies is important for harvesting potential ancillary benefits.

The results presented in this chapter clearly demonstrate that integrating climate change and regional air pollution policies will lead to important efficiency gains. However, further development of tools and methods is necessary. In particular, the assessment models need to be extended to non-CO_2 greenhouse gases. Costing methodologies used in the analysis also need to be harmonized.

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APPENDIX 9.1 MODEL DESCRIPTION AND LINKAGES BETWEEN THE MODELS

This Appendix describes the three models that have been used in this exercise and their linkages.

The FAIR 2.0 model

The FAIR 2.0 model (Framework to Assess International Regimes for differentiation of future commitments) was designed to quantitatively explore the outcomes of different climate regimes in terms of possible environmental and economic impacts (including emission trading). It is a decision-support tool that uses expert information from more complex models (in particular, IMAGE), such as baseline emissions and marginal abatement cost curves. The basic assumption of the model is that regions will reach their emission reduction commitments on the basis of least cost. These costs are calculated using marginal abatement cost (MAC) curves, which reflect the additional costs of reducing the last unit of carbon. These MACs allow an assessment of the willingness of any party to buy permits or to abate more than is required to meet the Kyoto commitment and sell permits. Extensive documentation of the FAIR model can be found in Elzen and Lucas (2003a).

The TIMER model

The global energy system model, TIMER (The IMage Energy Regional Model), has been developed to simulate (long-term) energy baseline and mitigation scenarios. The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and resource depletion. Inputs to the model are macro-economic scenarios and assumptions on technology development, preference levels and restrictions to fuel trade. The output of the model demonstrates how energy intensity, fuel costs and competing non-fossil supply technologies develop over time. In TIMER, implementation of CO_2 mitigation is generally modeled on the basis of price signals (a tax on carbon dioxide). In response to the carbon tax, the model generates several outputs, such as investments in energy-efficiency, fossil fuel substitution, and extra investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels. The model does not account for any feedback from the energy system to economic drivers. It should be noted that in TIMER costs are not related to the implementation of one single measure, as its implementation also changes 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. The TIMER model has been described in Chapter 2 of this thesis and in De Vries et al. (2001).

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 for all pollutants relevant for acidification, eutrophication and formation of ground-level ozone (Amann et al., 1999). It also includes a module that estimates the emissions of particulate matter (PM) from anthropogenic sources (see (Klimont et al., 2002))[xii]. Within RAINS, a non-linear optimization is used to identify the cost-minimal combination of measures, taking into account regional differences in emission control costs and atmospheric dispersion characteristics. RAINS covers almost all European countries and incorporates detailed data on their energy consumption. Scenarios for energy development form an exogenous input to the model. For emissions, it is calibrated on the basis of EMEP (compare http://webdab.emep.int), CORINAIR (EEA, 2001) and CEPMEIP data (CEPMEIP, 2002). In RAINS, emission reductions are achieved exclusively by technical measures. Feedbacks of emission controls on economic and energy system are not included. For example, emissions of SO_2 can be controlled through lowering the sulfur content of fuels or through flue gases desulfurization, but not by substituting coal by natural gas. Effects of changing the structure of energy supply and demand need to be analyzed as a separate scenario. Atmospheric dispersion processes for all pollutants are modeled on the basis of results of the EMEP air pollution transport models. The impacts of scenarios are evaluated using a set of indicators reflecting sensitivities of ecosystems and people to pollution (critical loads and levels). More details about the indicators used can be found in Cofala et al. (2002).

TIMER to FAIR

In principle, the TIMER and FAIR models use a similar regional breakdown and data can be easily transferred between them. For the Former Soviet Union (FSU), however, FAIR distinguishes between Annex-I countries that have emission obligations under the Kyoto Protocol (in particular the Russian Federation and Ukraine) and non-Annex-I countries that have no emission obligations. 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 was that FAIR uses data on base year emissions from the CDIAC database (CDIAC, 1999), that are somewhat different from the TIMER modeling results for 1990. Therefore relative changes compared to 1990 were used in the data transfer between these models.

TIMER to RAINS

For RAINS, country-level energy scenarios are necessary as inputs for emission 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 are different (TIMER is calibrated against IEA data, RAINS uses in addition data from national sources). A methodology had to be developed to translate the TIMER energy results into RAINS input. First, existing RAINS data for each fuel-sector combination are aggregated into the

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[xii] PM is estimated separately for the fine fraction ($PM_{2.5}$ – particles with aerodynamic diameter smaller than 2.5 μm), coarse fraction (particles between 2.5 and 10 μm) and total suspended particles (TSP). The sum of emissions of fine and coarse fractions (PM_{10}) is also calculated.

(lower) level of detail of the TIMER model. This aggregation is done for the base year (1995) and for the target year (2010) using a previous RAINS scenario, with very similar assumptions to the TIMER baseline. Second, for each country, fuel type and sector, the original RAINS data are scaled to the TIMER values using equation 9.1.

$$En\_R_{c,s,f,2010} = En\_R_{old,c,s,f,1995} {}^{*} \left(En\_T_{R,s,f,2010} / En\_T_{R,s,f,1995}\right){}^{*} \\ \left(En\_R_{old,c,s,f,2010} / En\_R_{old,c,s,f,1995}\right) / \left(En\_R_{old,R,s,f,2010} / En\_R_{old,R,s,f,1995}\right) \tag{9.1}$$

Where:
En_R is the fuel use as used in the RAINS model (GJ),
“Old” refers to the data of an earlier RAINS run,
En_T is the fuel use in the TIMER format (GJ),
The prefixes c and R refer to country and region level,
The prefixes s and f are used for sector and fuel type.

Some further assumptions 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 and livestock farming). Here data from RAINS were used. This has also been done for energy sources for which TIMER does not include information (the use of solid waste as a fuel). Secondly, equation (9.1) cannot be applied to fuels with very small (or even zero) consumption in the base year, i.e. for “new” renewable energy sources such as solar and wind in power generation and for natural gas use in transport. In these cases, 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. Similarly, data on compressed natural gas (CNG) use in transport was distributed on the basis of total national demand for transport fuels. Finally, using the scaling method of equation 9.1 does not necessarily result in supply meeting demand on a country level. For energy forms for which export/import is possible we assumed that potential surpluses/deficits will be leveled out through international trade within each country group. For district heat we have scaled back the demand per country to its production level.