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Industrial Benefits and Costs of Greenhouse Gas Abatement Strategies: Applications of E3ME

Modelling external secondary benefits in the E3ME model

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Preface:

This working paper is prepared for private circulation among the participants of the E3ME project "Industrial Benefits and Costs of Greenhouse Gas Abatement Strategies: Applications of E3ME". The working paper belongs to Task 9 of the project, "GHG abatement benefits and costs", and is numbered as Working Paper No 9c. As the results are preliminary, please do not quote without permission of the author. Comments, corrections and additions are gratefully received. The views represented in this paper are those of the author and are not necessarily those of the European Commission.

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Executive Summary

Introducing carbon taxes or other measures against CO_2 emissions gives rise to so-called secondary (or ancillary) benefits, as emissions of other pollutants are also reduced. This paper describes how such benefits are implemented into the E3ME model, and discusses the size of secondary benefits from fulfilling the Kyoto requirement in the EU.

The paper first explains how local and regional damage costs from emissions of NO_x, SO_2 and PM_{10} are implemented into the E3ME model. The damage costs are taken from the ExternE study, which has a sort of consensus status within the EU. Damage costs vary across pollutant and across country in the model.

The projection of damage costs until 2010 show a dramatic fall due to expectations of large reductions in emissions of NO_x and especially SO_2.

The Kyoto protocol requires that the EU countries should reduce their total emissions of CO_2 and 5 other greenhouse gases by 8 per cent in 2008-2012 compared to 1990. Since the 5 other greenhouse gases are projected to fall significantly over this period, CO_2 emissions have to be reduced by merely 2-3 per cent, according to the model results. In this paper we present four alternative mitigation scenarios that fulfils the Kyoto requirements, with either multilateral carbon taxes, permit scheme or a combination of these. The necessary tax rates or permit prices lie between 172 and 192 1990-Euro per tonne carbon.

In all cases we find that the secondary benefits in EU in 2008-12 are about 11 billion 1990-Euro per year, i.e., 0.13 per cent of total GDP. Compared to the change in GDP from the carbon policy, the secondary benefits constitute between 15 and 40 per cent. Hence, including the secondary benefits in the overall assessment of the policy measure is of vital importance. This result holds even though emissions of NO_x and SO_2 are projected to fall significantly until 2010 due to a European protocol on transboundary pollution. If the protocol becomes difficult to comply with, the secondary benefits may be even higher than in our results.

Finally, the secondary benefits constitute around 112 1990-Euro per ton reduction in carbon emissions. Hence, even if there are uncertainties about the marginal damage costs of CO_2 emissions, the secondary benefits imply that fairly high marginal costs of mitigation may be justified.

1 Introduction[1]

1.1 Purpose of the Paper

Mitigation of greenhouse gases, particularly CO_2, has favourable impacts on emissions of other pollutants, too, as the use of fossil fuels is reduced. When the costs and benefits of climate policies are evaluated, it is thus important to include the benefits from reduced local and regional pollution. As the main goal of climate policies is to reduce emissions of greenhouse gases, these benefits are usually referred to as secondary benefits (or ancillary benefits). Reductions in other negative externalities, especially related to road transport, are also often included in studies of secondary benefits. Ekins (1996) gives a review of studies of secondary benefits.

This paper discusses how secondary benefits can be implemented into the E3ME model. As the emission calculations of the relevant pollutants are discussed in Working Paper No 9b, the focus here is on how to value changes in these emissions. This valuation is very complex, comprising the connection between emissions and pollution levels in various locations, the physical impacts of pollution on health, material, plants etc., and finally the valuation of mortality, morbidity and other physical effects. Much scientific effort has been devoted to the various links in this chain, and in later years several studies have been undertaken in order to estimate the costs of emissions by going through the whole chain. The most comprehensive and well-known example is the ExternE project (EC 1995), which is also supported by the European Commission. This project was initiated to calculate external costs of electricity generation from different kind of power plants in Western Europe. Because of the importance and comprehensiveness of the ExternE project, we choose to rely on the results they arrived at rather than reviewing all relevant literature.

1.2 Remaining Sections of the Paper

In the next section a literature review is given, first on secondary benefits and then on damage cost calculations based on the ExternE project. In section 3 the choice of methodology is discussed and proposed changes to the E3ME model is presented in general terms (i.e., new equations, variables and parameters are presented). Moreover, the parameter values to be used in the equations are derived and presented. Then in section 4 an assessment of current damage costs from emissions within the E3ME area is showed, and also a projection of damage costs until 2010. An analysis of secondary benefits of fulfilling the requirements in the Kyoto protocol is also presented. In section 5 we conclude the paper.

2 Literature Review

Although the number of studies estimating costs of climate policies has exploded over the last years, particularly related to the so-called double dividend hypothesis, very few studies have emphasised or even included secondary benefits. In Ekins' (1996) review of the literature, most reported studies are from the years 1991-93, with one exception from 1995 (e.g., Alfsen et al. (1992, 1995), Barker (1993) and Pearce (1992)). Since then, the international literature contains little or no such studies. One reason for this may be the difficulties in estimating such benefits, both with respect to estimating the physical effects and the corresponding economic value of specific emissions, but also because the impacts of emissions are very site-specific. Thus, transferring results from other studies may be questionable. The studies reported by Ekins (1996) generally use quite simplistic approaches regarding damage assessments and transferring results, and also use national estimates for the unit costs of various emissions despite the importance of location (these problems are also stressed by the authors).

[1] Thanks to Geir Abel Ellingsen for valuable research assistance and helpful discussions.

Moreover, in view of the epidemiological studies over the last decade, e.g. stressing the damaging effects of particulate matter, the resulting figures may be further questioned.

According to Ekins (1996) a 'consensus range' for the secondary benefits in the studies he refers to is \$250-400 per tonne carbon reduced. By comparing with the mitigation costs reported in the literature, he concludes that secondary benefits alone justify large reductions in CO_2 emissions.

In a newer study from Norway (Glomsrød et al. 1996)[2] the general method used by the ExternE project (i.e., using dose-response functions etc.) is connected to a general equilibrium model for the Norwegian economy. Concentrations of pollutants are calculated in several towns based on emissions from various sources. Hence, the problem of site-specificity mentioned above is taken into account. Health and environmental impacts partly affect the input of the model (i.e., a simultaneous modelling of economic and environmental interactions), and are partly valued in a post model. Traffic injuries are also included in the model, whereas other traffic-related effects are only assessed at the end. In this study secondary benefits of a gradually rising carbon tax are calculated to be 16 per cent of the GDP loss (for the effects included in the model), half of it coming from traffic injuries. Compared to the reduction in CO_2 emissions, the secondary benefits amount to about Nkr 200 per tonne CO_2, or \$110 per tonne carbon. The assessment of other traffic-related benefits indicates a doubling of the secondary benefits, i.e., still somewhat below the 'consensus range' in Ekins (1996). One reason for the small benefits of reduced air pollution is that the emissions of particulate matter in the towns, being the main contributor to health damages, are not affected very much by the carbon tax.

Calculations of damage costs of air pollutants have got increased credibility the last years, in line with the ExternE project among others. One important reason is that the scientific knowledge of physical effects of air pollution has increased remarkably. Hence, the updated knowledge of damage costs should motivate to make new studies of secondary benefits.

Sáez and Linares (1999) present an overview of damage costs from energy production in about 60 plants estimated under the ExternE project. The damage costs are presented for SO_2, NO_x and particulates (PM_{10}). The costs for NO_x is related to its impact via nitrates. In addition an average figure for the whole Europe is estimated for its impact via ozone. The plants cover all EU-countries (except Luxembourg), and a summary table is constructed for damage costs related to emissions in each EU-country. The damage costs are presented as intervals where the lower and upper limits are equal to the lowest and highest damage costs from plants in the relevant country. For half of the countries the upper limit is more than twice the lower limit for at least one of the three pollutants. This underlines the importance of site specificity, both with regard to closeness to large cities and with regard to which way the emissions are transported (e.g. into the ocean). In France, one of the plants is located outside Paris, and the damage costs of particulate pollution from this plant are almost 10 times higher than the lower limit for France.

Despite the importance of site specificity even within a country, the authors recommend to use national figures in applications to other power plants whenever more advanced methods are impracticable.

The estimated damage costs include damages that occur within the whole of Europe. Hence, only a fraction of the damage costs reported occurs within the EU, and an even smaller fraction occurs in the country where the emissions are released. Still, in an EU perspective, the fraction is probably not very far from unity.

[2] The study is in Norwegian, but the modelling approach (except for the carbon tax calculations) is presented in detail in English in Rosendahl (1998).

It is difficult to see what physical effects and valuation method are used behind the monetary damage costs in Sáez and Linares (1999). However, in Krewitt et al. (1999), who present a case-study for Germany based on the ExternE methodology, the monetary figures are split up on physical effects. Based on these figures it is possible, at least to some degree, to calculate the physical effects behind, e.g., 1,000 Euro in PM_{10} damages. The methodology volume of ExternE (European Commission, 1999) also presents some useful background information.

3 Methodology

3.1 Chosen Methodology

When choosing the appropriate methodology, two main approaches are at hand. The simplest one is to use fixed damage cost coefficients on each pollutant in each region of the model, alternatively differing between emission sources within the region. The coefficients must then be based on results from other studies, e.g. results from the ExternE project (Sáez and Linares 1999). The more sophisticated one is to implement into the model the so-called impact-pathway method used by the ExternE in their calculations. This method includes relationships between emissions from a region (or possibly from an emission source in a region) and concentration levels in other regions, dose-response functions for health and environmental impacts, and valuation of physical effects. The latter method is more flexible and transparent and can be used to calculate damage costs brought upon individual regions. However, it requires far more information than the simple one.

Since the results from the ExternE project have become a sort of consensus results within the EU, and national figures are available in Sáez and Linares (1999), we choose the simple method using fixed coefficients. A possible extension in the future could however be to implement the impact-pathway described above. This is done in the GEM-E3 model, partly because the national figures above were not available at the moment.

Despite the importance of site specificity, which has been stressed above, we choose to use identical damage coefficients for each emission source in the model. The reason is first of all that we do not have information of the geographical dispersion of emissions within each region. Secondly, although the damage costs from road traffic emissions probably are higher than costs from power plant emissions (because it generally leads to higher human exposure), it is difficult to assess how much the coefficients should be increased.

3.2 Proposed Changes to the Model

Hence, we end up with the following general equations:

$$D_j = d_j^{SO2} \cdot E_j^{SO2} + d_j^{NOx} \cdot E_j^{NOx} + d_j^{PM10} E_j^{PM10}$$

- D_j denotes the total damage costs inflicted by region j on other countries in Europe (in Euro)
- E_j^k denotes the total emissions of pollutant k (k = SO_2, NO_x, PM_{10}) in region j (in tonnes)
- d_j^k denotes the damage cost coefficients of pollutant k in region j (in Euro per tonne). For NO_x this coefficient include the effects through ozone, which is equal across countries

Total damage costs across the regions within the model are then:

$$D = \sum_j D_j$$

It is important to note that we are only able to calculate the damage costs *caused by* a specific region, not the costs *inflicted on* the region. Moreover, the damage costs include costs inflicted on areas outside the E3ME regions (i.e., other parts of Europe).

A point should be made about the selection of pollutants. Only damage costs of SO_2, NO_x and PM_{10} are included in Sáez and Linares (1999), whereas the E3ME model contains several other pollutants which are relevant in the context of secondary benefits (e.g. CO and VOC). However, the three selected are surely the most important ones.

Another point should be made about reductions in other externalities. The literature review indicated that reductions in traffic-related externalities may be important in estimating secondary benefits of climate policies. As this is not included in the model, the calculations will probably underestimate the total secondary benefits.

3.3 Damage cost coefficients

Table 3.1 shows the range of damage costs of SO_2, NO_x and PM_{10} in the various countries according to the ExternE project, and is taken from Sáez and Linares (1999). In addition come the effects from NO_x emissions on ozone concentration, which is valued at 1,500 1995-Euro per ton for each country.

Table 3.1. Damages of air pollutants (in 1995-Euro per t of pollutant emitted)

Country	SO_2	NO_x	Particulates
Austria	9,000	16,800	16,800
Belgium	11,388-12,141	11,536-12,296	24,536-24,537
Denmark	2,990-4,216	3,280-4,728	3,390-6,666
Finland	1,027-1,486	852-1,388	1,340-2,611
France	7,500-15,300	10,800-18,000	6,100-57,000
Germany	1,800-13,688	10,945-15,100	19,500-23,415
Greece	1,978-7,832	1,240-7,798	2,014-8,278
Ireland	2,800-5,300	2,750-3,000	2,800-5,415
Italy	5,700-12,000	4,600-13,567	5,700-20,700
The Netherlands	6,205-7,581	5,480-6,085	15,006-16,830
Norway	na	na	na
Portugal	4,960-5,424	5,975-6,562	5,565-6,955
Spain	4,219-9,583	4,651-12,056	4,418-20,250
Sweden	2,357-2,810	1,957-2,340	2,732-3,840
United Kingdom	6,027-10,025	5,736-9,612	8,000-22,917

na: not available.

As noted in chapter 2, the intervals in table 3.1 cover the damage costs from various power plants in the specific country. We see that the differences between lower and upper limit are quite large, especially for particulates. This is because local effects are relatively more important for particulates than for the two other pollutants. As a comparison, Rosendahl (1999) finds that the local marginal costs of PM_{10} emissions in four cities of Norway range from about 60 to 150 thousand 1995-Euro per ton (highest for Oslo). This study is based on the same methodology as ExternE, using a detailed dispersion model for each city. These results indicate that the local damage costs of PM_{10} emissions within cities may be much higher than the damages from power plants shown in the table above.

We do not have suitable information about how representative the plants are with respect to impact of emissions. In United Kingdom, for instance, there are case-studies for three plants. The plant with the lowest damage costs of particulate emissions (i.e., 8,000 Euro per t) is situated at the western tip of south Wales, between the sea and the mountains. The plant with the highest costs (i.e., 22,917 Euro per t) is situated on the south coast of England, upwind of London. The third plant, with damage costs in the middle (i.e., 14,063 Euro per t), is located in Yorkshire. It is difficult to state whether the damage costs from these three plants are representative or not for UK emissions in general. Moreover, we do not have similar information about plants in the other countries.

Hence, we choose to compute the average of the unit costs reported by the individual plants in each country. Then we come up with the following suggested damage cost coefficients (d_j^k), see table 3.2. Here we have added to ozone-effect of NO_x emissions. The number of plant locations in each country is showed in parentheses behind the country-name, which may be an indication of how representative the coefficients are.

Table 3.2. Damage cost coefficients (in 1995-Euro per t of pollutant emitted)

Country (no. of plants)	SO_2	NO_x	PM_{10}
Austria (1)	9,000	18,300	16,800
Belgium (2)	11,765	13,295	24,536
Denmark (3)	3,603	5,421	5,028
Finland (3)	1,373	2,683	1,835
France (3)	10,567	15,967	24,867
Germany (3)	12,077	14,606	21,589
Greece (4)	4,363	5,800	4,944
Ireland (2)	4,050	4,375	4,108
Italy (9)	8,688	10,007	10,400
The Netherlands (2)	6,999	7,259	16,137
Portugal (3)	5,218	7,830	6,439
Spain (13)	6,684	9,072	7,654
Sweden (2)	2,584	3,649	3,286
United Kingdom (3)	7,623	9,143	14,993

First we notice that the highest damage costs are related to emissions released in the middle of Europe (i.e., France, Belgium, Germany and Austria). Moreover, the lowest damage costs are related to emissions in the Nordic countries, Greece and Ireland, which are located in the outskirts of Europe and not upwind of other countries (such as the UK). This is what we should expect in advance. In fact, emissions of SO_2, NO_x and PM_{10} in France are respectively 8, 12 and 14 times more costly than the corresponding emissions in Finland. This confirms the importance of site specificity. Thus, even though we are not able to distinguish between sites of emissions within a country, we are able within the E3ME model to distinguish between emissions released in various locations of Europe.

When we compare the countries in table 3.2 with the regions in the E3ME model, we observe that we lack damage cost coefficients for Norway, Switzerland and Luxembourg, whereas Germany and Italy should be divided into West- and East-Germany and North- and South-Italy. At this stage we do not have enough information about the location of the plants in Germany and Italy, so until further we use the same coefficients as for the whole country. For Italy the damage costs are probably higher for North- than for South-Italy - for Germany the differences are probably minor. For Norway we choose the average of the coefficients for Denmark and Sweden. For Switzerland we choose the average of the coefficients for Austria and for one of the plants in Germany (i.e., Lauffen which is situated in the south). For Luxembourg we use the coefficients for Belgium. Then we get the following damage cost coefficients for the regions not included in table 3.2, see table 3.3.

Table 3.3. Damage cost coefficients (in 1995-Euro per t of pollutant emitted)

E3ME Region	SO_2	NO_x	PM_{10}
Germany (east)	12,077	14,606	21,589
Germany (west)	12,077	14,606	21,589
Italy (north)	8,688	10,007	10,400
Italy (south)	8,688	10,007	10,400
Luxembourg	11,765	13,295	24,536
Norway	3,093	4,535	4,157
Switzerland	10,850	16,537	19,326

As health effects dominate the damage cost figures, one may ask whether the figures will increase over time (in real terms) as there is generally a positive relationship between income level and valuation of specific health effects (e.g. in willingness-to-pay surveys of mortality risks). However, this is not taken into account at this stage.

It is important to stress the uncertainty related to the damage cost coefficients, and that several controversial assumptions are hidden in the calculations. Uncertainty relates especially to relationships between emissions and concentrations, and to physical effects of air pollution, but also to economic valuations. For instance, one has to choose how to value premature mortality due to increased pollution levels. In the ExternE calculations, which we rest our coefficients on, the cost of premature mortality has been estimated as the value of life years lost (VLYL) rather than the value of a statistical life (VOSL). This is a very controversial issue with big implications for the results (using VOSL would probably have increased the damage costs by 50 per cent, see AEA (1999)).

According to Sáez and Linares (1999) the damage costs are dominated by the health impacts. This is confirmed in Krewitt *et al.* (1999), who present damage costs from fossil electricity generation in Germany and the EU based on the ExternE methodology. Their results show that between 96 and 101 per cent of total damage costs are due to health effects (more than 100 per cent means that there are positive yield effects in agriculture). For the EU as a whole the fraction is 97 per cent. Moreover, 77 per cent of damage costs related to health effects is due to mortality. Hence, it is reasonable to assume that around 75 per cent of damage costs in our calculations are due to increased mortality. As mentioned above, mortality is valued based on life years lost (VLYL). However, Sáez and Linares do not write what monetary value is used. Krewitt *et al.* use \$110,000 (1995-\$) per average life year lost, which is based on a discount rate of 3 per cent, whereas AEA (1999) uses 110,000 and 67,000 1990-Euro for acute and chronic mortality effects, respectively, based on a discount rate of 4 per cent. Both studies are based on the ExternE methodology. In the methodology volume of ExternE (European Commission, 1999) several figures are mentioned, based on different discount rates and death causes. Most figures lie around 100,000 1995-ECU. Hence, the implicit present value of a life year lost in the damage costs above is presumably around 100,000 1990-Euro. This means that 1 million 1990-Euro in calculated total damage costs is split into around 750,000 Euro due to mortality, around 220,000 due to morbidity and around 30,000 due to environmental damages. Furthermore, the mortality costs are derived from a loss of about 7.5 life years.

4 Results

4.1 Projection of damage costs from emissions within the E3ME area

We are now able to make a crude assessment of total damage costs from emissions of SO_2, NO_x and PM_{10} within the E3ME area. As the damage cost coefficients in the tables above are calculated based on marginal changes in emissions, we cannot simply use these coefficients on the total level of emissions in the various countries. One reason for the presumable difference between the marginal and the average damage costs is the existence of thresholds, particularly with respect to health effects. On the other hand, WHO (1997) does no longer recommend specific air quality guidelines for particulate matter as health effects have been observed at very low levels (Note that health effects from SO_2 and NO_x emissions are mainly due to the transformation to secondary particles). Moreover, as we don't have the information we need to adjust the marginal damage cost coefficient, we choose to use them directly in order to arrive at a very crude assessment of the total damage costs from emissions within the E3ME area. The results must not, however, be referred to as a credible calculation of damage costs in Western Europe. The results will probably overestimate the real damages (at least with respect to the pollutants and impacts included).

Table 4.1 shows the emissions of SO_2, NO_x and PM_{10} in each country in the base year. Moreover, the calculated damage costs are also shown.

Table 4.1. Emissions (in 1,000 tons) and crude assessment of corresponding damage costs (billions (90) Euro) of air pollutants in baseyear 1994

E3ME Region	SO_2 emissions	SO_2 damage costs	NO_x emissions	NO_x damage costs	PM_{10} emissions	PM_{10} damage costs	**Total damage costs**
Austria	55	0.4	183	2.9	39	0.6	**3.9**
Belgium	279	2.9	345	4.0	27	0.6	**7.5**
Denmark	157	0.5	272	1.3	14	0.1	**1.9**
Finland	111	0.1	282	0.6	72	0.1	**0.9**
France	1,013	9.5	1,831	26.0	211	4.7	**40.2**
Germany	2,998	30.3	2,042	24.9	755	13.6	**68.8**
Greece	556	1.3	358	1.1	0	-	**2.4**
Ireland	177	0.6	116	0.5	105	0.4	**1.5**
Italy	1,436	9.6	1,791	13.7	501	4.0	**27.3**
Luxembourg	13	0.1	22	0.3	0	-	**0.4**
The Netherlands	146	0.9	493	3.2	38	0.5	**4.7**
Norway	34	0.1	212	0.9	24	0.1	**1.1**
Portugal	273	1.0	379	2.0	0	-	**3.0**
Spain	2,061	10.1	1,206	8.0	33	0.2	**18.3**
Sweden	74	0.2	329	1.0	48	0.1	**1.2**
Switzerland	31	0.3	140	2.0	19	0.3	**2.6**
United Kingdom	2,697	16.5	2,289	16.8	426	5.1	**38.5**
Total E3ME area	**12,111**	**84.5**	**12,290**	**109.4**	**2,312**	**30.4**	**224.3**

Source: E3ME project, E3ME22 C92F7BB, January 2000

We see that the total calculated damage costs exceed 200 billions 1990-Euro for the whole E3ME area. Half the costs are due to NO_x emissions, whereas SO_2 emissions cause more than one third of the total costs. Damage costs from PM_{10} emissions are lower. However, there are reasons to believe that these costs are underestimated, as emissions of particulate matter within the cities are more harmful than emissions from power plants (see above). Moreover, the emissions data for PM_{10} are much more uncertain than those for NO_x and SO_2, and are possibly underestimated. Emissions in Germany account for more than one third of total damage costs from SO_2 emissions, more than one fifth of total damage costs from NO_x emissions, and almost half the total damage costs from PM_{10} emissions. This is both due to a high level of emissions and relatively high damage costs per ton emission compared to other countries. Damage costs from emissions in France and the UK are also high; UK mainly because of high emissions level and France mainly because of high damage costs per ton emission. Total emissions in Italy are either higher or equal to the level in France, but since damage costs per ton emission are lower, the total damage costs from Italy are much lower than that for France. Similar conditions relate to Spain, which also have quite high emissions but low marginal damage costs.

In table 4.2 we show the projected annual damage costs in 2008-12 for the EU-15 countries based on the E3ME model simulation. Note that emission coefficients of SO_2 and NO_x are calibrated so that national emissions in 2010 are in accordance with a European protocol for transboundary air pollution (United Nations, 1999).[3] PM_{10} emission coefficients are in general supposed to follow the trend in

[3] This is further explained in Ellingsen et al. (2000).

1990-95, as there is no protocol for this pollutant. The emissions data for PM_{10} is very uncertain, which means that this extrapolation is indeed questionable. Moreover, damage cost coefficients are held constant.

Table 4.2 Crude assessment of annual damage costs (billions (90) Euro) of air pollutants in 2008-12 (baseline)

E3ME Region	SO_2	NO_x	PM_{10}	Total costs	Change from baseyear
Austria	0.3	1.7	0.6	2.5	-34%
Belgium	1.1	2.1	0.8	4.1	-46%
Denmark	0.2	0.6	0.2	1.0	-46%
Finland	0.1	0.4	0.1	0.6	-28%
France	3.8	12.2	2.6	18.7	-54%
Germany	6.3	13.2	13.6	33.1	-52%
Greece	1.2	1.1	-	2.3	-4%
Ireland	0.2	0.2	0.4	0.8	-47%
Italy	3.4	7.7	4.0	15.1	-45%
Luxembourg	0.0	0.1	-	0.2	-57%
The Netherlands	0.3	1.7	0.5	2.6	-44%
Portugal	0.6	1.4	-	2.0	-33%
Spain	3.9	5.7	0.2	9.8	-47%
Sweden	0.1	0.4	0.2	0.8	-37%
United Kingdom	4.1	8.7	3.8	16.6	-57%
Total EU-15	**25.9 (-69%)**	**57.3 (-46%)**	**27.1 (-10%)**	**110.2**	**-50%**

Source: E3ME project, E3ME22 C92F7BB, January 2000

We see that total damage costs have fallen by 50 per cent in the period from 1994 to 2008-12. This is due to the requirement of large reductions of especially SO_2 emissions in Europe, but also significant reductions of NO_x emissions. PM_{10} emissions are moderately reduced over this period, according to the model results. However, as indicated above, this last finding should be taken with great caution. The results imply that the protocol eventually brings about damage cost reductions of about 110 billion 1990-Euro per year compared to the baseyear level. Of course, it is difficult to know how large emissions would be without the protocol. They could both increase or decrease over time, due to a combination of economic growth, technological improvements and environmental restrictions.

We see that NO_x emissions now account for just above 50 per cent of total damage costs, whereas SO_2 and PM_{10} emissions account for just below 25 per cent each. As mentioned before, total PM_{10} emissions are probably undervalued, which means that the percentage reduction in damage cost over the period will be somewhat lower.

Damage costs are mostly reduced in the United Kingdom, France and Germany, where costs are at least halved. On the other hand, costs caused by emissions in Greece are more or less unchanged.

4.2 Analysis of secondary benefits of carbon taxes

We will now investigate how the SO_2, NO_x and PM_{10} emissions are reduced when a carbon tax or a carbon permits scheme that fulfils the Kyoto protocol, is introduced. Since both emissions of CO_2 and the three pollutants above are closely related to combustion of fossil fuels, restrictions on CO_2 emissions will indirectly reduce emissions of the other three pollutants, too. Reductions in these emissions reduce the local and regional costs from health and environmental damages, and are denoted secondary benefits of the carbon tax. Reductions in other greenhouse gas emissions are already incorporated in the baseline of the E3ME, based on projections by the IPCC (see Ellingsen *et al.*, 2000). Hence, in the baseline non-CO_2 GHG emissions are reduced by 27 per cent in 2008-12 compared to 1990/95.

Four scenarios are investigated. All scenarios aim at reducing the total annual GHG emissions for the EU in 2008-12 by 8 per cent compared to the baseyear (taken as 1990 for CO_2, CH_4 and N_2O; 1995 for HFC, PFC and SF_6).[4] The baseyear value for Kyoto GHG target for the EU is 1129.9m tonne carbon-equivalent (for EURO-19 it is 1156.5m tonne), so that an 8% reduction is 1039.5m tonne (EURO-19 1064)). The 1990 total for CO_2 is 877.0 mtC (EURO-19 897.2). Since non-CO_2 GHG emissions are considerably reduced in the baseline, CO_2 emissions have to be reduced by merely 2.3 - 2.6 per cent in the four mitigation scenarios. The base projection is denoted 'Base' in the tables. The four mitigation scenarios are described in the following:

1. *Introducing multilateral carbon tax ('Carbon tax')*
   All 19 European regions and sectors are subject to the same carbon tax rate in the form of additional excise duties, which is set at 15.4 euro/toe and increased by 15.4 euro every year for the simulation period. This escalation achieves a reduction in EU GHGs sufficient to meet the EU target of an 8% reduction below a 1990/1995 base (the 1995 base is chosen for the GHGs HFCs, PFCs and SF_6). The electricity industry is taxed on the carbon content of it inputs, allowing for full passing on of the extra costs in the electricity prices. All revenues from such taxes are used to reduce regional employers contributions to social security. No permit schemes are introduced.
2. *Multilateral emission permit scheme - all permits grandfathered to 2000 emissions and implicit revenues to profits ('Permits+profits')*
   All regions and sectors participate in the same emission permit scheme. Permit prices are endogenously determined in the model by market demand and supply, and are the same across the regions. All permits are allocated on a grandfathered basis on 2000 emissions. Target reductions for CO_2 in terms of permits issued to the year 2010 are calculated to be 2.3% below those of 1990 levels to achieve the 8% EU target for GHG reduction. No carbon tax schemes are introduced.
3. *Multilateral emission permit scheme - all permits grandfathered to 2000 emissions and revenues used to reduce prices ('Permits+prices')*
   All regions and sectors participate in the same emission permit scheme. Permit prices are endogenously determined in the model by market demand and supply, and are the same across the regions. All permits are allocated on a grandfather basis on 2000 emissions. Target reductions for CO_2 in terms of permits issued to the year 2010 are calculated to be 2.4% below those of 1990 levels to achieve the 8% EU target for GHG reduction. Industrial prices are reduced according to the increase in profits implied by the allocation of permits. No carbon tax schemes are introduced.

[4] Switzerland's requirement is also 8 per cent, whereas Norway's requirement is 1 per cent above 1990 level. Whether or not Norway and Switzerland are included in the 8 per cent reduction scenario or not, has only marginal impact on the overall effects.

4. *Mixed multilateral permit and tax scheme - all permits grandfathered to 2000 emissions and revenues used to reduce prices ('Mixed policies')*
   Energy-intensive fuel users (power generation, iron and steel, non-ferrous metals, chemicals, non-metallic mineral products and ore-extraction) in all European regions participate in the same emission permit scheme. Permit prices are endogenously determined in the model by market demand and supply, and are the same across the regions. 70% of permits are allocated on a grandfather basis on 2000 emissions in 2001, 60% in 2002, 2003 and 2004, 55% in 2005 and 50% for all later years. Target reductions for CO_2 in terms of permits issued to the year 2010 are assumed to be 24% below those of 1990 levels. All extra implied values of grandfathered permits are allowed to increase profits. A carbon tax is introduced for all fuel users not covered by the permit scheme, including transportation and households.

Before we study the secondary benefits of the mitigation scenarios, we will briefly present the macroeconomic results of the four scenarios. These are shown in Table 4.3. A more thorough discussion is found in Ellingsen *et al.* (2000).

Table 4.3. Macrovariables in EURO-19 for 2010 in the four mitigation scenarios

	Base	Carbon tax	Permits +profits	Permits +prices	Mixed policies
Tax rate euro/tC	0	191.9	0	0	192.3
Tax revenue bn euro	0	167.3	0	0	105.9
Permit price euro/tC	0	0	174.3	171.8	185.1
Permit revenue bn euro	0	0	0	0	30.5
GDP %pa 2000-10	2.4	2.5	2.4	2.5	2.5
GDP % diff from 2010 base	0	0.8	-0.3	0.1	0.6
Employment 2010 m	162.5	164.2	162.4	162	163.7
Employ. % diff 2010 base	0	1	-0.1	-0.3	0.8
Prices (PSC) %pa 2000-10	2.3	2.3	2.5	2.2	2.3
Prices % diff 2010 base	0	0.3	1.6	-1.4	0.5
Trade bal. pp from base	0	-0.2	0	0	-0.1
Gov fin bal pp from base	0	-1.2	0.2	-0.1	-0.7
Energy profits bn90e dfb	0	-20.5	20.3	-50.5	-0.3

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

We see that the tax rates or permit prices lie between 172 and 192 (1990) Euro per tonne carbon. Moreover, the impact on GDP is quite small, less than one percent from base in all scenarios. In fact, in three of four scenarios the GDP effect is positive. Two scenarios lead to increased employment by about 1 per cent, whereas the other two scenarios lead to a fall in employment of at most 0.3 per cent. Introducing carbon taxes with revenue recycling seems to be the best policy choice measured in GDP and employment effects, whereas the two pure permit scheme scenarios seem to be the least advantageous.

Table 4.4 to 4.6 show how much the emissions of SO_2, NO_x and PM_{10} are reduced in the years 2008-12 in the four mitigation scenarios. The differences between the four scenarios are quite small. We see that SO_2 emissions are reduced most, i.e., by around 16 per cent in EU as a whole. NO_x emissions in EU are reduced by almost 9 per cent, whereas PM_{10} emissions are reduced by almost 5 per cent. Moreover, we see that the highest percentage reductions take place in Denmark (all components), Spain (SO_2 and NO_x) and Belgium (PM_{10}). Denmark and Spain are also the two countries with highest percentage reduction in CO_2 emissions.

Table 4.4. Annual SO_2 emissions in EU-15 in 2008-12 in base (1,000 tonne), and percentage change from base in the four mitigation scenarios

	Base 1,000 tonne	**Carbon tax** %	**Permits +profits** %	**Permits +prices** %	**Mixed policies** %
Austria	39	-12	-11.4	-10.9	-10.6
Belgium	108.8	-15.6	-15.5	-14.1	-13.3
Denmark	56.7	-32.7	-30.1	-30.1	-31.6
Finland	115.8	-13	-13.3	-13.8	-13.9
France	409.5	-13	-11.9	-12.5	-13.1
Germany	624.2	-13.5	-12.6	-12.4	-12.6
Greece	528.1	-5.4	-6.8	-9	-5.9
Ireland	43.5	-26.1	-23.8	-24.3	-21
Italy	516	-21.9	-20.4	-20.2	-19.2
Luxembourg	4.1	-10.1	-10.4	-12.4	-11.9
The Netherlands	51.8	2.5	-1.1	2.4	1.4
Portugal	170	-0.8	-2.1	-1.5	-1.2
Spain	798.4	-37	-35.3	-35.4	-33.6
Sweden	67	-14.6	-14.3	-13.8	-16.6
United Kingdom	670.8	-6.8	-6.5	-6.7	-6.6
Total EU-15	**4,203.9**	**-16.6**	**-16**	**-16.2**	**-15.5**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

Table 4.5. Annual NO_x emissions in EU-15 in 2008-12 in base (1,000 tonne), and percentage change from base in the four mitigation scenarios

	Base 1,000 tonne	Carbon tax %	Permits +profits %	Permits +prices %	Mixed policies %
Austria	107	-3.9	-3.4	-3.5	-3.8
Belgium	181	-6.9	-6.2	-5.7	-7.1
Denmark	126.9	-17.5	-15.5	-15.9	-16.7
Finland	169.8	-6	-6.3	-6.7	-6.7
France	859.6	-12.2	-10.6	-11.7	-12
Germany	1,080.9	-7.9	-7.6	-7.3	-8.6
Greece	344.1	-2.7	-3.6	-5.8	-3.3
Ireland	63.7	-9.3	-8.5	-8.8	-8.5
Italy	1000	-7.8	-7.4	-7.6	-7.7
Luxembourg	10.9	-5	-5.2	-7.4	-5.6
The Netherlands	265.2	-3.2	-4.6	-3.5	-3.9
Portugal	260.1	-2.4	-3	-3.8	-2.7
Spain	850.5	-18.8	-17.9	-18.3	-17.8
Sweden	148	-8	-7.5	-8.1	-8.8
United Kingdom	1,180.9	-5.8	-5.8	-6.5	-6.1
Total EU-15	**6,648.4**	**-8.9**	**-8.5**	**-8.9**	**-8.9**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

Table 4.6. Annual PM_{10} emissions in EU-15 in 2008-12 in base (1,000 tonne), and percentage change from base in the four mitigation scenarios

	Base 1,000 tonne	Carbon tax %	Permits +profits %	Permits +prices %	Mixed policies %
Austria	39	-0.4	-0.5	0.2	-0.4
Belgium	39	-12.6	-11.9	-11.7	-12
Denmark	50	-12.1	-10.9	-10.7	-14.3
Finland	72	-5.3	-5.9	-6.3	-5.7
France	118.9	-6.1	-5.3	-6.2	-6.3
Germany	754.9	-8.6	-8	-7.8	-8.5
Greece	0	0	0	0	0
Ireland	104.5	-0.9	-1	-0.9	-0.7
Italy	500.8	0.2	-0.8	-0.2	0
Luxembourg	0	0	0	0	0
The Netherlands	38	-2.9	-2.5	-2.2	-3.1
Portugal	0	0	0	0	0
Spain	33	-5.7	-5	-6.1	-5.8
Sweden	80.3	0.1	-0.2	0	0
United Kingdom	312.7	-3.7	-3.5	-4.5	-3.9
Total EU-15	**2,143.1**	**-4.7**	**-4.6**	**-4.6**	**-4.8**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

In table 4.7 we show the annual change in externality damages from the three pollutants SO_2, NO_x and PM_{10} in the four mitigation scenarios, as differences from the base level in 2008-12 (measured in billions (90) Euro). This reduction in damages is what is called the secondary (or ancillary) benefits from the mitigation scenarios. We see that these benefits are in the order of 11 billions Euro, which is a reduction in damages of about 10 per cent. The largest benefits occur from reduced emissions in Germany, Spain and France. For Germany and France, this has to do with large initial damages, For Spain, however, the large reduction is also related to the relatively large reduction in SO_2 and NO_x emission (see above).

Most of the benefits come from reduced NO_x and SO_2 emissions. For NO_x the reason is that NO_x emissions are responsible for more than half the damage costs in 2010 in the baseline, combined with a significant reduction in NO_x emissions caused by the CO_2 tax or permit price. For SO_2 the reason is that SO_2 emissions are very responsive to a carbon tax or permit price. Whereas CO_2 (and NO_x) emissions are reduced by around 10 per cent, SO_2 emissions are actually reduced by around 16 per cent. On the other hand, emissions of PM_{10} are only reduced by around 5 per cent, and these damages constituted only one quarter of total damages in the base level.

Table 4.7. Regional externality damage (SO_2+NO_x+PM_{10}). Annual average 2008-12. Billons (90) Euro for base levels and differences from base.

	Base	Carbon tax	Permits +profits	Permits +prices	Mixed policies
Germany	33.1	-3.1	-2.9	-2.8	-3.1
France	18.7	-2.1	-1.9	-2.1	-2.1
Spain	9.8	-2.5	-2.4	-2.4	-2.3
Italy	15.1	-1.3	-1.3	-1.3	-1.2
United Kingdom	16.6	-0.9	-0.9	-1	-1
Rest of EU-15	17	-1.1	-1.1	-1.1	-1.1
Eurozone EMU-11	89.5	-9.8	-9.3	-9.3	-9.6
non-EMU4	20.7	-1.3	-1.3	-1.4	-1.3
EU-15 (EU)	**110.2**	**-11.1**	**-10.5**	**-10.7**	**-10.9**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

It may be interesting to compare the total secondary benefits with the total reduction in CO_2 emissions due to the carbon tax or permit price. Hence, in Table 4.8 we show the change in CO_2 emissions in the four mitigation scenarios. In the 'Carbon tax' scenario we calculate a secondary benefit of 112 1990-Euro per ton carbon reduced (the figures are almost the same in the other scenarios). This is somewhat below the figures referred to in chapter 2. One important reason for this is the projected reduction in emissions of NO_x and SO_2 from 1994 to 2010. Without these reductions, the secondary benefits would have been more than twice as high. A second reason is that we only include secondary benefits from reduced air pollution, and not benefits from reduced traffic externalities, which in other studies are found to be at least as much important.

Table 4.8. Annual CO_2 emissions in EU-15 in 2008-12 in base (1,000 tonne), and percentage change from base in the four mitigation scenarios

	Base 1,000 tonne	Carbon tax %	Permits +profits %	Permits +prices %	Mixed policies %
Germany	265.4	-7.7	-7.8	-7.4	-8.2
France	111.6	-13.2	-12	-12.9	-13.1
Spain	70.9	-23	-21.8	-22.2	-21.4
Italy	126.7	-11.7	-11	-11	-11
United Kingdom	169.2	-6.8	-6.8	-7.1	-6.9
Rest of EU-15	209.7	-10.4	-10.4	-10.4	-10.4
Eurozone EMU-11	719	-11.5	-11.1	-11	-11.4
non-EMU4	234.4	-7.3	-7.3	-7.8	-7.4
EU-15 (EU)	**953.4**	**-10.4**	**-10.1**	**-10.2**	**-10.4**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

The secondary benefit per ton reduction in carbon emissions is particularly high in Spain (153 Euro), Germany (151 Euro) and France (143 Euro), relatively low in United Kingdom (78 Euro) and Italy (88 Euro), and lowest in Rest of EU-15 (50 Euro). This is related to high damage cost per emissions in Germany and France, to large reductions in SO_2 and NO_x emissions in Spain, and to low damage costs per emissions in most of the smaller countries (e.g. the Nordic countries, Greece and Ireland).

Since the GDP level is increasing in three of the four mitigation scenarios, it is somewhat difficult to compare the secondary benefits with the changes in GDP. Still, GDP in the whole E3ME area changes by at most 70 billion 1990-Euro, which means that the secondary benefits constitute at least 15 per cent of the change in GDP. In the single case where GDP is reduced, the secondary benefits constitute about 40 per cent of the GDP loss. Moreover, the secondary benefits amount to about 0.13 per cent of the total GDP level in 2010.

What does the size of the secondary benefits mean for the reduction in life years lost? Based on the discussion in chapter 3, we obtain that the benefits correspond with a saving of around 80,000 life years.

5 Conclusions and Policy Implications

The analyses presented in this paper indicate that the secondary benefits of a carbon tax or a permit scheme that fulfils the Kyoto requirements for the EU countries may be significant. By secondary benefits we mean reductions in externality damages from SO_2, NO_x and PM_{10} emissions in Europe. We have presented four mitigation scenarios with different policies directed at reducing CO_2 emissions in a multilateral way in EU. Concentrating on CO_2 emissions is justified by the fact that mitigation effort directed at emissions of other greenhouse gases are implicitly included in the baseline projection.

Meeting the Kyoto requirement for EU means reducing annual greenhouse gas emissions by 8 per cent in 2008-12 compared to the baseyear (1990/95). As non-CO_2 emissions are considerably reduced in the baseline of the E3ME model, CO_2 emissions have to be reduced by 2-3 per cent compared to 1990. Compared to the baseline projection for the years 2008-12, a reduction of 10-11 per cent is necessary. The four alternative mitigation scenarios use either a carbon tax, a permit scheme with grandfathered permits, or a combination of these. In respect to secondary benefits, the results are quite similar for the four alternative scenarios.

The secondary benefits of introducing the carbon tax or permit scheme amount to about 11 billion (1990) Euro, or 0.13 per cent of total GDP in EU in 2010. Moreover, the secondary benefits constitute between 15 and 40 per cent of the change in GDP (which is positive for three of the four scenarios). This means that including the secondary benefits in the overall assessment of the policy measure is of vital importance.

Furthermore, the secondary benefits account of about 112 1990-Euro per ton reduction in carbon emissions. These are somewhat below earlier studies (see, e.g., Ekins, 1996), which is partly due to much lower emissions in 2010 than in the 1990-ties, and because other traffic-related externalities are not included in our study. Still, we may conclude that even if there are uncertainties about the marginal damage costs of CO_2 emissions, the secondary benefits imply that fairly high marginal costs of mitigation may be justified.

The main part of the secondary benefits are due to reduced SO_2 and NO_x emissions, and to a lesser degree from reduced PM_{10} emissions. This holds true even though the baseline projection is based on expectations of large reductions in emissions of NO_x and SO_2. These expectations are due to the signing of a European protocol on transboundary pollution. If this agreement is not followed, and emissions are not reduced as much as indicated, the secondary benefits of a carbon tax will be higher. On the other hand, introducing measures against CO_2 emissions may be one way to reduce emissions of the other pollutants. If so, the secondary benefits will not be related to less damage costs, but to less control costs. These will probably be at least as high as the damage costs, as the marginal costs at high level of reduction (which will then be avoided) is supposed to be excessive.

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