ANCILLARY BENEFITS OF GHG MITIGATION IN EUROPE: SO_2, NO_X AND PM_{10} REDUCTIONS FROM POLICIES TO MEET KYOTO TARGETS USING THE E3ME MODEL AND EXTERNE VALUATIONS

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Abstract

Mitigation of greenhouse gas (GHG) emissions can lead to reductions in associated externalities, such as emissions of sulphur dioxide (SO_2), fine particulate matter, and other pollutants, some of which are known to damage human health. These so-called ancillary (or secondary) benefits of mitigation policies can be contrasted with the primary benefits of such policies, namely the reduction in climate change. This paper describes how some of these benefits (associated with the reduction in 3 pollutants: SO_2, oxides of nitrogen (NO_x) and some fine air-borne particles (PM_{10})) have been assessed for 19 regions of Western Europe. The analysis uses a large-scale econometric model of Europe, E3ME, and assumes that Kyoto targets are achieved by using stylised economic instruments, with tax/permit revenues spent on reducing employer taxes.

The paper first explains how local and regional damage costs from emissions of NO_x*,* SO_2 *and* PM_{10} *are included in E3ME. The damage costs are taken from the ExternE study, which is a substantial assessment of the external costs of electricity generation in Europe funded by the European Commission. Damage costs vary across pollutant and across country in the model. The projection of damage costs to 2010 shows a dramatic fall due to expectations of large target reductions in emissions of* NO_x *and* SO_2*. The Kyoto protocol requires that EU countries reduce GHG emissions (*CO_2 *and five other GHGs) by 8% in 2008-2012 compared to 1990 or 1995. The paper reports that since the non-*CO_2 *GHGs are projected to fall significantly over the period 1995-2010,* CO_2 *emissions have to be reduced by merely 2-3% below 1990 levels.*

Ancillary benefits are estimated under three alternative mitigation scenarios that meet the Kyoto targets: multilateral carbon taxes, a CO_2 *emission-permit scheme, and a combination of policies. The necessary tax rates or permit prices are 135 to 154 euros (2000) per tonne carbon. In all the scenarios, the estimated ancillary benefits by 2008-12 are about 9bn (1990) euro per year, i.e., about 138 euro (2000) per tonne reduction in carbon-equivalent (e/t) or 0.11% of total GDP. They represent, each year, a saving of around 104,000 life-years, 11,000 fewer new incidences of chronic bronchitis in adults, and 5.4 million fewer restricted activity days. These benefits constitute 15-35% of the change in GDP brought about by the mitigation policies, showing the importance of including ancillary benefits in the overall assessment of mitigation policy, even though emissions of* NO_x *and* SO_2 *are expected to fall significantly by 2010.*

There are three reasons why this estimate may be nearer the lower bound of the range of possible outcomes. First, if the SO_2*,* NO_x *and* PM_{10} *target reductions are not reached, and emission coefficients remain at 1995 levels, the ancillary benefits rise to some 300 e/t, or 0.25% of GDP. Second, if* CO_2 *emissions rise more that the modest 9% from 1990 to 2010 in the base scenario then mitigation policy will have to be stronger and the ancillary benefits will also be larger (e.g. 140 e/t or 0.34% of GDP). Third, if oil prices fall well below the assumed $(2000) 22.5 per barrel in the baseline projection, then the tax/permit policies will again have to be stronger and the ancillary benefits could rise (to 141 e/t or 0.22% of GDP). (But if world oil prices rise to about $(2000) 40 per barrel by 2010, then fuel use is so reduced that no additional mitigation policies are needed; and ancillary benefits are zero.) Finally, ExternE estimates are themselves conservative, covering only 3 main types of air pollutants and including only some of the damages from the pollution. Even where data exist on the pollutants, they are likely to underestimate the true size of the effect.*

1. Introduction

1.1 Purpose of the paper

Mitigation of greenhouse gases (GHGs), particularly CO_2, can often have favourable impacts on emissions of other pollutants and on other damaging side-effects, mainly because the burning of fossil fuels is reduced. When the overall benefits and costs of climate policies are assessed, it is thus important to include such benefits e.g. those from reduced local and regional pollution. As the main benefit of climate policies is to reduce climate change, these benefits are usually referred to as ancillary benefits (or secondary benefits). Reductions in other negative externalities, especially related to road transport, are also often included in studies of ancillary benefits. Ekins (1996) gives a review of earlier European studies of ancillary benefits. Pearce (2000) reviews the current literature in the context of policy advice.

This paper develops a top-down framework for estimating the impacts on ancillary benefits of GHG mitigation policies. It is an application of a large-scale 19-region energy-environment-economy model for Europe (E3ME: see the model description in http://www.camecon.co.uk/e3me/index.htm). An earlier version of E3ME covering 11 regions has been applied to assess different aspects of CO_2 abatement, namely effects on equity (Barker and Köhler, 1998) and on competitiveness (Barker, 1998) and the advantages of EU coordination (Barker, 1999).

The valuation of emission damage is very complex, involving the connection between emissions in one set of locations at one time and pollution concentrations and exposures in other locations at later times:

- the physical impacts of pollution on human and animal health and welfare, materials, buildings and other physical capital, and vegetation; and finally

- the valuation of mortality, morbidity and other physical effects.

Much scientific effort has been devoted to the various links in this chain. Recently, 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), funded by the European Commission. This project was initiated to calculate external costs of electricity generation from different kind of power plants in Western Europe. The ExternE work has continued and a study of transport externalities is due to be published in 2000, but this paper relies on the results from the ExternE electricity study, rather than constructing valuations from the literature.

1.2 Remaining sections of the paper

In the next section a literature review is given, first on ancillary benefits and then on damage cost calculations based on the ExternE results. In section 3 the choice of methodology is discussed and the E3ME model is briefly described. Then in section 4 an assessment of current damage costs from emissions within the E3ME area is given, with a projection of damage costs to 2010 and an estimate of ancillary benefits of meeting Kyoto targets. Section 5 gives a sensitivity analysis of the results and there are some conclusions in section 6.

2. Literature review

Although the number of studies estimating costs of climate policies has multiplied over the last few years, particularly related to the so-called double dividend hypothesis, very few studies have emphasised or even included ancillary 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 very few 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. In addition, most of these studies are site or sector specific. Thus, results cannot easily be transferred from one sector or one region to all sectors at national or international levels. 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). 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 ancillary benefits in the studies he refers to is $250-400 per tonne carbon reduced. All studies reviewed are from the UK or Norway. By comparing with the mitigation costs reported in the literature, he concludes that ancillary benefits alone justify large reductions in CO_2 emissions.

Two Norwegian studies that are not reported in Ekins (1996) are Brendemoen and Vennemo (1994) and Johnsen *et al.* (1996). However, they both use more or less the same macroeconomic model (MSG) and the same submodule for calculations of emissions, environmental damages and traffic externalities as the Norwegian studies reviewed by Ekins. Brendemoen and Vennemo find that ancillary benefits of a carbon tax make up almost all the GDP loss, and their figures indicate that these benefits amount to around $450 per tonne carbon reduced. Johnsen *et al.* use a different baseline with much more gas power installed, and find much lower ancillary benefits, i.e., about $70 per tonne carbon reduced, or 20% of the GDP loss. Thus, these two studies obtain results that are respectively higher and lower than the ones in Ekins (1996).

Håkonsen and Mathiesen (1997) distinguish between ancillary benefits with productive impact and benefits with direct utility impact in their model for the Norwegian economy. They find that taking ancillary benefits into account, the impact of reducing CO_2 emissions changes from a welfare loss of 1% to a gain of 1%.

Barker *et al.* (1993) present some ancillary benefits of a carbon/energy tax, using the macroeconometric model MDM for the UK economy. They concentrate on the traffic-related externalities, and obtain ancillary benefits around £13 per tonne carbon reduced. This is an order of magnitude below the results in Ekins (1996), due to the very small effect on petrol consumption by the tax. Moreover, benefits of reduced air pollution are not included in the study.

Bergman (1995) calculates an environmental quality adjusted national income for Sweden, using a CGE model. He takes into account ancillary benefits of reduced SO_2 emissions through economic welfare for households and feedback effects on production in the forest industry. With differentiated CO_2 taxes, the loss of gross national income is more than fully compensated by gains in environmental quality.

A newer study from Norway (Glomsrød *et al.* 1996)[1] employs the general method used by the ExternE project (i.e., using dose-response functions etc.) within 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, as in the U.S. sector studies. Health and environmental impacts partly affect the input of the model (i.e., a simultaneous modelling of economic and environmental interactions), whereas other impacts are valued after the model is solved. Avoidable injuries associated with marginal changes in traffic are also included in the model, whereas other traffic-related effects are only assessed at the end. In this study, ancillary benefits of a gradually rising carbon tax are calculated to be 16% of the GDP loss (for the effects included in the model), half of it coming from reduction in traffic injuries. Compared to the reduction in CO_2 emissions, the ancillary 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 ancillary 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.

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[1] The study is in Norwegian, but a brief presentation in English is given in Alfsen and Rosendahl (1996). The modelling approach is presented in detail in Rosendahl (1998).

Studies of ancillary benefits from carbon policies in the U.S. seem to find much smaller benefits that the ones reported by Ekins (1996). Burtraw and Toman (1997) review both general equilibrium studies and sector studies (i.e., electricity production) with emphasis on locational differences. However, many of the studies reviewed are difficult to interpret, as the policy tool is not targeted directly at CO_2 emissions only. Two general equilibrium studies with carbon taxes are referred to - Scheraga and Leary (1993) obtain ancillary benefits of $33 per ton carbon reduction, whereas Boyd *et al.* (1995) find benefits amounting to $40 per ton. Thus, the U.S. benefits are almost one order of magnitude below the European benefits. One explanation for the difference is the much lower population density for the US, 28 inhabitants per square kilometer, compared to 116 for the EU in 1996 (OECD, 1999).

Moreover, the electricity sector studies in the U.S. find even lower benefits. For instance, in a recent study Burtraw *et al.* (1999) calculate ancillary benefits of small, $10 per ton, carbon taxes in the electricity sector in the U.S., taking into account the SO_2 cap imposed on overall electricity production. The benefits (related to NO_x emissions only) amount to merely $3 per ton carbon reduced, plus avoided SO_2 control costs of $3 per ton carbon reduced. The authors argue that the sector studies include a better description of the physical effects than the general equilibrium models, as they take into account the locational characteristics. On the other hand, a general carbon tax imposed in the whole economy may cause relatively larger damage reduction per ton carbon reduced, as the emission reduction also takes place in cities.

Calculations of damage costs of air pollutants have become increasingly credible in recent years, partly due to the ExternE study among others. One important reason is that scientific knowledge of physical effects of air pollution has improved considerably. The updated knowledge of damage costs provides a good reason for new assessments of ancillary benefits of environmental policies, such as those for GHG mitigation.

Capros et al (1999) use the GEM-E3 model with the ExternE valuations to measure the externalities of CO_2 mitigation in the EU. GEM-E3 is a general equilibrium model, treating each member state as a separate region. The ExternE valuations are implemented as fixed relationships between emissions of SO_2, NO_x, PM_{10} and VOC in one country, and deposition/concentration of PM_{10}, nitrates, sulphates, SO_2 and ozone in the same or another country (transport matrix). Further, a fixed damage cost is assigned to each pollutant per 1,000 persons in the affected country (based on the ExternE). Capros et al (1999) do not cover the achievement of the Kyoto target, but rather a 10% reduction in CO_2 emissions in 2010 compared to 1990 (other GHGs are not incorporated in this version of the model). Nevertheless, it provides the most comparable set of results to those in the analysis below. They find that the damage reductions are substantial, with SO_2 and PM_{10} emissions falling by around 25 and 28%, respectively, in the CO_2 mitigation scenarios (CO_2 emissions are reduced by 18% from baseline). Revenues from CO_2 permit auctions are recycled via reductions in labour taxes. The reduction in air pollution in the EU is valued to about 0.16% of GDP.

In our work we have relied directly on the results from case-studies under the ExternE project. Sáez and Linares (1999) present an overview of damage costs from these case-studies, which cover about 60 power plants in 14 countries, throughout Europe. The damage costs are presented for SO_2, NO_x and fine air-borne particulates (PM_{10}). Costs of NO_x are related to their impact via deposition of nitrates. In addition an average figure for the whole of Europe is estimated for their impact via ozone creation, which is the result of complex atmospheric chemical interactions among all the other air pollutants. The combustion plants cover all EU-countries (except Luxembourg).

A summary table is constructed in their paper for damage costs related to emissions in each EU-country, showing a wide range of values, reflecting site-specific differences. 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 result 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, where 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, Sáez and Linares (1999) recommend the use of national figures in applications to other power plants whenever more advanced methods are impracticable. This is especially pertinent regarding efforts to estimate regional or global impacts tied with various mitigation policies. However, it may be questioned whether the figures may be used for other emission sources, as the effects on human exposure may depend crucially on where the emission is released. For instance, NO_x emissions come chiefly from transportation, which probably leads to higher exposure than emissions from power plants. SO_2 and PM_{10} emissions stem from a broader cross of sectors, including energy, industry, and transport.

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.

It is difficult to see what physical effects are behind the monetary damage costs in Sáez and Linares (1999). However, by using the methodology volume of ExternE (European Commission, 1999) together with two applications of the methodology (Krewitt *et al.*, 1999, and Schleisner and Nielsen, 1997), a rough estimate can be made of the physical effects.

3. Evaluating ancillary benefits

3.1 The chosen method

When choosing the appropriate methodology for assessing the costs of ancillary benefits, two main approaches are at hand. The simplest method relies on fixed damage cost coefficients on each pollutant in each region of the model, alternatively differing between emission sources within the region. This method can only be employed where coefficients are derived from other studies, e.g. results from the ExternE project (Sáez and Linares, 1999). The more sophisticated method relies on so-called impact-pathway method used by the ExternE researchers in their calculations. This 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 the status of consensus estimates within the EU, and national figures are available in Sáez and Linares (1999), the simple method using fixed coefficients has been chosen. A possible extension in the future could however be to implement the impact-pathway described above. An intermediate position is adopted in the GEM-E3 model (Capros et al, 1999), as described in section 2 above.

In developing the broader regional estimates in this study, identical damage coefficients for each emission source have been used for each country-region in E3ME. The reason is first of all that there is no readily available information on 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. An ExternE study of transport externalities is expected to provide more reliable estimates in due course.

3.2 The E3ME model

A full description of the model, with extracts from the User's Manual, is available on the website http://www.camecon.co.uk/e3me/index.htm). E3ME is an econometric, dynamic, simulation model estimated using econometric panel-data techniques on cross-section and annual time-series data 1970-1995. It is an integrated E3 model covering 19 regions of Western Europe (the EU plus Norway and Switzerland), with an annual solution 1970-2012 allowing for lagged responses and a calibration of the solution using recent data and short-term forecasts 1996-2000. It has been designed specifically to simulate top-down E3 policies such as carbon taxes and emission permits (i.e. market-based instruments), which rely on relative price effects to influence economic activity and environmental emissions.

3.3 SO_2, NO_x, PM_{10} damages in E3ME

The following general equations are included in the model:

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

- D_j denotes the total damage costs inflicted by region j on all 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:

$$D = \sum_j D_j$$

Note that these equations are used to estimate the *differences* in damage costs between various scenarios, not to estimate the total damage costs of air pollution in Europe per se. The ExternE methodology does not attempt to estimate total or average damage; only marginal damage from small changes in emission. Due to the possibilities of thresholds and to complex atmospheric interactions, the relationship between emissions and physical effects may be far from linear when emissions are reduced all the way down to zero.

Moreover, it is important to note that the estimates are of 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 that are relevant in the context of ancillary benefits (e.g. CO and VOC). However, the three selected are the ones for which the strongest consensus on damage valuation exists at this time.

This paper cannot fully assess the ancillary benefits of mitigation policies for two main reasons. First of all, the ExternE estimates are themselves conservative, covering only three main types of air pollutants and including only some of the damages from the pollution. Even where data exist on these three pollutants, they are likely to underestimate the true size of the effect. Thus, recent studies (Dominici, Zeger and Samet, in press) indicate that exposure misclassification in epidemiologic studies biases results toward the null hypothesis. This means that the relative risk, or size of the coefficients, obtained from air pollution epidemiology is likely to underestimate the true magnitude of the risk.

Another point should be made about reductions in other externalities. The literature review indicated that reductions in other traffic-related externalities, such as traffic congestion, noise, morbidity and mortality tied with traffic crashes, and local air pollution, may be important in estimating ancillary benefits of climate policies. Indeed a recent tri-national assessment from France, Switzerland and Austria suggests that the number of deaths tied with air pollution linked with traffic today is greater than those tied with traffic crashes alone (Sommers *et al.* 2000). In principle, the traffic-related effects of air pollution are included in our model. However, as noted in the beginning of this chapter, these effects are probably underestimated as we assign the same damage costs to traffic emissions as to power plant emissions. Moreover, as many other traffic-related externalities are not included at all in the model, the calculations underestimate the total ancillary benefits.

3.4 Damage cost coefficients

Table 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 the effects from NO_x emissions on ozone concentration are valued at 1,500 1995-Euro per tonne for each country.

Table 1. **Damages of air pollutants (in euro (1995) per tonne 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

Source: Sáez and Linares (1999).

Notes: (1) na: not available. (2) Although the numbers in this and later tables are shown with apparent precision, this does not indicate their accuracy. The uncerainty of the estimates and projections is discussed in the text.

As noted above, the intervals in Table 1 cover the damage costs from various power plants in the specific country. It can be seen 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 (2000) finds that the local marginal costs of PM_{10} emissions in four cities of Norway range from about 60 to 150 thousand euro (1995) per tonne (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.*

There is no 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 tonne) 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 tonne) 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 tonne), 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. Hence, the average of the unit costs reported by the individual plants in each country has been chosen for this study. The estimated cost coefficients (d_j^k) for damages are shown in Table 2 with the ozone-effect of NO_x emissions included. The large variance between unit costs from different plants within a country implies that the coefficients are very crude figures, and should be used with caution. The number of plant locations in each country is shown in parentheses behind the country-name, which may be an indication of how representative the coefficients are.

Table 2. **Damage cost coefficients (in 1995-Euro per tonne 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

The differences in damage costs across the countries are remarkable, but reasonable. First, notice that the highest damage costs are related to emissions released in the middle of Europe, i.e., France, Belgium, Germany and Austria (see also Capros et al, 1999, ch. 8.4). These emissions will mainly be transported to densely populated areas, and consequently bring about relatively high damage to human health. 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). Thus, much of these emissions will be transported to less densely populated areas and to the ocean, and therefore bring about less damage to human health. 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 it has not been possible to distinguish between sites of emissions within a country, it is possible within the E3ME model to distinguish between emissions released in various broader areas of Europe.

Comparing the countries in Table 2 with the regions in the E3ME model, there are no damage cost coefficients for Norway, Switzerland and Luxembourg, and Germany and Italy have to be divided into West- and East-Germany and North- and South-Italy. At this stage there is not enough information on the location of the plants in Germany and Italy, so the same coefficients are used 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, the average of the coefficients for Denmark and Sweden is used. For Switzerland, the average of the coefficients for Austria and for one of the plants in Germany (i.e. Lauffen situated in the south) is used. For Luxembourg, the coefficients for Belgium are used. Table 3 shows the damage cost coefficients for the regions not included in Table 2.

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. In a prospective study like ours, this probably leads to an underestimation of the ancillary benefits of greenhouse gas mitigation.

Table 3. **Damage cost coefficients (in euro (1995) per tonne 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

Source: Derived from estimates in Sáez and Linares (1999).

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, 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). Thus, deaths of younger people are valued far more than deaths of elderly people with few years left to live. This is a very controversial issue with big implications for the results (using VOSL would probably have increased the damage costs by 50%, see AEA (1999)).

According to Sáez and Linares (1999) the damage costs are dominated by the health impacts, linked with fine-particulate-air-pollution mortality. However, they don't describe in detail how the costs are built up from mortality effects, various morbidity effects and damages to buildings, crops etc. This will of course differ between the three pollutants, but also between countries. Whereas PM_{10} emissions only cause health damages from exposure to particulate pollution, SO_2 emissions bring about health damages from both SO_2 and sulphates (i.e., fine particulate) exposure, in addition to impacts on buildings, crops and other natural habitats. NO_x emissions produce health damages from ozone and nitrates (i.e., fine particulate) exposure, but also impacts on buildings, crops etc. The physical effect is not only determined by the extra amount of emissions, but also on where the pollutants are transported, how they react in the atmosphere, and the state of the population, building stock, crops etc. in the exposed area.

Still, we are able to construct a rough estimate of some important health effects from the overall damage assessment. The reason is that the fraction of damages coming from health effects due to particulate exposure is very high for all three pollutants. For instance, Krewitt *et al.* (1999), who present damage costs from fossil electricity generation in Germany and the EU based on the ExternE methodology, find that between 96% and 101% of total damage costs are due to health effects (more than 100% means that there are positive yield effects in agriculture). For the EU as a whole the fraction is 97%. Schleisner and Nielsen (1997), who report the ExternE implementation for Denmark, find that health damages are responsible for 99% of total damages (in their case-study mainly NO_x emissions are released). Moreover, in the methodology volume of ExternE (European Commission, 1999, table 8.1), the exposure response functions recommended are totally dominated by functions related to particulate exposure (i.e., PM_{10}, $PM_{2.5}$, sulphates or nitrates).[2] This is confirmed by the results in Schleisner and Nielsen (1997).

Even though most damage costs are coming from health effects from particulate pollution, it is not given how large share is due to mortality effects vs. morbidity effects. For instance, according to Krewitt *et al.*(1999) the fraction is 77%, whereas Schleisner and Nielsen (1997) find that the fraction is 86%. One reason may be that the mortality effects not only depend on the extra exposure, but also on the mortality rate in the population, which differ across countries. Another reason could of course be different valuation, but this is not likely given the recommendations by the ExternE.

The conclusion for this paper is that around 80% of the overall damage costs are due to mortality effects. As mentioned above, mortality is valued based on life years lost (VLYL). In the methodology volume of ExternE (European Commission, 1999), the recommended monetary value for 'chronic' mortality is 84,330 ECU (1995) (based on a 3% discount rate). Using the information in Schleisner and Nielsen (1997) about morbidity effects, the following rough estimates of physical impacts behind 1 million Euro (1995) in total damage costs can be made:

- 800,000 Euro due to mortality effects - derived from 9.5 life years lost (i.e., 84,330 Euro per life year);
- 105,000 Euro due to chronic bronchitis - derived from 1 more adult with chronic bronchitis (i.e., 105,000 Euro per adult with chronic bronchitis);

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[2] Some notable exceptions are acute mortality effects and effects on hospital admissions from both SO2 and ozone exposure.

- 37,000 Euro due to restricted activity days (RAD) - derived from 500 more RADs (i.e., 75 Euro per RAD);
- 28,000 Euro due to other morbidity effects;
- 30,000 Euro due to damages to buildings, crops and other natural habitats.

4. Estimates of some ancillary benefits

4.1 Projection of damage costs from selected emissions within the E3ME area

A crude assessment of total damage costs from emissions of SO_2, NO_x and PM_{10} within the E3ME area can now be made. As mentioned above, the damage cost coefficients in the tables above are calculated based on marginal changes in emissions, and so these coefficients cannot simply be used with 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 for some pollutants. It should be noted that the World Health Organization (1997) no longer recommends 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 their transmission via particulate matter.) Since the information needed to adjust the marginal damage cost coefficients is not available, the marginal coefficients are used directly in order to arrive at a very crude assessment of the total damage costs from emissions within the E3ME area. The results are not, therefore, to be treated as credible calculation of *total* damage costs in Western Europe. Nonetheless, the method provides an assessment of the *incremental* impact of mitigation policy on pollution, making the calculated values of the damage reductions more reasonable.

Table 4. **Emissions (in 1,000 tonnes) and crude assessment of corresponding damage costs [billions (90) Euro] of air pollutants in the base year 1994**

E3ME Region	**SO_2**		**NO_x**		**PM_{10}**		**Total damage costs**
	emissions	damage costs	emissions	damage costs	emissions	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**
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**
UK	2,697	16.5	2,289	16.8	426	5.1	**38.5**
Total area	**12,111**	**84.5**	**12,290**	**109.4**	**2,312**	**30.4**	**224.3**

Source: E3ME project, E3ME22 C92F7BB, January 2000.

Table 4 shows the emissions of SO_2, NO_x and PM_{10} in each country in the base year and the calculated damage costs. The total calculated damage costs exceed 200bn euro (1990) 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 tonne 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 tonne emission. Total emissions in Italy are either higher or equal to the level in France, but since damage costs per tonne emission are lower, the total damage cost for Italy is much lower than that for France. Similarly, Spain also has high emissions but low marginal damage costs.

Figure 1. **Baseline emissions 1990/95 to 2008-12: EU15 selected non-GHG pollutants**

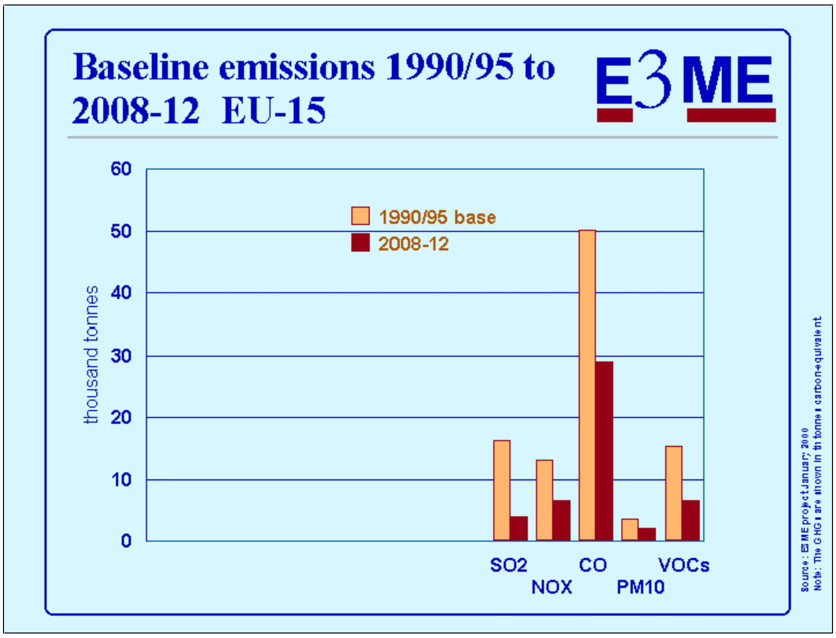

Table 5. **Crude assessment of annual damage costs (billions (90) Euro) of air pollutants in 2008-12 (baseline)**

E3ME Region	**SO_2**	**NO_x**	**PM_{10}**	**Total costs**	**Change from baseyear**
Austria	0.3	1.6	0.6	2.5	-35%
Belgium	1.0	2.0	0.8	3.9	-48%
Denmark	0.2	0.6	0.2	1.0	-46%
Finland	0.1	0.4	0.1	0.6	-29%
France	3.9	12.3	2.7	18.8	-53%
Germany	6.1	13.1	13.2	32.5	-53%
Greece	1.3	1.1	-	2.4	-2%
Ireland	0.1	0.2	0.4	0.8	-47%
Italy	3.2	7.6	4.0	14.8	-46%
Luxembourg	0.0	0.1	-	0.2	-56%
The Netherlands	0.3	1.7	0.5	2.5	-46%
Portugal	0.6	1.4	-	2.0	-34%
Spain	2.9	5.4	0.2	8.5	-54%
Sweden	0.1	0.4	0.2	0.8	-38%
United Kingdom	4.4	9.0	3.9	17.3	-55%
Total EU-15	**24.6** **(-71%)**	**57.0** **(-46%)**	**26.8** **(-11%)**	**108.4**	**-51%**

Source: E3ME project, E3ME22 C92F7BB, March 2000.

Figure 1 shows the projected falls in the emission tonnages in the baseline. 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 1990-95, as there is no protocol for this pollutant. The emissions data for PM_{10} are very uncertain, which means that this extrapolation is indeed questionable. Moreover, damage-cost coefficients are held constant.

Table 5 shows the projected annual damage costs, 2008-12, for the EU-15 countries based on the E3ME baseline simulation. The total damage costs fall by 51% from 1994 to 2008-12. Because Greece is largely exempt from much of the air pollution protocol, its emissions fall the least. This overall reduction in damage costs is due to the requirement of large reductions of SO_2 emissions in Europe, but also significant reductions of NO_x emissions. PM_{10} emissions fall moderately over this period, according to the model results. However, as indicated above, this last finding should be treated with great caution. The results imply that the protocol eventually brings about damage cost reductions of about 115bn euro (1990) per year compared to the base year levels. It is difficult to know how large emissions would be without the protocol: they could increase or decrease over time, due to a mix of economic growth, technological improvements and environmental controls.

NO_x emissions 2008-2012 account for just above 50% of total damage costs, whereas SO_2 and PM_{10} emissions account for just below 25% 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, Spain, France and Germany, where costs are more than halved. These countries have obliged to the largest reductions in SO_2 and NO_x emissions compared to their emissions in 1994 (i.e., the baseyear of the model). On the other hand, costs caused by emissions in Greece are more or less unchanged.

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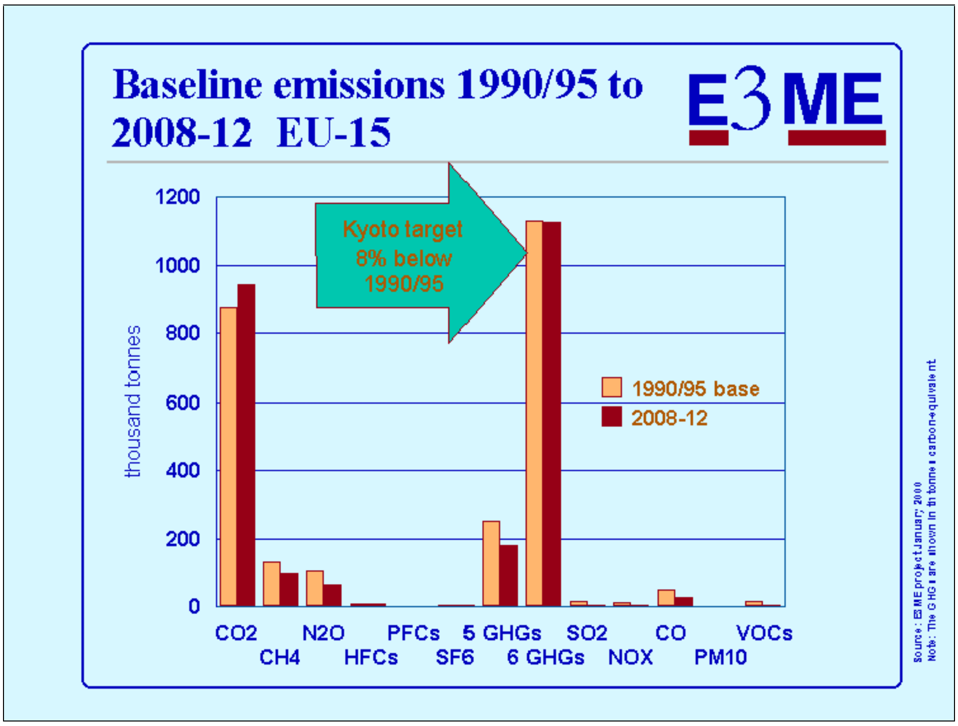
[3] This is further explained in Ellingsen et al. (2000).

4.2 *Analysis of ancillary benefits of GHG mitigation*

GHG mitigation policies will lead to reductions in SO_2, NO_x and PM_{10} emissions, and other air pollutants not considered in detail in this paper. Emissions of CO_2 and the three pollutants above are closely related to combustion of fossil fuels, so that many of the changes in energy demand and technologies resulting from GHG mitigation policies will also reduce these pollutants. In other words, actions reducing CO_2 emissions will indirectly reduce emissions of the other three pollutants and will reduce local and regional costs from health and environmental damages. The effects of policies to reduce other non-CO_2 GHG emissions are already incorporated in the baseline of the E3ME, based on projections by the IPCC (see Ellingsen *et al.*, 2000). Major reductions are projected for emissions of N_2O and methane: the N_2O reductions are due to strong environmental policies aimed at improving the pollution performance of combustion engines; and the methane reductions are due to no-regrets policies leading to the increased capture and use of the gas from waste disposal, coal mining and agriculture. Hence, in the baseline annual non-CO_2 GHG emissions are reduced by 28% in 2008-12 compared to 1990/95 as illustrated in Figure 2.

Figure 2. **Baseline emissions 1990/95 to 2008-12: GHGs and other pollutants**



In order to use the damage-cost estimates, it must be assumed that the projected levels of pollutants are not fixed by command-and-control policies (e.g. capped by the Second Sulphur Protocol). If they are capped, then the ancillary benefit from GHG mitigation will take the form of avoided costs, namely a reduction in the investment in pollution control.

Three scenarios are investigated. All the scenarios reduce the total annual GHG emissions for the EU in 2008-12 by 8% compared to the baseyear (taken as 1990 for CO_2, CH_4 and N_2O; 1995 for HFC, PFC and SF_6).[4] No country-specific commitments apply. Permit trading is confined to the EU, Norway and Switzerland; and there is no significant contribution from joint implementation (JI) or clean development mechanism (CDM) projects in meeting EU targets. The base year value for Kyoto GHG target for the EU is 1129.9m tonne carbon-equivalent (mtC), so that an 8% reduction is 1039.5 mtC. The 1990 total for CO_2 is 877.0 mtC. Since non-CO_2 GHG emissions are reduced by 28% in the baseline, CO_2 emissions have to be reduced by merely 1.9% to 2.3% in the three scenarios. The base projection is denoted 'base' or 'reference base' in the tables.

There are further assumptions underlying the scenarios. Interest rates and exchange rates are held at baseline levels. The rest of the world is assumed to be unaffected by the EU achievement of Kyoto targets (i.e. the world oil price does not change from baseline levels - the sensitivity of the results to changes in oil prices is examined in the next section). Prices and wage rates are determined by estimated behavioural responses to costs and changes in market conditions. And employment can adjust freely to changes in demand. The three mitigation scenarios are as follows:

Mitigation Scenario 1: 'carbon tax'

A multilateral carbon tax

This scenario assumes that all 19 European regions and sectors (including electricity, transportation and households) are subject to the same carbon tax rate in the form of additional excise duties on energy products in proportion to their carbon content. The rate is set at 15.4 euro/toe and increased by 15.4 euro every year for the simulation period. This escalation is computed (by a trial and error procedure) to achieve a reduction in EU GHGs sufficient to meet the EU target of an 8% reduction below the 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 its 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. These assumptions are chosen to approximate an ideal carbon tax in the context of an econometric simulation model, with no allowance for exemptions, WTO rules or other legal, political or social considerations.

Mitigation Scenario 2: 'Permits+profits'

In the multilateral scheme all CO_2 permits are grandfathered to 2000 emissions and implicit revenues are attributed to profits.

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

All regions and sectors participate in the same CO_2 emission permit scheme. Permit prices are endogenously determined year by year 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 and issued to meet annual targets calculated to achieve the overall EU Kyoto target. No banking of permits is allowed and new entrants to the market have to buy permits at the market price. Target reductions for CO_2 permits issued to the year 2010 are calculated to be 1.9% below those of 1990 levels to achieve the 8% EU target for GHG reduction. No carbon tax schemes are introduced.

Mitigation Scenario 3: ‘Mixed policies’

This is a mixed multilateral permit and tax scheme with a permit scheme for the energy sector (energy-intensive industries and electricity generation) and a carbon tax for the rest of the economy.

This scenario links energy-intensive fuel users (power generation, iron and steel, non-ferrous metals, chemicals, non-metallic mineral products and ore-extraction) in all European regions. All participate in the same CO_2 emission permit scheme. Permit prices are endogenously determined year by year 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. Reductions for CO_2 emissions in terms of permits issued to the year 2010 are calculated to be 25% below those of 1990 levels for the scenario to achieve the Kyoto target. All implied values of grandfathered permits are allowed to increase profits. A carbon tax at the rates in scenario 1 above is introduced for all fuel users not covered by the permit scheme, including transportation and households. All revenues from taxes and auctions are used to reduce regional employers’ contributions to social security.

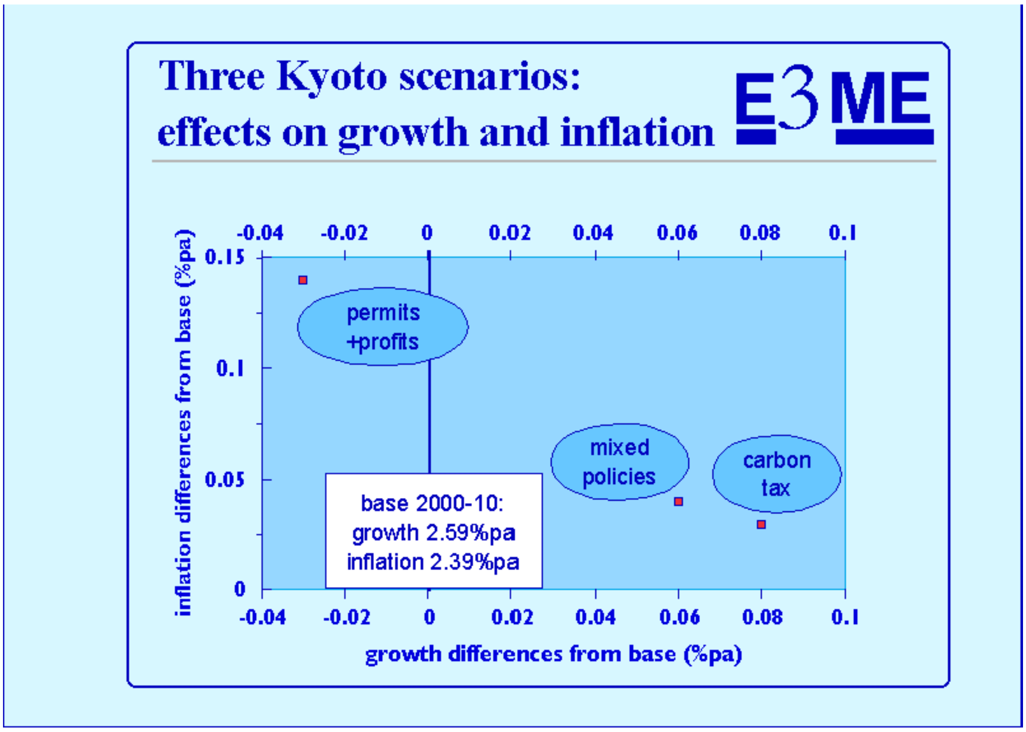
The macroeconomic results of the scenarios are discussed before those for the ancillary benefits. These are shown in Table 6 and illustrated in Figure 3.

Table 6. **Macrovariables in EURO-19 for 2010 in the three mitigation scenarios**

	Base	**Carbon Tax**	**Permits +profits**	**Mixed policies**
Tax rate euro(2000)/tC	0	153.1	0	153.1
Tax revenue bn euro	0	170.1	0	108.4
Permit price euro(2000)/tC	0	0	135.2	147.8
Permit revenue bn euro	0	0	0	30.7
GDP %pa 2000-10	2.6	2.7	2.6	2.6
GDP% diff from 2010 base	0	0.8	-0.3	0.5
GDP cost euro(2000)/tCe	0	-1008.5	355.7	-698.6
Anc. ben. diff. as % GDP	0	0.11	0.10	0.10
Anc. ben. euro(2000)/tCe	0	137.5	126.3	133.0
Employment 2010 m	162.2	163.9	162.1	163.5
Employ. % diff 2010 base	0	1.1	-0.1	0.8
Prices (cons.) %pa 2000-10	2.4	2.4	2.5	2.4
Prices % diff 2010 base	0	0.2	1.4	0.4
Trade bal. Pp from base	0	-0.2	0	-0.1
Gov fin bal pp from base	0	-1.2	0.2	-0.7
Energy profits bn90e dfb	0	-19.2	20.1	0.8

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

Figure 3. **Kyoto scenarios: effects on growth and inflation Euro-19**



According to the model, the tax rates or permit prices in 2010 lie between 135 and 154 euro (2000) per tonne carbon. Moreover, consistent with other simulations of the Energy Modelling Forum (see e.g. Weyant, 1999), the net impact on GDP is quite small, less than 1% from base in all scenarios. Indeed, in two of the three of three scenarios the GDP effect is positive. Figure 3 shows the effects on the growth rates of GPD (rather than the levels) and the rates of inflation. The effects are very small with inflation higher in all the scenarios, with the fully grandfathered permit scheme implying the highest price rises. Two scenarios increase employment by about 1% above base, whereas the second scenario, that is grandfathered permits with higher profits, shows more or less no change in employment. Introducing carbon taxes with revenue recycling seems to be the best policy choice measured in GDP and employment effects. In contrast, the permit scheme scenario with higher profits seems to be the least advantageous.

Figure 4. **Effects on emissions in the mixed-policies scenario**

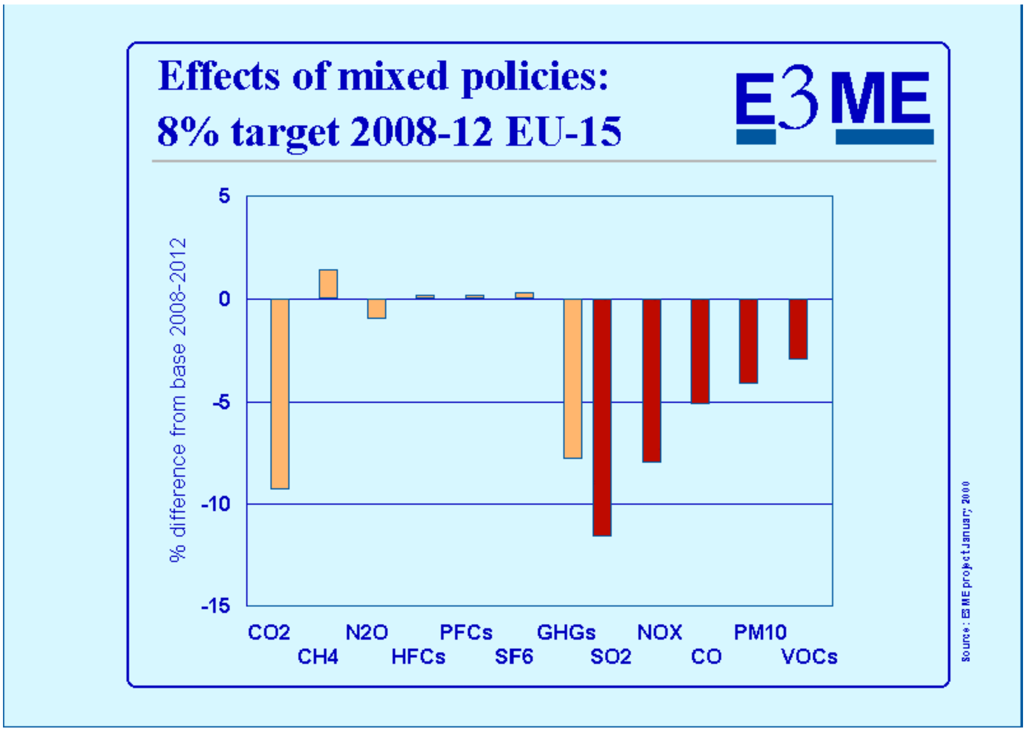


Figure 4 summaries the overall effects on emissions in the mixed-policies scenario: here the Kyoto target is met for GHGs, with substantial further reductions below baseline in all other pollutants included in the model. Tables 7 to 9 show how much the emissions of SO_2, NO_x and PM_{10} are reduced in the years 2008-12 by region in the three mitigation scenarios. The differences between the three scenarios are quite small. SO_2 emissions are reduced most, i.e., by around 12-13% in the EU as a whole; NO_x emissions are reduced by around 8%; and PM_{10} emissions are reduced by 4%. Moreover, the highest percentage reductions take place in Denmark (all components) and Spain (SO_2 and NO_x). Denmark and partly Spain are also the two countries with highest percentage reduction in CO_2 emissions.

Table 7. **Annual SO_2 emissions in the EU-15 over 2008-12 in the base (1,000 tonnes), and percentage change from base in the three mitigation scenarios**

	Base 1,000 tonne	**Carbon Tax** %	**Permits +profits** %	**Mixed policies** %
Austria	39	-11.7	-10.4	-10.0
Belgium	102	-10.1	-10.0	-8.8
Denmark	58	-33.6	-29.7	-29.8
Finland	115	-10.9	-11.7	-11.5
France	410	-11.9	-11.2	-12.4
Germany	603	-11.9	-10.7	-10.7
Greece	548	-6.2	-7.0	-6.0
Ireland	41	-22.6	-19.3	-17.3
Italy	481	-20.4	-17.4	-15.8
Luxembourg	4	-8.8	-10.6	-13.3
The Netherlands	49	-0.6	-2.3	-2.5
Portugal	168	-0.3	-1.6	-0.8
Spain	592	-26.1	-23.8	-20.1
Sweden	66	-12.0	-11.5	-13.9
United Kingdom	711	-9.2	-8.2	-8.0
Total EU-15	**3,987**	**-13.5**	**-12.4**	**-11.6**

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

Table 8. **Annual NO_x emissions in the EU-15 over 2008-12 in the base (1,000 tonnes), and percentage change from base in the three mitigation scenarios**

	Base 1,000 tonne	**Carbon Tax** %	**Permits +profits** %	**Mixed policies** %
Austria	105	-3.7	-2.9	-3.6
Belgium	175	-5.8	-5.2	-5.8
Denmark	125	-17.8	-14.7	-15.0
Finland	168	-5.4	-5.6	-6.3
France	863	-10.8	-9.3	-10.8
Germany	1,074	-7.4	-7.3	-8.0
Greece	352	-3.2	-3.7	-3.6
Ireland	64	-7.7	-6.6	-7.3
Italy	991	-7.5	-6.4	-7.2
Luxembourg	11	-4.5	-4.8	-5.8
The Netherlands	257	-5.0	-5.0	-5.6
Portugal	260	-2.6	-2.8	-3.0
Spain	809	-13.8	-12.4	-12.5
Sweden	144	-6.2	-5.5	-6.9
United Kingdom	1,220	-6.2	-5.8	-6.7
Total EU-15	**6,617**	**-7.9**	**-7.2**	**-8.0**

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

Table 9. **Annual PM_{10} emissions in the EU-15 over 2008-12 in the base (1,000 tonnes), and percentage change from base in the three mitigation scenarios**

	Base	**Carbon Tax**	**Permits +profits**	**Mixed policies**
	1,000 tonne	%	%	%
Austria	39	-0.3	-0.4	-0.3
Belgium	38	-7.3	-6.6	-7.1
Denmark	49	-11.6	-9.9	-13.8
Finland	72	-4.6	-5.1	-4.8
France	120	-5.7	-4.8	-5.9
Germany	734	-7.0	-6.4	-6.8
Greece	-	-	-	-
Ireland	105	-0.6	-0.7	-0.4
Italy	498	-	-0.8	-0.1
Luxembourg	-	-	-	-
The Netherlands	37	-1.7	-1.6	-2.4
Portugal	-	-	-	-
Spain	34	-6.4	-5.3	-6.5
Sweden	80	0.1	-0.2	-
United Kingdom	325	-4.1	-3.4	-4.4
Total EU-15	**2,130**	**-4.1**	**-3.9**	**-4.1**

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

Table 10 shows the annual marginal change in externality damages from the three pollutants SO_2, NO_x and PM_{10} in the three mitigation scenarios, assessed in terms of differences from the base level in 2008-12 (measured in billions (1990) Euro). This marginal reduction in damages constitutes the ancillary benefits from the mitigation scenarios. These benefits are of the order of 9bn euro (1990), which is a reduction in damages of slightly less than 10%. The largest benefits occur from reduced emissions in Germany, France and Spain. For Germany and France, this has to do with large initial damages in the baseline; for Spain, however, the large reduction is also related to the relatively large reductions of SO_2 and NO_x emission relative to their baselines (see above).

Most of the benefits come from reduced NO_x (50% of the benefits in the carbon tax scenario) and SO_2 (36%) 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 just below 10%, SO_2 emissions are reduced by 12-13%. On the other hand, emissions of PM_{10} are only reduced by 4%, and these damages constituted only one quarter of total damages in the base level (14% of the benefits come from reduced PM_{10} emissions).

Table 10. **Regional externality damage (SO_2+NO_x+PM_{10}). Annual average 2008-12 in billions euro (1990 prices) for base levels and differences from base**

	Base	**Carbon tax**	**Permits +profits**	**Mixed policies**
Germany	32.5	-2.6	-2.5	-2.6
France	18.8	-1.9	-1.7	-2.0
Spain	8.5	-1.5	-1.4	-1.3
Italy	14.8	-1.2	-1.1	-1.1
United Kingdom	17.3	-1.1	-1.0	-1.1
Rest of EU-15	16.7	-1.0	-0.9	-1.0
Eurozone EMU-11	87.0	-7.9	-7.2	-7.5
Non-EMU4	21.4	-1.5	-1.3	-1.5
EU-15 (EU)	**108.4**	**-9.4**	**-8.5**	**-9.0**

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

It may be interesting to compare the total ancillary benefits with the total reduction in CO_2 emissions due to the carbon tax or permit price. Hence, Table 11 shows the change in CO_2 emissions in the three mitigation scenarios. In the 'Carbon tax' scenario there is an ancillary benefit of 137.5 euro (2000) per tonne carbon reduced (see Table 6), which is slightly below the carbon tax rate. Similar results are found in the other scenarios. This benefit is somewhat below the figures from earlier European studies referred to above. One important reason for this is the projected reduction in emissions of NO_x and SO_2 from 1994 to 2010 that will take place under planned activities that are included in the baseline. If these reductions were not to take place, the ancillary benefits would have been more than twice as high (see Section 5 below). A second reason is that the ancillary benefits include those from reduced air pollution, and not those from reduced traffic externalities, which in other studies are found to be of the same magnitude, if not larger.

Table 11. **Annual CO_2 emissions in the EU-15 over 2008-12 in the base (1,000 tonnes), and percentage change from base in the three mitigation scenarios**

	Base 1,000 tonne	**Carbon tax** %	**Permits +profits** %	**Mixed policies** %
Germany	264.0	-7.2	-7.6	-7.8
France	108.4	-11.6	-10.7	-11.8
Spain	66.6	-16.5	-14.8	-14.3
Italy	124.2	-10.7	-9.2	-9.4
United Kingdom	174.8	-7.4	-7.1	-7.6
Rest of EU-15	207.6	-9.7	-9.8	-9.8
Eurozone EMU-11	711.1	-9.9	-9.6	-9.8
Non-EMU4	234.5	-7.8	-7.5	-7.9
EU-15 (EU)	**945.6**	**-9.4**	**-9.0**	**-9.3**

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

The ancillary benefit per tonne reduction in carbon emissions is particularly high in countries where the population density near major energy sources is higher, such as France (196 euro), Germany (178 euro), or where the baseline emissions per capita are high, such as Spain (177 euro). In contrast, ancillary benefits are relatively low in regions where the population density is lower, such as Rest of EU-15 (65 euro), which includes the Nordic countries, Greece and Ireland. The ancillary benefits for the UK (111 euro) and Italy (117 euro) are also below the EU average, as the damage costs per emission are lower than in the more centrally-located countries, and because emissions of SO_2, NO_x and PM_{10} are not reduced very much.

GDP increases in two of the three mitigation scenarios, so the environmental ancillary benefits should be added to the economic benefits of mitigation. GDP rises by at most 70bn euro (1990) and ancillary benefits add a further 14% of the change. In the case where GDP is reduced, the ancillary benefits offset about 35% of the GDP loss.

What does the size of the ancillary benefits mean for the reduction in life years lost and morbidity effects? Based on the discussion in section 3 above, the benefits by 2010 represent, each year, a saving of around 104,000 life-years, 11,000 fewer new incidences of chronic bronchitis in adults, and 5.4 million fewer restricted activity days. If traffic-related ancillary impacts were included this number would increase substantially, since the average death or injury that occurs due to traffic crashes is much younger, than that linked with air pollution. Since almost all costs are related to health damages, and almost all health damages are related to exposure to fine particles (NO_x and SO_2 emissions can be transmitted via secondary particles), the number of lifeyears saved can approximately be distributed on the three pollutants according to their share of ancillary benefits. Consequently, about 50% of the life years saved are due to lower NO_x emissions, about 36% to lower SO_2 emissions and about 14% to lower PM_{10} emissions.

5. Sensitivity of estimated ancillary benefits to changes in assumptions

5.1 Design of the sensitivity scenarios

The estimation of the value of the ancillary benefits of GHG mitigation is dependent on many assumptions. This section discusses how three critical assumptions in the baseline projection affect the results. The possible range of outcomes is not, however, symmetrical around the estimated value of 0.1% of GDP found for three mitigation policies analysed above. The lower bound is zero, since the benefits are attached to the policies and a range of realistic assumptions in the baseline projections can lead to the achievement of the Kyoto targets without taxes or permits. This is the case for low fuel-use scenarios, when the resulting GHG emissions fall below Kyoto targets; or when world oil prices rise so high as to achieve the same effect (calculated to be $40.88 per barrel by 2010 in year 2000 prices). In both cases, emissions of SO_2 and other pollutants will fall below base, but the benefits cannot be attributed to GHG policies and therefore by definition there are no ancillary benefits.

The three sets of assumed perturbations to the baseline projection, called ‘scenarios’ below, are:

- High pollution: SO_2, NO_x and PM_{10} levels are high as a results of the technical emissions coefficients being held constant at 1995 levels, ie emission intensities are at 1995 rates over the period 1995-2012, and various targets and protocols are not met. All other coefficients are left at base levels, so that the GHG emissions are the same as in the main base case (the reference base).

- High fuel use: Here fuel use is assumed to be much higher than base, such that CO_2 emissions 1990-2010 grow at rates similar to the IEA’s 1998 World Energy Outlook (note that the IEA assumed world oil prices at \$17(1993) per barrel 1998-2010 for their projection).

- Low oil prices: Real oil prices (Brent crude) are assumed to fall to \$15.1(2000) per barrel by 2010 instead of the \$22.5/bbl in the base.

Table 12 shows the extra damages estimated as a result of making these different assumptions. The table shows the differences of each of the perturbed bases from the reference base, discussed in section 4 above. Thus the high SO_2 scenario shows much higher SO_2 emissions as a % difference from base and higher costs of SO_2 damages. Table 13 shows the effects of imposing carbon taxes in the reference base and the perturbed scenarios to achieve Kyoto targets in each scenario for GHG emissions in the EU 15; the perturbed base levels are also shown to help with the interpretation of the tables. The differences between the perturbed base levels in Table 13 and the reference base levels in Table 12 are the differences shown in Table 12. Both tables show damages both in levels and differences from base. The totals for the damages (with a change in sign) correspond to the total ancillary benefits for the carbon tax scenario discussed in Section 4 above. The effects are illustrated in Figure 5 which shows the different levels of damages in the different “views of the world” and hence the different scale of the ancillary benefits when carbon taxes at different rates are introduced to meet the Kyoto target. Each pair of stacked bars represents a scenario without and with the Kyoto target, with the overall size of the bars representing the cost of pollution and the top section of the right bars representing the ancillary benefits in each scenario.

Table 12. **Sensitivity of damage estimates for the EU-15, annual average 2008-2012 (SO_2, NO_x, PM_{10})**

			High Pollution	High Fuel use	Low oil price
		Reference Base	Difference of perturbed base from reference base		
GHG	Mt carbon-equiv. And %	1126.82	0	14.5	7.08
CO_2	Mt carbon and %	945.64	0	16.83	6.94
SO_2	th tonnes and %	3986.92	136.22	11.32	19.16
NO_x	th tonnes and %	6616.78	118.37	17.06	6.62
PM_{10}	th tonnes and %	2129.81	26.35	7.57	2.41
SO_2 cost	Euro(90)bn	24.62	37.77	2.66	4.10
NO_x cost	Euro(90)bn	57.01	67.08	9.85	3.41
PM_{10} cost	Euro(90)bn	26.82	5.93	2.21	0.71
Total cost	Euro(90)bn	108.44	110.77	14.72	8.22
SO_2 cost	% of GDP	0.30	0.46	0.03	0.05
NO_x cost	% of GDP	0.69	0.81	0.12	0.04
PM_{10} cost	% of GDP	0.32	0.07	0.03	0.01
Total cost	% of GDP	1.31	1.34	0.17	0.10

Source: E3ME project, E3ME22 C92F7B, E, F and L GHG, March 2000.

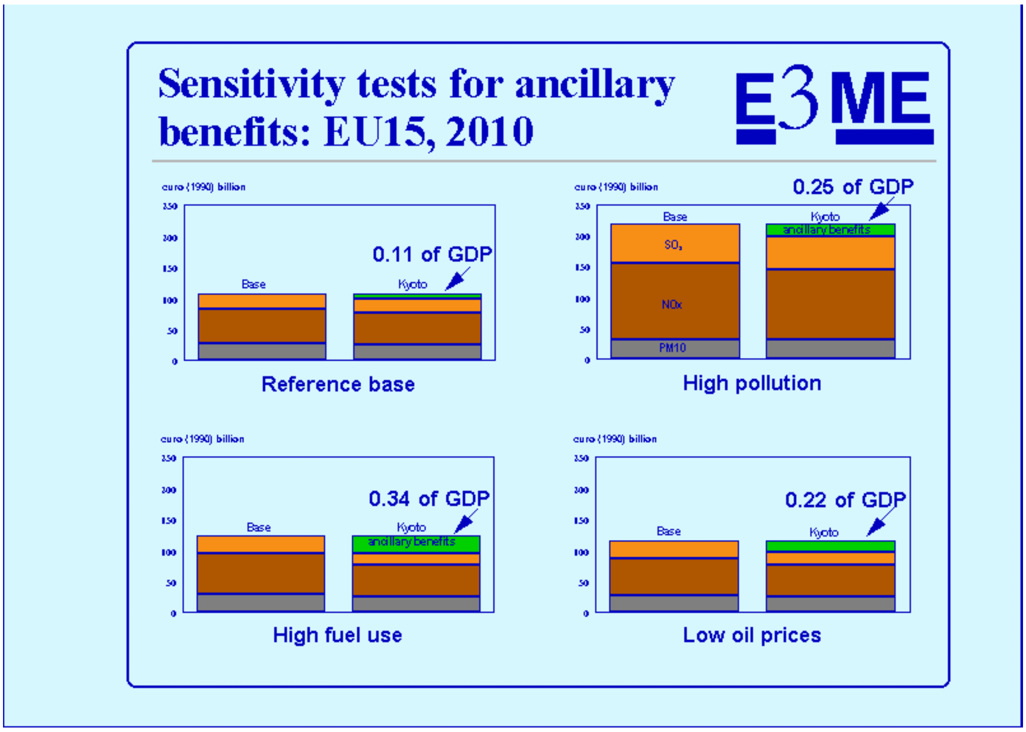
Table 13. **Sensitivity of damage estimates in achieving Kyoto targets via carbon taxes for EU-15 annual average 2008-2012 (SO_2, NO_x, PM_{10}): Levels and differences from base (dfb)**

		Main case	High pollution	
		Carbon tax Dfb	Perturbed base Levels	Carbon tax dfb
GHG	Mt carbon-equiv. And %	-7.76	1126.82	-7.76
CO_2	Mt carbon and %	-9.4	945.64	-9.4
SO_2	th tonnes and %	-13.46	9417.88	-13.8
NO_x	th tonnes and %	-7.94	14448.96	-7.9
PM_{10}	th tonnes and %	-4.09	2691.08	-3.74
SO_2 cost	Euro(90)bn	-3.35	62.38	-8.51
NO_x cost	Euro(90)bn	-4.68	124.09	-10.2
PM_{10} cost	Euro(90)bn	-1.36	32.74	-1.56
Total cost	Euro(90)bn	-9.39	219.21	-20.27
SO_2 cost	% of GDP	-0.04	0.76	-0.1
NO_x cost	% of GDP	-0.06	1.51	-0.12
PM_{10} cost	% of GDP	-0.02	0.40	-0.02
Total cost	% of GDP	-0.11	2.67	-0.25

		High fuel use		Low oil prices	
		Perturbed base Levels	Carbon tax dfb	Perturbed base levels	Carbon tax Dfb
GHG	Mt carbon-equiv. And %	1290.24	-19.44	1206.65	-13.95
CO_2	Mt carbon and %	1104.81	-23.71	1011.29	-16.94
SO_2	th tonnes and %	4438.29	-25.75	4751.00	-26.19
NO_x	th tonnes and %	7745.71	-22.11	7054.75	-14.61
PM_{10}	th tonnes and %	2291.1	-11.69	2181.13	-7.09
SO_2 cost	Euro(90)bn	27.28	-7.42	28.72	-7.40
NO_x cost	Euro(90)bn	66.86	-15.82	60.42	-9.07
PM_{10} cost	Euro(90)bn	29.02	-4.17	27.53	-2.42
Total cost	Euro(90)bn	123.16	-27.42	116.66	-18.88
SO_2 cost	% of GDP	0.33	-0.09	0.34	-0.09
NO_x cost	% of GDP	0.82	-0.19	0.72	-0.11
PM_{10} cost	% of GDP	0.35	-0.05	0.33	-0.03
Total cost	% of GDP	1.51	-0.34	1.39	-0.22

Source: E3ME project, E3ME22 C92F7B, E, F and L GHG, March 2000.

Figure 5. **Sensitivity tests on the ancillary benefits**



5.2 The high pollution scenario: higher SO_2, NO_x and PM_{10} emissions

The high pollution scenario holds the technical coefficients for SO_2, NO_x and PM_{10} fixed at 1995 levels. Since the baseline allows for the effects of substantial reductions in these emissions as countries implement measures to comply with various international agreements and protocols, this means that the scenario shows much higher pollution compared with the base. However, it also shows exactly the same levels of GHG emissions, since the coefficients for these gases are left unchanged and since the emissions of SO_2, NO_x and PM_{10} are assumed to have no effects on the economy or on GHG emissions. SO_2 and NO_x emissions are expected to fall over time, even with unchanged emission coefficients, mainly as a result of changes in fuel mix away from coal and towards gas in the European energy structure. However, they are more than double the levels in the base by 2010, and the overall *extra* cost of the pollution is estimated to be of the same magnitude as the total cost in the base. The reduction in pollution, estimated to be worth an annual 1.3% of European GDP by 2010 using ExternE valuations, gives an indication of the benefits of the reduction in emission coefficients expected over the period 1995-2010, most of which can be attributed to international agreements and protocols.

The third column of Table 13 shows that if the SO_2, NO_x and PM_{10} target reductions are not reached and the emission technology remains at 1995 levels, the ancillary benefits of GHG mitigation rise to 0.25% of GDP, or some 300 euros per tonne abated GHG carbon-equivalent (e/t). The first column of numbers in the table shows the corresponding effects in the main carbon tax scenario; the conclusion is that the ancillary benefits are more than doubled if pollution were to remain high. In other words, as air quality improves in Europe the value of the ancillary benefits of GHG mitigation falls substantially, although it remains significant.

5.3 The high fuel use scenario

This scenario shows the outcome if CO_2 emissions rise more that the modest 9% in 1990-2010 in the base scenario as a result of much higher fuel use. The fuel use in the scenario is based on that in the International Energy Agency's World Energy Outlook (1998) which is at the top of various projections of European energy use and CO_2 emissions (see Ybema, *et al.*, 1999, pp. 58-60 for a comparison of 6 projections to 2010). The IEA has an increase of 26% in CO_2-emissions for OECD Europe 1990-2010, based on a real oil price of $17 per barrel in 1993 prices 1998-2010. Column 4 of Table 12 shows that this scenario has 14% higher GHG emissions and 17% higher CO_2 emissions that the base; emissions of other gases associated with fuel use are also higher, with the overall extra cost estimated to be 0.17% of GDP.

With much higher fuel use, mitigation policy has to be much stronger (the carbon tax rate rises from 154 to 779 euro per tonne carbon), there is much more abatement, and the ancillary benefits are therefore much larger at 0.34 of GDP (see Table 13 totals). The value of the benefits is 140 e/t GHG abated. Total ancillary benefits are three times those in the reference base.

5.4 The low oil price scenario

If the Kyoto Protocol comes into force, the world demand for fossil fuels will fall. Consequently, it is not unreasonable to assume that the international oil prices will fall below the assumed $(2000) 22.5 per barrel by 2010 in the baseline projection. Then fuel use and emissions will rise and the tax/permit policies will have to be stronger to reach Kyoto targets. The scenario assumes a real oil price of $(2000) 15.1 per barrel by 2010, about half the market price of mid-March 2000. In this scenario, GDP growth is higher and, as a consequence, electricity use is higher and coal-fired generation, which would otherwise have been closed down, is kept in operation. SO_2 emissions are therefore higher than in the base. Table 12 shows them to be 19% above the reference base, much more than for the other emissions. Again mitigation policy has to be much stronger than in the reference base, with the carbon tax rising to 203 euros per tonne carbon-equivalent (e/t) to achieve the Kyoto targets. Ancillary benefits rise to 0.22% of GDP or 141 e/t.

Figure 6. **Sensitivity of ancillary benefits to the oil price and effects of the oil price on pollution damages**

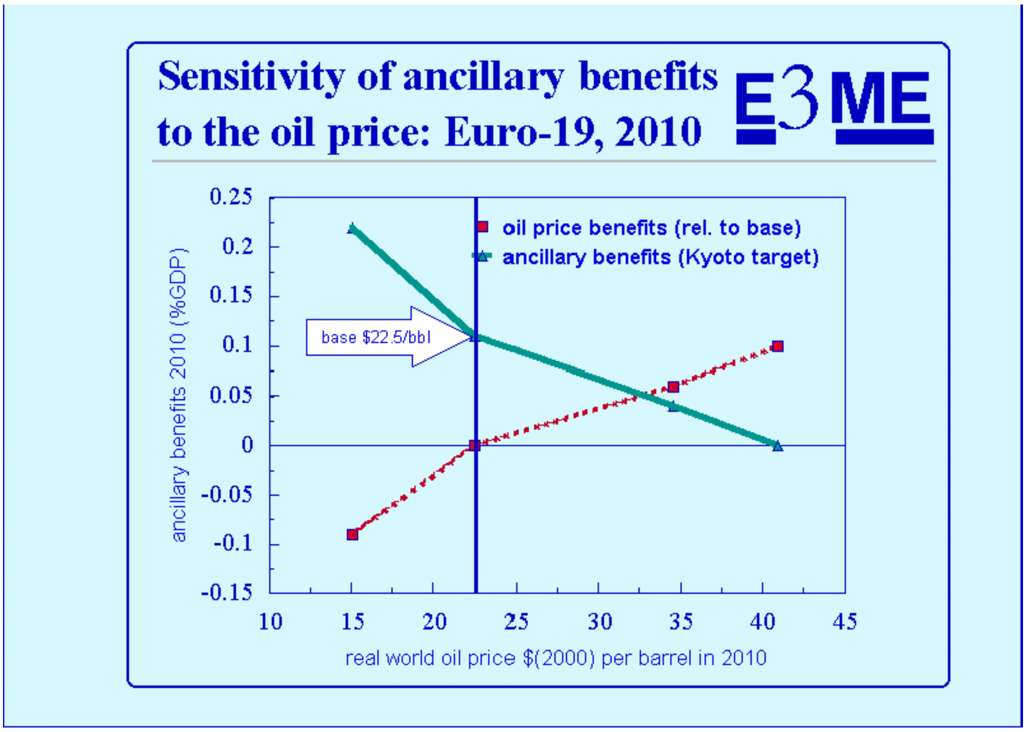


Figure 6 illustrates how the assumed level of world oil prices changes the estimated ancillary benefits. The baseline outcome is represented by the vertical line at the price of $22.5 per barrel, year 2000 prices. At this price, ancillary benefits are 0.11% GDP, using the carbon tax to achieve the Kyoto target; by assumption the oil price effects on the pollutants are zero. When real oil prices are lower, more oil is burned and economic growth is higher; the carbon tax has to rise from 154 e/t in the base to 203 e/t for an oil price of $15 per barrel. When oil prices are higher the carbon tax is lower and ancillary benefits diminish until at a price of $41 per barrel (year 2000 prices) the Kyoto target is met without further policy actions and there are no ancillary benefits by definition. The dashed upward-sloping line in the chart gives the value of the changes in the SO_2, NO_x and PM_{10} damages relative to the baseline which are associated with the oil price assumption. When oil prices are high, more of the reduction in damages comes from the oil price effect, and less from the carbon tax effect.

5.5 Sensitivity of the ancillary benefits by region

It is interesting to see if there are significant differences between countries in the various sensitivity tests, especially since damage costs per emission vary substantially. Table 14 shows the ancillary benefits for the achievement of the Kyoto target in the reference base and the 3 alternatives distributed on regions. Note that the benefits are attributed to the regions where the pollutants are emitted, not the regions suffering the damages. For instance, in the high pollution scenario tt might be expected that unchanged emission coefficients would have increased emissions mostly in central (and northern) Europe compared to baseline, since these countries have agreed upon the highest percentage reduction in the protocol. As damage costs are highest in these regions (e.g. Germany), this would mean that damage costs should increase relatively more than emissions. However, apart from some effect for SO_2 costs and emissions (154% vs. 136% increase), this is not the conclusion. The reason is that much of the emission reduction is taking place through changes in fuel use and industry structure. In particular the very high sensitivity of the estimates for Spain is an effect of the use of coal in electricity generation in Spain: in the alternative scenarios there is more pollution from coal burning or much more use of coal and so more pollution.

Table 14. **Regional ancillary benefits (lower damage from SO_2, NO_x, PM_{10}) – Annual average 2008-12 – Differences of carbon tax scenarios from perturbed bases as % of GDP**

	Reference Base	High Pollution	High Fuel use	Low oil price
Germany	0.14	0.31	0.43	0.25
France	0.13	0.28	0.46	0.24
Spain	0.23	0.46	0.59	0.70
Italy	0.10	0.22	0.25	0.18
United Kingdom	0.09	0.21	0.29	0.14
Rest of EU-15	0.06	0.11	0.13	0.09
Eurozone EMU-11	0.12	0.26	0.36	0.25
Non-EMU4	0.08	0.19	0.25	0.13
EU-15 (EU)	0.11	0.25	0.34	0.22

Source: E3ME project, E3ME22 C92F7B GHG, March 2000.

6. Conclusions

Most studies of GHG mitigation policies for Europe have calculated the direct costs and impacts from the use of various proposed policy instruments. To date, only one other study (Capros et al, 1999) has addressed the marginal impact of these policies for the EU on public health and the environment. The analysis above is an innovative assessment of the ancillary benefits of such policies using E3ME, a validated model of the European Community. Three different GHG mitigation scenarios are compared, each of which reaches the Kyoto target in terms of reductions in GHG emissions for the EU of 8% below 1990/1995 levels. The ancillary benefits of a carbon tax or CO_2 emission-permit scheme for the EU are estimated to range from zero to 0.32% of GDP depending on the assumptions chosen. Ancillary benefits here mean reductions in externality damages from SO_2, NO_x and PM_{10} emissions in Europe using ExternE valuations.

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% compared to 1990 and by 9-10% compared to the baseline projection for the years 2008-12. The three alternative mitigation scenarios use a carbon tax, a permit scheme with grandfathered permits, or a combination of these. The estimated ancillary benefits are quite similar for the three alternative scenarios; they amount to about 9 billion euro in 1990 prices, or 138 euro (2000 prices) per tonne of carbon-equivalent reduced, or 0.11% of total GDP in EU in 2010. Most of them are due to improvements in human health: these benefits by 2010 represent, each year, a saving of around 104,000 life-years, 11,000 fewer new incidences of chronic bronchitis in adults, and 5.4 million fewer restricted activity days. Moreover, these values constitute between 15 and 35% of the change in GDP (which is positive for two of the three scenarios). This means that including the ancillary benefits in the overall assessment of the policy measures is important.

The estimate of the ancillary benefits is somewhat below earlier European studies, but slightly above the results in studies from the US. One explanation for the lower benefits compared to other European studies is the much lower emissions in 2010 than in the 1990s. The importance of this was clearly confirmed by the sensitivity analysis. Another reason is that traffic-related externalities other than emissions are not included here (most American studies also include only a part of the total ancillary benefits). Even if there are uncertainties about the direct costs and benefits of GHG mitigation, the existence and scale of the ancillary benefits imply that higher direct costs of mitigation can be justified.

Around 50% of the ancillary benefits are due to reduced NO_x emissions, about 35% to reduced SO_2 emissions, and about 15% to reduced PM_{10} emissions. This holds true even though the baseline projection includes large reductions in emissions of NO_x and SO_2 after the signing of a European protocol on transboundary pollution. If this agreement is not effective, and emissions are not reduced as much as expected, the ancillary benefits of a carbon tax will be higher. On the other hand, measures to mitigate CO_2 emissions can be a deliberate policy to reduce emissions of the other pollutants. If so, the ancillary benefits will not be related to lower damage costs, but to lower control costs. These will probably be at least as high as the damage costs, as the marginal costs at high levels of abatement (which will then be avoided) are expected to be much higher than the average costs.

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