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Inclusion of 6 greenhouse gases and other pollutants into 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 9b. As the results are preliminary, please do not quote without permission of the authors. Comments, corrections and additions are gratefully received. The views represented in this paper are those of the authors and are not necessarily those of the European Commission.

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Contents

Executive Summary

The Kyoto protocol puts limits on the emissions of CO_2 and five other greenhouse gases (GHGs) in 2008-12 in the so-called Annex-B countries (i.e., mainly OECD, Eastern Europe and FSU). Consequently, it is important to include all six GHGs in analyses of the impacts of the protocol. Earlier versions of the E3ME model have only included emissions of CO_2. This paper describes how the 5 non-CO_2 GHG, as well as 5 other pollutants, are being implemented into the model. The first analyses based on the extended model are also presented.

Emissions are first divided into 10 different emission sources, in correspondence with our main data source DG XI (European Commission, 1999). To complement this data source, data from IPCC, CORINAIR and Eurostat among others are also used. Emissions data in the baseyear for each gas, country and source are linked to one or several economic variables in the model by fixed coefficients. However, these coefficients are changed over time to reflect political actions, changes in energy mix, technologies etc. We have used national projections presented by IPCC to calibrate the coefficients in future years for the 5 non-CO_2 GHG. These projections are mainly based on new, expected policy measures. The outcome of a recent European protocol for transboundary air pollution is used for SO_2, NO_x and VOC. Hence, several expected policy measures are implicitly included for these 8 gases in the baseline projection of the E3ME model. The change in the emission coefficients from 1990 to 1994 is extrapolated for PM_{10} and CO.

According to the Kyoto protocol, the EU countries are required to reduce their total annual GHG emissions in the period 2008-2012 by 8 per cent compared to the baseyear (mainly 1990). In the baseline scenario of the E3ME model emissions of greenhouse gases other than CO_2 fall by 27 per cent over the same period. CO_2 emissions increase by 9 per cent. This means that total greenhouse gas emissions increase by 1 per cent before any measures against CO_2 emissions are introduced. The largest increase is in Sweden and Portugal, whereas the projections indicate major reductions in e.g. France and the United Kingdom.

The EU ministers have suggested a certain differentiation across the countries of the required reduction in the Kyoto protocol. Following that suggestion implies that Sweden will be most far from their target according to the model baseline, whereas several countries do not have to implement measures against CO_2 (e.g., France, Greece and Ireland).

In order to achieve the 8 per cent reduction in GHG emissions, CO_2 emissions have to be reduced by merely 2-3 per cent compared to the 1990 level since other GHG emissions drop significantly. This means a 10 per cent reduction compared to baseline. It is obvious that an 8 per cent reduction (from the baseyear) in CO_2 emissions alone would have required much tougher policy measures than in the case of the Kyoto protocol, where 6 greenhouse gases are treated together.

The paper presents the results of four mitigation scenarios that fulfil the Kyoto requirement. If a multilateral carbon tax is introduced within the EU, with tax revenues recycled through reductions in pay-roll taxes, the overall GDP and employment effects in EU is slightly positive according to the E3ME model. Consequently, there are prospects for strong double dividends of the carbon policy. On the other hand, if grandfathered permits are used instead, there is a marginal reduction in GDP and employment. The necessary carbon taxes or permit prices lie between 172 and 192 (1990) Euro/ton carbon.

The amount of trade of emission permits between countries in the EU is determined by three factors: the baseline GHG emissions in the years 2008-12; the choice of burden sharing; and the GHG emission reductions in the mitigation scenarios. Introducing carbon taxes or a carbon permit scheme leads to particularly large GHG emission reductions in Denmark and Spain. If the burden sharing rule suggested by the EU ministers is followed, the results indicate that France and Germany both will be involved in half of the trade, as respectively seller and buyer of permits.

The carbon taxes or permit scheme lead to reduction of CO_2 emissions of about 10 per cent. Other greenhouse gas emissions are only slightly changed; CH_4 and N_2O emissions are either decreased or increased by up to 2 per cent. Emissions of other pollutants like SO_2 and NO_x are, however, significantly reduced. SO_2 emissions are reduced by 16 per cent, whereas NO_x emissions drop by 9 per cent. This leads to major secondary benefits of the carbon policy, which is discussed in Working paper 9c (Rosendahl, 2000).

1 Introduction

1.1 Purpose of the Paper

The Kyoto protocol (UNFCCC, 1997) puts restrictions on the total emissions of 6 greenhouse gases (GHG). However, former versions of E3ME, and most other models, only include CO_2-emissions and CO_2-abatement policy. Table 1.1 shows that the non-CO_2 GHG contribute to 22.4 per cent of total GHG-emissions in the E3ME-area in the reference year for the Kyoto Protocol.

Table 1.1. Regional contribution of CO_2- and non-CO_2 GHG emissions in the reference year[a] for the Kyoto protocol.

E3ME - region	CO_2	Non-CO_2
Belgium (BE)	81.9 %	18.1 %
Denmark (DK)	72.8 %	27.2 %
Germany (east) (DO)	86.0 %	14.0 %
Germany (west) (DW)	82.1 %	17.9 %
Greece (EL)	79.6 %	20.4 %
Spain (ES)	74.2 %	25.8 %
France (FR)	69.7 %	30.3 %
Ireland (IR)	56.1 %	43.9 %
Italy (north) (IN)	82.6 %	17.4 %
Italy (south) (IS)	71.8 %	28.2 %
Luxembourg (LX)	93.0 %	7.0 %
Netherlands (NL)	73.1 %	26.9 %
Portugal (PO)	65.9 %	34.1 %
United Kingdom (UK)	76.8 %	23.2 %
Austria (AT)	82.4 %	17.6 %
Finland (FI)	80.0 %	20.0 %
Sweden (SE)	76.9 %	23.1 %
Norway (NO)	67.6 %	32.4 %
Switzerland (CH)	82.3 %	17.7 %
Total	**77.6 %**	**22.4 %**

[a] Reference year is 1990 for CO_2, CH_4 and N_2O and 1995 for HFC, PFC and SF_6. No HFC, PFC and SF_6 emission statistics are available for Greece, Spain, Ireland, Luxembourg and Portugal.

Among others, Gielen and Kram (1998) and Reilly *et al.* (1999) show that a multi-gas control strategy could reduce the costs of fulfilling the Kyoto-protocol compared with a CO_2-only strategy. Hence, it is important to include not only CO_2 but also the remaining 5 greenhouse gases in the E3ME-model.
To get a complete picture of the costs and benefits of climate policies, one should also consider the benefits of reductions in other pollutants like SO_2, NO_x and PM_{10}, indirectly caused by the measures against greenhouse gases. These pollutants have damaging effects on health, buildings and plants. The reduction in such damages are called secondary benefits of the climate policy (see Rosendahl, 2000, Working Paper 9c).

In this paper we present how we have implemented into the E3ME model emission calculations of the 5 extra greenhouse gases (excluding CO_2) and 5 other pollutants, some of which are relevant in the context of secondary benefits. Emission data for each region are found from various data sources, and the emissions are distributed on a new E3ME classification called Emission Source (ES).

We introduce new equations that link the emissions from the various ES to variables in the E3ME model. Each equation generally consists of three factors: A fixed emission coefficient from the base year (1994), a weighted sum of one or several economic variables already existing in the model, and an adjustment parameter that reflects how the emission intensity, i.e. the relation between emission and the economic variable(s), develops over time.

For the non-CO_2 GHGs, the adjustment parameter changes in accordance with projections by the IPCC. As these projections seem to have taken into account new, expected policy measures, the baseline of the E3ME model will implicitly have incorporated measures against non-CO_2 GHGs. For SO_2, NO_x and NMVOC we use future emission ceilings in The Convention on Long Range Transboundary Air Pollution (United Nations, 1999), whereas for PM_{10} and CO we use specific assumptions regarding the technological development.

Finally, the paper presents a base-case projection to 2012 for all pollutants, and compare the projection with the requirements in the Kyoto protocol and the burden sharing between member states suggested by the EU. An interesting point is that bringing in the five non-CO_2 greenhouse gases into the protocol seems to have significant impact on how much CO_2 emissions will have to be reduced in EU. We also present four different mitigation scenarios, with multilateral carbon taxes or permit schemes for CO_2 emissions, which fulfil the requirements in the Kyoto protocol. Economic as well as environmental effects are studied.

1.2 Remaining Sections of the Paper

In section 2 we discuss the relevant data sources available for collecting emission statistics, and how other models have implemented emission calculations. Section 3 deals with the methodological questions, i.e. how the emission calculations are implemented into the model. The new coefficients and parameters in the model are also presented. In section 4 we present a base-case projection and the scenario analyses. In Section 5 we present the conclusions and briefly discuss further analyses.

2 Literature Review

2.1 Data sources for emission statistics

There are several data sources available for European emission statistics. However, the sources vary with respect to the pollutants and countries included, and the distribution on emission sources. Moreover, the data sources are not completely consistent as e.g. the total emissions in a country in a year may differ significantly between the data sources. Thus, we have to choose which data source we use as our main source, and which one we use as our secondary and third source to complement. The choice of order is based on several considerations.

We have chosen to use the Annual European Community Greenhouse Gas Inventory 1990-1996 (European Commission and EEA 1999) as our main data source (called DGXI). This source has based its emission calculations on several other sources, and is therefore assumed to have reached a more complete overview of the emissions. The DGXI source does not report emissions very different from all other data sources. Moreover, the emissions are distributed on more than 20 sources (see table A.2.a.), which gives a good basis for the construction of links to the economic module of E3ME.

The DGXI source does not include Norway and Switzerland, and the two pollutants SO_2 and PM_{10} are not included. In addition we found the DGXI data for HFC and PFC not usable because the numbers are reported in tonnes and not in Global Warming Potensial (GWP). It is not possible to convert the numbers since the GWP value varies among the different HFC- and PFC-gases. Hence, we must rely on other sources.

Our secondary data source is IPCC (1998), which presents emissions of all the 5 greenhouse gases for all relevant countries. We use the IPCC data for HFC and PFC for all countries (except Norway, see below). Regarding Switzerland we also use the IPCC data for SF_6.

The Corinair Inventory is our third data source. It includes emissions for the same pollutants as the DGXI data source (except HFC, PFC and SF_6) for all relevant countries. In addition, it includes emissions of SO_2. Thus Corinair is our primary source for emissions of SO_2 for all countries (except Norway).

Corinair is very close to the DGXI inventory, and so are the emission results. In addition, Corinair has subcategories (see table A.2.b) with more detailed information. These are used to link the emissions to the E3ME variables. This is described in chapter 3.2 and in table A.3.

Our fourth data source is Eurostat, which presents emissions of particulate matter (PM_{10}). This inventory is not complete. Several countries lack data, and for other countries the emissions are not disaggregated on activities.

For Norway we rely on data from Statistics Norway (1999) for all the 10 gases. For the Swiss emissions of CH_4, N_2O, NMVOC, CO and NO_x we use data from Departement für Umwelt, Verkehr, Energie und Kommunikation (1999).

DGXI reports emissions for the years 1990 and 1994-1996. Corinair reports 1990 and 1994, IPCC 1990 and 1995, while Eurostat reports 1990 and 1994. We have chosen 1994 as the baseyear in the E3ME-model since this is the latest year with Corinair and Eurostat data and complete DGXI statistics. For HFC, PFC and SF_6 we use 1995 as baseyear since this is the year with the best IPCC data.

Also, it is important that the data for 1990 is as complete and consistent as possible, since this is the baseyear for the Kyoto protocol (for the greenhouse gases) and The Convention on Long Range Transboundary Air Pollution (for SO_2, NMVOC and NO_x). There are no international protocols for PM_{10} and CO emissions.

To sum up, fairly good information is available for the emissions of the two most important greenhouse gases (next to CO_2), CH_4 and N_2O, and of the pollutants NO_x, SO_2, CO and NMVOC. However, for the three least important greenhouse gases, i.e. HFC, PFC and SF_6, and for one of the most important pollutants with respect to secondary benefits, particulate matter, the data are not satisfactory. Following table A.3 there is a detailed description of specific data problems for each country.

2.2 Other relevant literature

Statistics Norway has a long tradition in linking emissions to air to disaggregated macroeconomic models (see Alfsen et al. 1996). All the five pollutants above, which have important local/regional environmental effects, have been included in a similar way as we describe in this paper. However, until lately only CO_2 of the greenhouse gases was included in these models. CH_4 and N_2O emissions have also been linked to specific sector activities in the models, but exogenously. At present time, however, Statistics Norway aims to model the greenhouse gases endogenously. The work of distributing emissions on the various sectors activities is done in co-operation with the Division for Environmental Statistics within Statistics Norway and Norwegian Pollution Control Authority.

Statistics Norway has also for several years been working specifically with projections of waste amounts in Norway (see e.g. Bruvoll and Ibenholt 1997). These projections have been used to project Norwegian methane emissions from landfilled waste (Norconsult, 1999). Moreover, in Bruvoll and Bye (1998) the costs of various methods to reduce methane emissions were studied. This experience is used both in the current work with the Norwegian models, and in the work presented here on the E3ME model.

We also use some literature to supplement the statistics, e.g., Harnisch *et al.* (1998) on PFC emissions, Maiss and Brenninkmeijer (1998) on SF_6 emissions, and EC (1995) on emission coefficients for various fuels.

According to Gielen and Kram (1998), the uncertainty regarding non-CO_2 GHG emissions in the EU is much higher than the uncertainty regarding CO_2-emissions. This is due to the different accounting practice. CO_2 emissions are mainly proportional to fossil energy use and energy statistics are well established. They estimate the uncertainty regarding CO_2 emissions to be 2-5 %. The other GHG emissions are calculated either on basis of different economic activities or on the basis of consumption of substances that are GHGs themselves (parts of HFCs, PFCs and SF_6). The problem is that the proportionality factors are often uncertain. Gielen and Kram discuss in detail the uncertainty of the main emission sources for the different non-CO_2 GHG. Total uncertainty for non-CO_2 GHG emissions is estimated to be in a range of 150-200%.

Gielen and Kram (1998) also discuss different abatement options for the non-CO_2 GHG and estimate possible emission reductions and costs. Finally they refer to a spreadsheet model for EU where the contribution of non-CO_2 GHGs to an 8 % emission reduction of GHG in 2010 is analysed. They show that the non-CO_2 GHG contribute to 27 % of a cost-effective emission reduction to meet the Kyoto-target.

Reilly *et al.* (1999) present a model of the Annex-B area where they analyse economic and environmental effects of controlling CO_2 emissions only vs. all GHG emissions. They find that strictly focusing on reducing CO_2 emissions to meet the Kyoto target would increase the cost by more than 60 % compared to a multiple-gas approach.

3 Methodology

3.1 General methodology

Emissions of greenhouse gases and other pollutants are partly connected to various economic activities described by e.g. the E3ME model, partly to more micro-related economic choices of technology etc., and partly to non-economic activities like specific treatment of emissions and waste etc. Hence, the implementation of emission calculations in the E3ME model should link emissions to economic variables in the model, and include shift parameters to make possible adjustments of the relationship between the economic variables and the emission level, i.e. the emission intensity. Moreover, in order to include emissions or measures that are difficult to relate to economic variables, an exogenous parameter should also be included. Compared to the former version of E3ME, the Environment Emission (EM) classification has been extended, as CO_2 and CH_4 (methane) were the only greenhouse gases included before. This is shown in Table 3.1. Here the last four greenhouse gases, N_2O, HFC, PFC and SF_6, are included at the bottom. Moreover, black smoke has been replaced by the more up-to-date particle component PM_{10}. In this paper we discuss emission calculations of all pollutants except CO_2, Nuclear, Lead and CFC.

Table 3.1. Emission Classification

EM	Environment Emission (EM)
1.	CO_2
2.	SO_2
3.	NO_x
4.	CO
5.	Methane (CH_4)
6.	PM_{10}
7.	NMVOC
8.	Nuclear-air
9.	Lead-air
10.	CFC
11.	N_2O
12.	HFC
13.	PFC
14.	SF_6

As emissions are caused by different economic activities, it is advantageous to divide the total emissions in a region into various sources. Hence, a new classification called Emission Source (ES) is included in the E3ME model. Emissions of all pollutants are then specified for each ES (which is equal for all pollutants except CO_2). The suggested ES classification is directly related to the classification used by DGXI (European Commission 1999), and is shown in Table 3.2 (the connection between the new ES classification in E3ME and the classification in DGXI is shown in the third column). The ES classification is also very similar to the one used by Corinair (the connection here is shown in the last column).

Table 3.2. Emission Classification (ES)

ES	Emission Source	DGXI Classification	Corinair Classification
1.	Fuel combustion: Energy Industries	1.A.1	1.
2.	Fuel combustion: Manufacturing Industries and Construction	1.A.2	3.
3.	Fuel combustion: Transport	1.A.3	7., 802-805
4.	Other fuel combustion	1.A.4-5	2., 801, 806-810
5.	Fugitive Emissions from Fuels	1.B	5.
6.	Industrial Processes	2	4.
7.	Solvent and Other Product Use	3	6.
8.	Agriculture	4-5	10.
9.	Waste	6	9.
10.	Other	7	

For each emission source there is one or more economic variables in the E3ME model that should be used to calculate the emissions of a specific pollutant. The selection of variables may differ across the pollutants, as the origin of emissions may differ even within the emission sources in Table 3.2. The final emission source (ES10), i.e. other emissions, is marginal and the level fixed for all pollutants except particulate matter. ES10 is only included so that total emissions in the base year should be in accordance with the corresponding figures in the data sources.

Based on the considerations above, and the introduction of a new ES classification, we propose the following general equations to be included in E3ME:

$$(1)\qquad ESY_{i,j}^{k} = \alpha_{i,j}^{k} \cdot \gamma_{i,j}^{k} \cdot X_{j} + \overline{ESY}_{i,j}^{k}$$

- $ESY_{i,j}^{k}$ are new endogenous variables denoting emissions of pollutant *k* (*k* ∈ EM) from emission source *i* (*i* ∈ ES) in region *j* (*j* ∈ RZ) in a specific year *t* (*t* is omitted from the equation). The variables are measured in 1000 tons.
- X_{j} denote economic variables related to region *j* that already exist in the model, or a weighted sum of such variables. This could be e.g. the consumption of energy by a fuel user, or the production level, the capital level or the material input level in an industry, or a combination of these. This depends upon which variable(s) is the most relevant to explain the emission of the different pollutants. Whereas emissions of CO_2 are directly related to the combustion of fossil fuels, most of the emissions of the other 5 greenhouse gases are not related to fossil fuel combustion at all, but to other economic activities like agricultural production, waste amounts etc.
- $\alpha_{i,j}^{k}$ denote emission coefficients from the base year (1994), i.e., the relationship between the emission level $ESY_{i,j}^{k}$ and the level of X_{j} in the base year.
- $\gamma_{i,j}^{k}$ are parameters included to capture eventual changes in emissions intensities over time, i.e., changes in the relationship between the economic variable X_{j} and the emission level $ESY_{i,j}^{k}$. This

may be due to e.g. new technologies or regulations that are expected to come in place. The values of these parameters are equal to 1 in the baseyear. In the Base case the shift parameters are assumed to change over time due to various conditions (see section 3.4).[1] In most cases we will have $\gamma_{i,j}^{k} \leq 1$, i.e. the emission intensities will either decrease or stay unchanged over time. However, in the case of e.g. HFC, it is expected that this gas will replace the use of CFC so that the emission intensity will increase over the next decades.

- $\overline{ESY}_{i,j}^{k}$ are exogenous variables included to take care of emissions or measures that are difficult to relate to economic variables.

When X_j denotes a weighted sum of several economic variables, it can be replaced by the following expression:

$$(2) \qquad X_j = \sum_{l=1}^{n} \beta_{i,j}^{k,l} X_{j,l} \qquad , \qquad \sum_{l=1}^{n} \beta_{i,j}^{k,l} = 1$$

In this case the interpretation of $\alpha_{i,j}^{k}$ and $\beta_{i,j}^{k,l}$ is not straightforward, however, the product of these two coefficients is the emission coefficient for the impact of the economic variable $X_{j,l}$. Note that we have *not* chosen to include separate adjustment parameters (i.e., $\gamma_{i,j}^{k}$) for each economic variable $X_{j,l}$, but rather for the emission source in total. Eventually, this could be changed if desired.

Some summation equations should also be included:

$$(3) \qquad ESY_j^k = \sum_i ESY_{i,j}^k$$

$$(4) \qquad CO2EQ_j = \sum_{k=1,5,11-14} ESY_j^k \cdot GWP^k$$

$$(5) \qquad CO2EQ = \sum_j CO2EQ_j$$

Equation (3) sums up (over all emission sources) the total emissions of pollutant *k* in region *j*. In Working Paper 9c the variables ESY_j^k for *k* = SO_2, NO_x and PM_{10} are used in the calculation of secondary benefits. Equation (4) sums up (over all greenhouse gases including CO_2) the total greenhouse gas emissions in region *j*. The variables $CO2EQ_j$ are measured in tons of CO_2-equivalents, and the parameters GWP^k are the global warming potentials of gas *k* relative to CO_2 as used by the IPCC (1995). Alternatively, the GWP^k parameters could be included already in equation (1), i.e. by adjusting $\alpha_{i,j}^{k}$, so that $ESY_{i,j}^{k}$ were measured in CO_2-equivalents (then equation (4) must be

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[1] Instead of including the shift parameter $\gamma_{i,j}^{k}$, one could change the emission coefficient $\alpha_{i,j}^{k}$ in the same manner. This is actually done in the implementation of the E3ME model.

removed). Equation (5) sums up (over all regions) the total greenhouse gas emissions in the model area (alternatively in the EU area).

The variables on the left-hand side of equations (3)-(5) are endogenous. However, when it comes to analyses of how to fulfil the specific Kyoto target (either in EU in total or in each country), it would be suitable to transform $CO2EQ_j$ and $CO2EQ$ into exogenous variables, and have endogenous carbon taxes or permit prices.

Note that abatement measures directly related to the extra 5 greenhouse gases are not explicitly included in the E3ME model. Rather, the baseline of the model implicitly incorporates measures against these gases, as the adjustment parameters are changed in accordance with projections by the IPCC that seem to take into account new policy measures (see section 3.4). At the same time, some of the emissions (notably methane and N_2O) are related to energy use, and will be indirectly affected by a carbon tax. Although a cost-effective policy is characterised by equal marginal abatement costs (per CO_2-equivalent) across the greenhouse gases, it is difficult at this stage to include the relevant measures against other gases than CO_2 into the E3ME model. The costs of such measures are uncertain and depend on country-specific characteristics of technology, waste and emissions treatment, agricultural structure and existing regulation. Hence, it may be preferable to allow the model user to adjust the emission intensities $\gamma_{i,j}^{k}$ or the exogenous variables $\overline{ESY}_{i,j}^{k}$ compared to the base-case. Abatement measures related to the other pollutants are neither incorporated, as these pollutants are included to capture the secondary benefits of measures against greenhouse gases. However, in the baseline of the E3ME model the adjustment parameters are significantly reduced over time to reflect expected policy and technology measures (see section 3.4).

3.2 Emissions in the base year distributed on emission sources

The total emissions for all regions in the baseyear distributed on emission sources are presented in Table 3.3.a (GHGs) and 3.3.b (other pollutants). The baseyear is either 1994 or 1995. In chapter 2 we explained which data sources we have used and in what order they were utilised. Table C.1 in Appendix C gives a detailed description of this for each pollutant and emission source. In Table C.1 we also describe how we have used the Corinair data to disaggregate the emissions further in order to connect emissions even more precisely to economic variables in the E3ME model. For instance, for ES1 for CH_4 we use the DGXI source (classification 1.A.1) to find total emissions. Then we distribute the emissions from ES1 on the four economic variables X_1-X_4 with the percentage distribution of the Corinair Subcategories[2] 101-102, 103, 105 and 105.

In countries where no emissions data exist, we set the emissions equal to zero when we aggregate across countries or gases (e.g., when we calculate total GHG emissions). The notes to Table 3.3.a and 3.3.b state which countries and pollutants this applies to.

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[2] For the countries where detailed information is not specified in Corinair (i.e., Greece, Italy, Portugal and Finland), we use the average distribution for the other countries.

Table 3.3.a. Total emissions of 5 greenhouse gases in the whole E3ME area distributed on emission sources (ES). 1994 for CH_4 and N_2O and 1995 for HFC, PFC and SF_6.

ES	CH_4	N_2O	CH_4[a]	N_2O[a]	HFC[b]	PFC[b]	SF_6[b]
	(1000 tonnes)		(Mill. tonnes CO_2-eq.)				
1. Fuel combustion: Energy Industries	62	60	1.3	18.7	0.0	0.0	0.0
2. Fuel combustion: Manufacturing Industries and Construction	58	31	1.2	9.6	0.0	0.0	0.0
3. Fuel combustion: Transport	225	58	4.7	18.0	0.0	0.0	0.0
4. Other fuel combustion	407	36	8.5	11.3	0.0	0.0	0.0
5. Fugitive Emissions from Fuels	3,638	1	76.4	0.3	0.0	0.0	0.0
6. Industrial Processes	25	321	0.5	99.6	0.0	7.0	15.5
7. Solvent and Other Product Use	1	10	0.0	3.1	31.2	1.0	0.0
8. Agriculture	9,438	672	198.2	208.4	0.0	0.0	0.0
9. Waste	7,601	12	159.6	3.9	0.0	0.0	0.0
10.Other	2	4	0.0	1.1	0.0	0.0	0.0
Total	**21,456**	**1,206**	**450.6**	**374.0**	**31.2**	**7.9**	**15.5**

[a] CH_4 and N_2O have global warming potentials (GWP) of 21 and 310, respectively, i.e. one ton of CH_4 (N_2O) is equal to 21 (310) tons of CO_2-equivalents.

[b] Emissions of HFC, PFC and SF_6 only include emissions in countries that have reported emissions to the IPCC (i.e., excluding Greece, Spain, Ireland, Luxembourg and Portugal).

Table 3.3.b. Total emissions of 5 pollutants in the whole E3ME area in 1994 distributed on emission sources (ES) (1,000 tons).

ES	SO_2	NO_x	PM_{10}[a]	CO	NMVOC
1. Fuel combustion: Energy Industries	7303	2327	932	284	106
2. Fuel combustion: Manufacturing Industries and Construction	2324	1452	3475	231	145
3. Fuel combustion: Transport	684	6850	28253	727	5361
4. Other fuel combustion	1113	1391	7216	282	1003
5. Fugitive Emissions from Fuels	33	24	109	0	1491
6. Industrial Processes	570	154	2419	483	744
7. Solvent and Other Product Use	0	0	2	0	4100
8. Agriculture	0	20	589	0	868
9. Waste	83	67	638	0	132
10. Other	0	2	0	305	-3
Total	**12111**	**12286**	**43634**	**2312**	**13946**

[a] PM_{10} emissions: 1990 for Spain, Ireland, Italy, Austria and Finland; 1995 for Sweden. Greece, Luxembourg and Portugal have not reported emissions.

3.3 Specific characteristics of each pollutant

We now go on to discuss the characteristics of each gas, and how the emission sources are linked to the E3ME model. This is summarised in Table A.1 and C.1 in Appendix A and C.

3.3.1 Methane (CH_4)

The main sources of CH_4 emissions are agriculture, waste and fugitive emissions related to fossil fuel supply and distribution. Some emissions also come from fuel combustion. Our main data source for CH_4-emissions are DGXI, but we use the information in Corinair to disaggregate the figures further.

Almost one half of total methane gas emissions stem from agriculture, mostly from enteric fermentation and manure management (IPCC 1998). We link the agricultural emissions (ES8) to the agricultural output (QR1), as this is the closest approximation to this emission source in E3ME.

Waste treatment causes almost as much CH_4 emissions as agriculture, and is expected to be the most important methane emission source in the future (see chapter 4). This is due to waste from landfills. The determinants of methane emissions from landfills are described more fully in Appendix D. We distinguish between waste from households and commercial waste. The growth in household waste is linked to the growth in selected consumption goods (C1-4,10-13,24), whereas the growth in commercial waste is partly linked to the growth in input of commodities (70 per cent) and partly to the growth in output (30 per cent). For the moment, the total value of input and output in all industries are included. A more thorough investigation of the industries could justify singling out the relevant waste generating fraction of the material inputs in the model.

In order to connect the methane emissions to household and commercial waste respectively, three factors are important. The first factor is the share of household waste versus commercial waste. The second is the share of landfilled waste versus other waste treatment, which may differ between household and commercial waste. The third factor is the methane emissions per ton landfilled waste, which may also differ between the two types of waste. These factors may vary across the countries, and information about these is difficult to obtain. Hence, we rely on the factors derived for methane generation in Norway for 1995 (see Appendix D). Household waste then constitutes 38 per cent of all landfilled waste. Moreover, 56 per cent of household waste is landfilled, whereas 82 per cent of commercial waste is landfilled. Finally, due to a higher share of organic waste, one ton landfilled household waste causes 25 per cent more methane emissions than one ton landfilled commercial waste. From these figures we find that in the base year household waste is responsible for 43 per cent of all methane emissions from landfills.

The emission data sources distinguish between emissions from different waste treatment, particularly landfills and waste incineration. Based on the figures above, we find that 69 per cent of the emissions coming from incineration (not important for methane) are caused by household waste.

Fugitive emissions (ES5) are mainly related to extraction of coal and the distribution of gas, but also somewhat to extraction of oil and gas. The DGXI data source distinguishes between solid and other fuels, and emissions from the former source are linked to the output in the Coal & coke industry (QR2). The emissions from oil and natural gas fuels are distributed on output in the industries Oil & gas extraction (QR3) and Gas distribution (QR4) according to the more detailed information in Corinair.

Emissions from fuel combustion (ES1-4) are generally linked to the model in the same way as described for SO_2 below. However, as we want to distinguish between the use of different fuels, we must decide on the emission intensities for CH_4. In the reference technologies used by the ExternE project (EC 1995) the emission intensities (measured in g emitted per kWh produced) are about 100 times higher for coal than for oil, whereas CH_4 emissions from natural gas combustion are negligible. Thus, we link emissions from fuel combustion excluding transport entirely to the use of coal by various fuel users. Transport emissions (ES3) are linked to the use of Middle Distillates by other fuel users (see the discussion of SO_2 below).

CH_4 emissions from industrial processes (ES6) are negligible and linked to the model as described for N_2O below. Emissions from solvent use (ES7) are almost zero and made exogenous.

3.3.2 N_2O

The main sources of N_2O emissions are agriculture and industrial processes. Fuel combustion also contributes to the total emission level. As for CH_4, our main data source for N_2O-emissions are DGXI and we use the information in Corinair to disaggregate the figures further.

Almost one half of the total N_2O emissions stem from agriculture, mostly from agricultural soils (IPCC 1998) (artificial fertilisers). We let the agricultural emissions (ES8) be linked to the use of intermediate commodities in agriculture (YRQ01).

Emissions from industrial processes (ES6) mean emissions in the industrial production not coming from the combustion of fuels. Hence, we choose to link it to the use of intermediate commodities in the various industries in E3ME. For N_2O the emissions from industrial processes are almost entirely related to chemical industries (i.e., QR10).

For the fuel combustion sources (ES1-4) we generally use the same procedure as described for SO_2 below. However, as we want to distinguish between the use of different fuels, we must decide on the emission intensities for N_2O. These are especially uncertain for this gas. In the reference technologies used by the ExternE project (EC 1995) the emission intensities (measured in g emitted per kWh produced) are almost equal for oil and gas, whereas the intensity for coal is around three times higher. Thus, we give the use of coal a 3 times higher weight than the use of oil and gas (measured in toe) in the calculation of emissions from fuel combustion excluding transport. Transport emissions (ES3) are linked to the use of Middle Distillates by other fuel users (see the discussion of SO_2 below).

N_2O emissions from ES7 are entirely related to the use of N_2O. We choose to link these emissions to the intermediate use of commodities in the industry Other non-market services (YRQ031). Fugitive emissions (ES5) are negligible, but related to the output in Oil & gas extraction (QR3). Emissions from waste (ES9) are distributed on waste incineration and disposal of waste on land, and linked to consumption and input/output in industries as described for methane above (i.e., 59.9 and 29.5 per cent of emissions from waste incineration and landfills, respectively, are related to consumption).

3.3.3 HFC

The three remaining greenhouse gases (HFCs, PFCs and SF_6) only constitute 1.4 per cent of all greenhouse gas emissions, and the statistics for these gases are less complete than for the other gases. For the countries with no national emission levels reported by DGXI or the IPCC, we set emission levels to zero.

HFCs are mainly used in refrigeration, air conditioning and aerosols, and are produced as replacements for e.g. CFCs, which are banned by the Montreal Protocol. As this replacement is in its initial stage, it is expected a major increase in HFC emissions over the next decades. Emissions of HFCs may occur in short or long term after the compound has been installed.

It is difficult to link HFC emissions to the E3ME model, as all the three applications above are used in most industries and in consumption. In the MSG model for the Norwegian economy the HFC emissions have recently been distributed on almost all sectors of the model. For the time being we rather choose to place these emissions under ES7 (Solvent and other product use) and link them to total industrial input (YRQ0SUM).

3.3.4 PFC

Emissions of PFCs have generally been linked to primary aluminium production. However, according to Harnisch et al. (1998) 40 per cent of global PFCs emissions in 1995 (measured in GWP - Global Warming Potentials) were related to other sources, e.g. from the semiconductor manufacturing sector and the use of solvents. As the IPCC only reports national emissions, and appropriate information for all the E3ME countries is not available, we have made assumptions on how these are distributed on emission sources.

We see three alternative options. The first assumes that the figures in Harnisch et al. are relevant for the E3ME area as whole. We then distribute national emissions, too, according to the distribution in Harnisch et al. This will certainly be wrong for individual countries (e.g. for Norway where all PFC emissions are related to its large aluminium production), but may be the best description for the whole E3ME area. The second option is to link all PFC emissions to the production of aluminium, as this is clearly the most important emission source. In this case we risk to calculate PFC emissions from aluminium production in countries without such production. The final option is to link national emissions to GDP or other macroeconomic aggregates as we actually don't have more detailed information.

For the time being we choose the first option. The emissions are linked to the use of intermediate products in the specified industries. 60 per cent is linked to industrial processes (ES6) in aluminium production (YRQ08), 15 per cent to industrial processes (ES6) in semiconductor manufacture YRQ011), 10 per cent to industrial processes (ES6) in the manufacture of fluoropolymers (YRQ010), and 15 per cent to the use of solvents and other products (ES7) in various applications (YRQ0SUM).

3.3.5 SF_6

All emissions of SF_6 are classified under industrial processes by DGXI, either related to metal production (DGXI 2.C) or directly to consumption/production of SF_6 (DGXI 2.E-F). According to a figure in Maiss and Brenninkmeijer (1998), 40 per cent of the distribution of SF_6 on end-use applications in Europe in 1995 were related to the production of electrical equipment. Moreover, 16 per cent were used in electric utilities, 6 per cent in magnesium production, 4 per cent in semiconductor production, 16 per cent in production of tires for cars, and 18 per cent in insulation of windows.

Following the DGXI data source, all SF_6 emissions are put in ES6. Emissions from metal production (DGXI 2.C) are linked to QR08 and QR011 (input to metal- production and -products). The rest of the emissions are linked to total input in all industries minus QR08 and QR11. According to Maiss and Brenninkmeijer the emission sources vary significantly among the countries. For instance, the use of SF_6 for filling tires of cars is more or less a German application and in Norway almost all SF_6 emissions are related to magnesium production. Thus the link to total input may not be very precise. However, since the DGXI inventory is not very detailed, this is the most precise link we can achieve for SF_6 emissions in the E3ME-model.

3.3.6 SO_2

The emissions of SO_2 are mainly related to combustion of fossil fuels, but also to industrial processes. SO_2 emissions due to combustion are mainly due to the burning of coal and oil. Burning of gas does not lead to emissions of SO_2. The only data source used for SO_2 is Corinair.

As seen in Table 3.3b, more than half of the SO_2 emissions comes from the first emission source, fuel combustion in energy and transformation industries. According to Corinair, 85 per cent of the specified emissions from this source is due to power generation. We will use the detailed information in Corinair to establish links from emissions from this source (ES1) to the various activities. For most countries, the main contributor in this link will be the use of coal (FRCT) and oil (FROT) in the fuel user 'Power Generation' (FU1). The emission intensities for coal and oil vary according to the sulphur content in the fuels and the use of 'clean up' technologies. In the reference technologies used by the ExternE project (EC 1995) the emission intensities (measured in g emitted per kWh produced) are almost equal for coal and oil. Thus, we give the use of coal and oil (measured in toe) equal weights in the calculation of emissions from power generation. The remaining emissions from ES1 are related to the industries 2-5 in E3ME, i.e. fossil fuel extraction, transformation and distribution. Here we link the emissions to the output (QR) in these industries.

Combustion in industries (ES2) is the second most important emission source. As we don't have information about emission intensities for the burning of coal and oil in industries, we assume that they are equal per energy content, such as for power generation. However, there may be reasons to believe that the emission intensities are higher for coal, as the sulphur content in coal is generally higher than for oil, and the use of 'clean-up' technologies are probably not as widespread as in power generation. Still, until we have more information, we stick to the assumption above. The data sources do not distinguish between industries. Thus, we use the sum of coal and oil use in the fuel users 2-11 as an indicator of SO_2 emissions from ES2.

SO_2 emissions from transport (ES3) are due to the use of oil products, mainly in road transport but also in inland navigation and to some degree in other transport. Corinair gives information about emissions from various transport forms, and we use this information to link transport emissions to the use of Middle Distillates (FR05) in E3ME by the fuel users 12-15.

The third largest emitter of SO_2 is ES4, i.e. fuel combustion not included in ES1-3. This emission is mainly due to residential, but also commercial plants. Here we link the emissions to the use of coal and oil in the fuel users 16-17 according to the information in Corinair. We still make the assumption of equal emission intensities for coal and oil.

The last important emission source for SO_2 is ES6, i.e. industrial processes. Here we use the same procedure as described for N_2O.

SO_2 emissions from the remaining sources are only marginal. Fugitive SO_2 emissions (ES5) are linked to the output in oil and gas extraction (QR3). Emissions from solvent and other product use (ES7) (essentially zero) are linked to the use of intermediate commodities in the construction industry (YRQ022). Emissions from agriculture (ES8) (also essentially zero) are linked to output in the agricultural industry (QR1). Emissions from waste (ES9) are linked to the model as described for N_2O.

3.3.7 NO_x

Emissions of NO_x are almost entirely related to combustion of fossil fuels. As opposed to SO_2, burning of gas is also responsible for large NO_x emissions in addition to burning of coal and oil. Our main data source for NO_x emissions are DGXI, but we use the information in Corinair to disaggregate the figures further.

From Table 3.3.b we see that more than half of the total NO_x emissions in the E3ME area is caused by fuel combustion related to transport use (ES3). Most of this is due to road transport. We use the same procedure as indicated above for SO_2 emissions from ES3, i.e., link the emissions to the use of Middle Distillates (FR05) by the fuel users 12-15 in E3ME.

NO_x emissions from ES1, i.e. fuel combustion in energy and transformation industries, are linked to fuel use in Power Generation (main contributor for most countries) and output from energy industries in the same manner as for SO_2. However, the question of emission intensities for gas, coal and oil must be resolved here, too. In the reference technologies used by the ExternE project (EC 1995) the emission intensities (measured in g emitted per kWh produced) are actually almost equal for all the three fuels, gas, coal and oil. Thus, we give the use of gas, coal and oil (measured in toe) equal weights in the calculation of emissions from power generation.

For ES2 and ES4 we use the same procedure as for SO_2, assuming identical emission intensities for gas, coal and oil. Hence, emissions from ES2 will be linked to the sum of gas, coal and oil use in FU2-11, whereas emissions from ES4 will be linked to the corresponding sum in FU16-17.

NO_x emissions from the remaining sources are quite low, and are linked to the model in the same manner as for SO_2.

3.3.8 PM_{10}

Emissions of particulate matter are less identified than emissions of SO_2 and NO_x. The available data from Eurostat indicate that both transport use, other fuel combustion and industrial processes are important emission sources. For several countries the emission statistics are not complete, and for some countries we don't have any information at all. For the countries with no national emission levels reported by Eurostat, we let emission levels be zero.

Eurostat includes the category 'Power stations' in their inventory. These emissions are placed in our ES1, and linked to the use of coal and oil by the fuel user 'Power generation'. According to EC (1995) the emission intensities for the reference technologies used by the ExternE project were more than 10 times higher for coal than for oil (measured in g emitted per kWh produced). Thus, we give the use of coal 10 times higher weight than the use of oil (measured in toe) in the calculation of emissions from power generation.

'Industrial fuel combustion' and 'Other combustion' are also separate categories in Eurostat. These emissions are placed in ES2 and ES4, and linked to the model in the same manner as for SO_2 using the same assumption as above regarding emission intensities. As we don't have information to separate 'Other combustion' into residential and others, we only apply one activity variable for PM_{10} emission from ES4.

Mobile emissions, which are placed in ES3, are divided into road transport and other mobile sources. Hence, we use two activity variables here - total use of middle distillates by the fuel users 12 and 14-15, and use of middle distillates by fuel user 13.

Industrial processes are also singled out by Eurostat, and these emissions are placed in ES6. They are linked to the total use of intermediate products in the industries 2-5 and 8-22.

Eurostat also includes a category called 'Miscellaneous', where a fairly large share of total emissions is placed. For the moment these emissions are placed in our ES10, 'Other', and kept exogenous.

3.3.9 CO

Around two third of CO emissions come from road transport. Other fuel combustion and industrial processes are also important emission sources. Our main data source for CO-emissions are DGXI, but we use the information in Corinair to disaggregate the figures further.

Emissions of CO from transport use (ES3) are linked to the use of Middle Distillates (FR05) by the fuel users 12-15, as for e.g. NO_x above.

Emissions from fuel combustion in ES1-2 and ES4 are related to aggregate energy use by the relevant fuel users, in the same manner as for NO_x. We use total energy use since we don't have appropriate information about the emission intensities for different fuel types.

Emissions from industrial processes (ES6) are also important, and are linked to the model in the same manner as for NO_x.

Fugitive emissions (ES5) are linked to output in the industries 2-4, i.e. coal and oil & gas extraction and gas distribution. Emissions from agriculture (ES8) and waste (ES9) are linked in the same way as NO_x, which is also true for the last emission source (ES7).

3.3.10 NMVOC

The two most important emission sources for NMVOC are road transport and solvent use. However, fugitive emissions, combustion in residential plants, agricultural activity and industrial processes are also influential. Our main data source for NMVOC emissions are DGXI, but we use the information in Corinair to disaggregate the figures further.

Emissions from solvent and other product use (ES7) are linked to intermediate use of commodities in the construction industry (YRQ022) and the textile industry (YRQ017), and the output from the chemicals industry (QR10), based on the detailed information in Corinair.

Emissions of NMVOC from transport use (ES3) is linked to the use of Middle Distillates (FR05) by the fuel users 12-15, as for e.g. NO_x and CO above.

Emissions from fuel combustion in ES1-2 and ES4 are related to aggregate energy use by the relevant fuel users, in the same manner as for CO. We use total energy use since we don't have appropriate information about the emission intensities for different fuel types.

Fugitive emissions (ES5) are linked to output in industries 3-5, i.e. oil & gas extraction, gas distribution and refined oil (mainly gasoline distribution).

Emissions from the remaining sources (ES6-9) are linked to the model in the same manner as for e.g. NO_x and CO.

3.4 Changes in emission intensities over time

From equation 1 we see that two certain aspects are important for the projections of emissions: 1) The future growth rates of the economic variables, X, that generate emissions, and 2) The changes in emission intensities from the base year, γ, i.e. changes in the relationship between emissions and economic activity.

Without changes in emission intensities, i.e. $\gamma=1$ in all periods, a projection of future emission would typically be steadily rising over time, since most economic variables are expected to grow. Substitution possibilities between fuels may of course dampen this effect for some pollutants. However, in the future we will probably see major changes in emission intensities, due to a combination of new and cleaner technologies and explicit measures that will be implemented due to international protocols on emission reductions.

To see how the emission intensities have changed in the nearest past, we have calculated emission coefficients for 1990 and compared them with the coefficients in the baseyear 1994. In Table E.1 in Appendix E we report the average yearly exponential growth rates for the most important Emission Sources for each pollutant. Not surprisingly, the growth rates are negative for all greenhouse gases except HFC.

One alternative way of changing the emission intensities in the nearest future, is to extrapolate the growth rates for 1990-94 (with e.g. upper limits on the absolute growth rate). However, there are several reasons to believe that the growth rates in the past are not necessarily good indicators for the future growth rates, especially since the Kyoto protocol may strengthen the development of better clean-up technologies.

Another alternative may be to use available information in the literature or from other sources regarding the expected evolution of emission coefficients for important emission sources. This would require some more literature review. For instance, in Appendix D it is indicated how changes in waste production and treatment in Norway may change the relationship between consumption and industry input/output, and methane emissions over time. If similar information is available for other countries, e.g. how the share of landfilled waste compared to total waste changes, this could be used to shift the adjustment parameters over time.

In the present version of the model, a third alternative is chosen. For the greenhouse gases (except CO_2) we use projections of future emissions presented by the IPCC, whereas for the other pollutants we use an international protocol for future emissions of SO_2, NMVOC and NO_x. In both cases we calibrate the emission intensities so that the future emissions in the base case of the model are identical to the future emissions presented by IPCC and the protocol. Detailed description is given in the following subsections.

3.4.1. The non-CO_2 greenhouse gases.

The IPCC (1998) presents projected emissions of each greenhouse gas for individual countries. These are used to calibrate emission intensities in the E3ME model. The projections are national totals only, and not distributed on emission sources. For most countries the projections indicate substantial decreases for both CH_4 and N_2O, which are the two most important greenhouse gases next to CO_2. For SF_6 and PFC the projections are somewhat mixed, whereas HFC emissions are expected to rise by several hundred per cent for many countries. This is because HFC is about to replace CFC, as this compound is phased out.

The IPCC projections are reported for 2000, 2005, 2010 and 2020. Then linear interpolation is used to construct total emissions in the years between. If a country only reports emissions to e.g. 2005, exponential extrapolation is used to project the emissions in the following years. If reported emissions only exist for one year and no projections are available, emissions are kept constant in all periods.

In order to distribute total emissions on emission sources (ES), the model is first allowed to project emissions for each ES on the basis of fixed emission intensities ($\gamma = 1$). Then the resulting emissions are scaled to match the IPCC-projections for the nation as a whole. This means that changes in the percentage distribution of the emission on different emission sources will only be due to different growth rates of the economic variables in the E3ME model. This will probably give a quite distorted picture of the future distribution on emission sources, as technological improvements and changes in treatment are more feasible for some sources than for others. For instance, it is presumably easier to reduce the methane emission coming from landfilled waste than from the enteric fermentation in animals.

The are also several other problems regarding these projections. First of all it is somewhat difficult to understand the interpretation of them, i.e. are future measures with the intention of complying with the Kyoto protocol taken into account or not? In IPCC (1998), page 84, in the explanatory notes to the projection-tables, it is said that:

To the extent possible, the figures in the tables are taken from the "with measures" projections or from projection scenarios that best represent or reflect the implementation of measures.

However, the answer is not clear since IPCC (1998) is a summary of the different national communications to the Buenos Aires Conference in 1998. So there are reasons to believe that the projections for the different countries could be based on differences in assumptions and methodology, and to what degree the projections include specific measures. Still, it is most natural to consider the projections as 'with measures', so that carbon taxes within the E3ME model are parallel measures.

Another problem is the fact that for many countries there are no projections at all or projections to 2000 or 2005 only. This makes the projections even more unclear.

3.4.2. The five other pollutants

Over the last two decades, several protocols have been signed in Europe in order to reduce long range air pollution. Recently a new protocol has been signed, with emission ceilings for individual countries in 2010 for the three pollutants SO_2, NO_x and NMVOC (United Nations, 1999 - see Appendix G). These ceilings are used to calibrate the emission intensities in the E3ME model. Moreover, total emissions are linearly interpolated up to the ceilings in 2010, and exponentially extrapolated from 2010.

This procedure implicitly assumes that all countries will follow their commitments in the protocol. Several questions could of course be raised about this assumption, but these projections are at least better than using constant emission intensities as new clean-up technologies are continually developed.

There exist no international protocols for CO and PM_{10}. For these two pollutants we use the procedure mentioned in the beginning of section 3.4, i.e. using the growth rates in the period 1990-94. We use linear interpolation between the years, and exponential extrapolation after 1994. For some regions there are data for only one year for PM_{10}. Then total emissions are kept constant.

4 Model results

4.1. Results from the baseline forecast

4.1.1 Projected emissions of greenhouse gases

In Table 4.1 below we present the projected annual emissions of greenhouse gases in EU in 2008-12 in the E3ME baseline, and compare it with the emissions in the baseyear of the Kyoto protocol.[3] We see that CO_2 emissions are projected to increase by almost 9 per cent from 1990, whereas other greenhouse gases in total are projected to decrease dramatically, i.e., by 27 per cent. Remember that non-CO_2 GHG emissions in the baseline implicitly have incorporated policy measures. It is mainly emissions of the two most important gases besides CO_2, i.e., CH_4 and N_2O, that drop significantly. There is also a slight reduction in PFC emissions, whereas SF_6 and in particular HFC emissions are projected to rise. In total, greenhouse gas emissions in 2008-12 are projected to be almost the same as in the baseyear. However, this is dependent on the implementation of the expected measures against the non-CO_2 GHGs.

Table 4.1. Projected annual emissions in 2008 - 2012 of greenhouse gases in EU-15. Million tonnes of carbon-equivalents and percentage change from the baseyear specified in the Kyoto-protocol (1990 for CH_4 and N_2O. 1995 for HFC, PFC and SF_6).

	Base 1990/95	**Average 2008-12**	**Difference from base**
Carbon dioxide (CO_2)	877.0	953.4	8.7 %
Methane (CH_4)	132.1	102.1	-22.7 %
N_2O	106.7	66.7	-37.4 %
HFCs	8.4	9.9	17.0 %
PFCs	1.8	1.7	-2.7 %
SF_6	3.9	4.1	5.2 %
Non-CO_2 GHG	252.9	184.5	-27.0 %
All GHG	1,129.9	1,137.9	0.7 %

Source: E3ME project, E3ME22 C92F7BB, January 2000

In table 4.2 we show how the projected emissions of CO_2, non-CO_2 GHG and total greenhouse gases in EU are distributed on emission sources.[4] We see that CO_2 emissions from transport rise most, whereas CO_2 emissions due to fuel combustion in both energy and manufacturing industries fall significantly. CO_2 emissions from other fuel combustion rise somewhat more than the average emission growth.

Other greenhouse gas emissions decrease for all emission sources except ES7 (Solvent and other product use), where HFC is the main contributor. Large reductions take place in agriculture (CH_4 and N_2O), industrial processes (N_2O) and especially fugitive emissions (CH_4), whereas there is less

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[3] Note that emissions are measured in tonnes of carbon equivalents and not CO_2-equivalents in this section.

[4] Note that CO_2 emissions are only distributed on the first four emission sources, i.e., various fuel combustion.

reduction in emissions from waste (CH_4). Since the emission intensities are reduced in the same manner across the emission sources, these differences between the sources are due to structural effects in the economy. For instance, agricultural production and energy supply within the EU are increasing less rapidly than waste production. As pointed out in section 3.4.1, identical change in emission intensities is a simplification. For instance, it may be easier to implement measures against CH_4 emissions from landfills than from agriculture, as waste treatment quite easily may be changed. Hence, in reality emissions from waste may be reduced by more than indicated in the table, whereas emissions from agriculture may be reduced less.

Since CO_2 emissions are only coming from the first four emission sources and the other GHGs are mainly coming from the remaining sources, we get the same picture for total GHG emissions as described above for either CO_2 or non-CO_2 GHG emissions.

Table 4.2. Projected annual emissions in EU-15 in 2008-2012 by emission source (ES). Million tonnes of carbon-equivalents, and percentage change from the baseyear specified in the Kyoto-protocol.

	CO_2		Non-CO_2 GHG		Total GHG	
ES	Average 2008-12	Change from base	Average 2008-12	Change from base	Average 2008-12	Change from base
1. Fuel combustion: Energy Industries	286.0	-9.9 %	4.8	-27.0 %	290.8	-10.2 %
2. Fuel combustion: Manufacturing Industries and Construction	138.9	-16.8 %	2.0	-48.9 %	140.9	-17.6 %
3. Fuel combustion: Transport	302.8	55.3 %	6.4	-6.5 %	309.2	53.2 %
4. Other fuel combustion	225.7	14.2 %	2.6	-63.4 %	228.3	11.4 %
5. Fugitive Emissions from Fuels	0	0.0 %	19.2	-36.6 %	19.2	-36.6 %
6. Industrial Processes	0	0.0 %	24.8	-26.9 %	24.8	-26.9 %
7. Solvent and Other Product Use	0	0.0 %	10.5	13.5 %	10.5	13.5 %
8. Agriculture	0	0.0 %	81.0	-31.6 %	81.0	-31.6 %
9. Waste	0	0.0 %	33.0	-9.5 %	33.0	-9.5 %
10.Other	0	0.0 %	0.2	*	0.2	*
TOTAL	**953.4**	**8.7 %**	**184.5**	**-27.0 %**	**1137.9**	**0.7 %**

Source: E3ME project, E3ME22 C92F7BB, January 2000

In Table 4.3 we present the projection of CO_2 and non-CO_2 GHG emissions distributed on regions in the E3ME model. There are huge differences between the regions. CO_2 emissions are increasing in all regions except Germany-east, Luxembourg and Switzerland. The highest increase is seen in two of the Nordic countries (Sweden and Finland) and some of the southern regions (Portugal, Italy-south and Spain).

Emissions of other greenhouse gases are decreasing in most countries (not in Italy, Austria, Spain, Portugal and Norway). In some countries these emissions are halved (i.e., Greece, United Kingdom and France). These differences may indicate that the methodological problems related to the IPCC projections discussed in chapter 3.4.1 are real, i.e. that not all countries have reported projected emissions *with* measures to the IPCC.

Although total GHG emissions in the E3ME area (EURO-19) are more or less unchanged from the baseyear, some regions experience significant changes. In Sweden and Portugal total GHG emissions are increasing by 57 and 41 per cent, respectively. For Sweden this is due to a replacement of nuclear by fossil fuels in electricity generation. On the other hand, in France and the United Kingdom emissions are falling by 10 and 7 per cent, respectively (even higher reductions are found for Germany-east and Luxembourg).

Table 4.3. Projected annual GHG emissions in 2008-2012 by region. Million tonnes of carbon-equivalents and percentage changes from the baseyear.

	CO_2		Non-CO_2 GHG		Total GHG	
	Average 2008-12	Change from base	Average 2008-12	Change from base	Average 2008-12	Change from base
Belgium	30.8	3.3 %	5.8	-11.9 %	36.5	0.6 %
Denmark	17.1	18.2 %	4.5	-16.8 %	21.6	8.7 %
Germany (east)	53.4	-34.3 %	7.3	-44.6 %	60.7	-35.7 %
Germany (west)	212.0	13.7 %	26.9	-34.0 %	238.9	5.2 %
Greece	22.2	12.6 %	2.3	-53.8 %	24.5	-0.9 %
Spain	70.9	20.8 %	22.5	9.8 %	93.3	18.0 %
France	111.6	8.2 %	21.9	-51.1 %	133.5	-9.8 %
Ireland	10.7	17.7 %	6.9	-2.7 %	17.6	8.7 %
Italy (north)	93.9	6.5 %	21.5	15.5 %	115.3	8.1 %
Italy (south)	32.8	41.3 %	11.6	27.5 %	44.3	37.4 %
Luxembourg	1.8	-39.1 %	0.2	-20.4 %	2.0	-37.8 %
Netherlands	45.5	3.5 %	13.1	-19.2 %	58.6	-2.6 %
Portugal	17.8	57.1 %	6.5	9.7 %	24.2	40.9 %
United Kingdom	169.2	6.0 %	23.1	-51.9 %	192.3	-7.4 %
Austria	16.8	3.5 %	4.0	15.2 %	20.8	5.5 %
Finland	21.2	43.1 %	3.3	-11.3 %	24.5	32.3 %
Sweden	25.9	80.5 %	3.3	-23.2 %	29.2	56.6 %
Norway	8.6	6.2 %	4.2	9.8 %	12.9	7.4 %
Switzerland	11.7	-3.0 %	2.5	-2.6 %	14.2	-2.9 %
EURO-19	**973.7**	**8.5 %**	**191.3**	**-26.2 %**	**1165.0**	**0.7 %**

Source: E3ME project, E3ME22 C92F7BB, January 2000

The Kyoto protocol states that the EU should reduce its GHG emissions by 8 per cent compared to the baseyear (1990/1995). Since total GHG emissions in EU are increasing by 0.7 per cent in the baseline forecast (see Table 4.1), these emissions have to be reduced by 8.7 per cent from the baseline level in 2008-12. Given that the baseline projections already include measures against the 5 GHG other than CO_2, this reduction should take place through measures against CO_2 only (some indirect effects on e.g.

CH_4 and N_2O emissions may come in addition from CO_2 measures). Analyses of such measures are presented in the next section.

Here we want to dwell on the burden sharing across the member states of EU. If the percentage reduction from the baseyear is chosen to be 8 per cent for all regions, the countries with highest growth in GHG emissions will have to implement the toughest measures against CO_2 emissions. As indicated above, this is mainly Sweden and Portugal. On the other hand, France does not need to implement any measures against CO_2 according to the projections (the United Kingdom and Germany are almost there).

However, the reductions may be shared in another way, e.g., as suggested by the Council of EU environment ministers (1998) (referred to as 'EC burden sharing'). This is shown in the last column of Table 4.4. Then the needed measures against CO_2 emissions change across the regions. Comparing column 3 and 6 in the table shows that Sweden is still most far from their target, whereas several countries no longer need to implement measures against CO_2 emissions (i.e., France, Greece, Ireland and Luxembourg). However, this depends crucially on the validity of the IPCC projection of the non-CO_2 emissions, and of course on the validity of the E3ME model.

Another burden sharing rule could be obtained based on the E3ME baseline, i.e., by applying the same percentage reduction from the base level in 2008-2012 across the countries (achieving the overall Kyoto target in EU). This rule is called 'Equal shares', and is displayed in column 5 of Table 4.4. We see that there are large differences between the two burden sharing rules in column 5 and 6. The rule 'Equal shares' naturally favours the countries that are farthest away from their target in the baseline (especially Sweden), and is disadvantageous for countries with expected reductions in GHG emissions. As the E3ME baseline is based on projections by the IPCC, presumably with policy measures against non-CO_2 GHGs included for some but not all countries, this rule may seem unfair.

Finally, in column 4 of Table 4.4 the effect of a multilateral carbon tax in the EU is shown, that reduces GHG emissions by 8 per cent compared to the baseyear. In this case the burden sharing rule is irrelevant, except for the trade effects that occur if the member states are required to buy and sell emission quotas from each other. We see that this outcome is much closer to the 'Equal share' than to the 'EC Burden sharing' rule, as should be expected. This and other policy scenarios are discussed in the next section.

Table 4.4. Comparison of changes in GHG emissions in EU member states in E3ME baseline, E3ME carbon tax scenario and two burden sharing rules ('Equal shares' and 'EC Burden sharing').

	EC base	E3ME base		EU carbon tax	Equal shares	EC Burden sharing
	1990	1990/95	2008-12			
	Mill. tonnes carbon-eq.		Percentage change from baseyear			
Austria	20.2	19.7	5.5 %	-8.2 %	-3.6 %	-13.0 %
Belgium	37.9	36.3	0.6 %	-11.8 %	-8.1 %	-7.5 %
Denmark	19.6	19.8	8.7 %	-10.8 %	-0.7 %	-21.0 %
Finland	19.9	18.5	32.3 %	19.3 %	20.9 %	0.0 %
France	173.7	148.0	-9.8 %	-19.5 %	-17.6 %	0.0 %
Germany	327.5	321.6	-6.9 %	-13.3 %	-14.9 %	-21.0 %
Greece	28.4	24.7	-0.9 %	-0.3 %	-9.5 %	25.0 %
Ireland	15.5	16.2	8.7 %	1.4 %	-0.7 %	13.0 %
Italy	147.8	139.0	14.9 %	4.0 %	5.0 %	-6.5 %
Luxembourg	3.8	3.2	-37.8 %	-42.2 %	-43.2 %	-28.0 %
Netherlands	56.7	60.1	-2.6 %	-10.6 %	-11.0 %	-6.0 %
Portugal	18.8	17.2	40.9 %	39.5 %	28.7 %	27.0 %
Spain	82.1	79.1	18.0 %	-1.7 %	7.8 %	15.0 %
Sweden	18.8	18.7	56.6 %	46.9 %	43.0 %	4.0 %
United Kingdom	211.4	207.8	-7.4 %	-12.7 %	-15.4 %	-12.5 %
Total EU	**1,187.2**	**1,129.9**	**0.7 %**	**-8.0 %**	**-8.0 %**	**-8.0 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

4.1.2 Projected emissions of the 5 other pollutants

In table 4.5 we show the projected emissions in 2008-12 in EU-15 of the five pollutants SO_2, NO_x, PM_{10}, CO and NMVOC. The projection indicates a dramatic fall in emissions of these pollutants. This is due to the ceilings for SO_2, NO_x and NMVOC stated in the recent protocol on long range transboundary air pollution (United Nations, 1999), and to the extrapolation of the reduced emission intensities in the period 1990-94 for PM_{10} and CO (see section 3.4.2). SO_2 emissions are projected to fall by 75 per cent, whereas emissions of the other four pollutants are more or less halved, according to the projection. From Appendix G, where the obligation of the protocol is displayed, we see that there are big differences between the countries. For instance, Germany and the United Kingdom, the two largest countries measured in emission level in 1990, have obliged to reduce SO_2 emissions by more than 80 per cent. At the other extreme, Greece is allowed to increase its emissions.

The major drop in these emissions has implication for the potential of secondary benefits due to indirect reduction in SO_2, NO_x and PM_{10} emissions, when carbon taxes or other measures against CO_2 emissions are introduced. This topic is discussed in Working paper 9c (Rosendahl, 2000).

Table 4.5. Projected annual emissions in 2008 - 2012 of air pollutants in EU-15. 1,000 tonnes and percentage change from 1990.

	Base 1990	Average 2008-12	Difference from base
Sulphur dioxide (SO_2)	16,436	4,204	-74.4%
Nitrogen oxides (NO_x)	13,161	6,648	-49.5%
Carbon monoxide (CO)	50,155	28,917	-42.3%
Particulates (PM_{10})	3,575	2,143	-40.1%
VOCs (NMVOC)	15,334	6,633	-56.7%

Source: E3ME project, E3ME22 C92F7BB, January 2000

4. 2. Scenario analyses

According to the baseline projection of the E3ME model, greenhouse gas emissions in EU are projected to increase by 0.7 per cent from the baseyear in the Kyoto protocol until 2008-12. In the protocol EU obliged to reduce these emissions by 8 per cent. Hence, if we ignore the possibility of emissions trading (and other flexible mechanism) between EU member states and other countries, GHG emissions have to be reduced by 8.7 per cent from its baseline level in 2008-2012, according to the E3ME model. Since measures against the five non-CO_2 GHGs are already incorporated into the baseline of the model, this reduction will most naturally take place by introducing measures against CO_2 emissions. These measures may be e.g. carbon taxes or a permit scheme for CO_2 emissions (or a combination of these). We focus on multilateral solutions, i.e. equal carbon taxes across the member states or a free market of emission permits within the EU. Unilateral solutions would probably lead to very different carbon taxes or permit prices between the countries, especially if the 'EC burden sharing' or an 8 per cent reduction from baseyear for all countries are chosen (see the discussion above).

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).[5] 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.

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[5] 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.

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. *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.

The differences between the scenarios are rather small when it comes to emissions, as is seen below. In all scenarios all emitters of CO_2 are facing the same shadow price of CO_2 emissions. Hence, the choice of scenario is more important for prices and profits in the different sectors, and for GDP and employment levels. Consequently we will not go much into the differences between the scenarios, except in the discussion of macroeconomic effects.

In Table 4.6 we show the impact of the mitigation scenarios on emissions in EU-15 in 2008-12. Note that all scenarios reduce GHG emissions by 8.6-8.7 per cent, which is sufficient to comply with the Kyoto requirement. Moreover, CO_2 emissions are reduced by just above 10 per cent in all scenarios. Emissions of the other greenhouse gases are also somewhat affected by the measures against CO_2 emissions. N_2O emissions fall by around 2 per cent, due to reduced fuel combustion. CH_4 emissions increase by up to 2 per cent in three of the scenarios, and decrease less than one per cent in the fourth scenario. This effect is partly related to the impact on GDP (see below), which has further impact on both waste and agricultural production, but also to the supply of energy. The other three GHGs are only marginally affected. Overall, non-CO_2 GHG emissions fall by up to 1.2 per cent in two of the scenarios, and rise by up to 0.6 per cent in the two other. Thus, there are indirect effects from CO_2 mitigation on other GHG emissions, but the overall effect is both small and ambiguous.

In Table 4.6 we also see that emissions of the five other pollutants are more responsive to the CO_2 mitigation than the five non-CO_2 GHGs. Especially SO_2 and NO_x emissions are reduced significantly - SO_2 emissions are in fact reduced far more than CO_2 emissions. The large reduction in these pollutants is of course explained by the fact that both CO_2, SO_2 and NO_x emissions are mainly related to the use of fossil fuels. In particular, if there is a shift from coal or oil towards gas, CO_2 emissions are less than halved, whereas SO_2 emissions are completely reduced.

Table 4.6. Projected annual emissions in 2008-2012 in EU-15 (million tonnes - GHGs are measured in carbon equivalents), and percentage change from baseline in four mitigation scenarios.

	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
Carbon dioxide (CO_2)	953.4	-10.4 %	-10.1 %	-10.2 %	-10.4 %
Methane (CH_4)	102.1	1.9 %	-0.5 %	0.2 %	1.4 %
N_2O	66.7	-1.4 %	-2.4 %	-2.1 %	-1.6 %
HFCs	9.9	0.1 %	-0.1 %	-0.1 %	0.1 %
PFCs	1.7	0.3 %	0.0 %	0.0 %	0.2 %
SF_6	4.1	0.3 %	-0.1 %	-0.2 %	0.2 %
Non-CO_2 GHG	184.5	0.6 %	-1.2 %	-0.6 %	0.2 %
All GHG	1,137.9	-8.6 %	-8.7 %	-8.7 %	-8.7 %
Sulphur dioxide (SO_2)	4.2	-16.6 %	-16.0 %	-16.2 %	-15.5 %
Nitrogen oxides (NO_x)	6.6	-8.9 %	-8.5 %	-8.9 %	-8.9 %
Carbon monoxide (CO)	28.9	-4.8 %	-4.6 %	-5.1 %	-5.0 %
Particulates (PM_{10})	2.1	-4.7 %	-4.6 %	-4.6 %	-4.8 %
VOCs (NMVOC)	6.6	-2.7 %	-2.8 %	-3.0 %	-2.9 %

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

In Table 4.7 we display how the total GHG emissions in EU are reduced in the 10 emission sources. As expected, emissions from the four fuel combustion sources are reduced most. This is mainly related to CO_2 emissions. Transport emissions are least reduced, as transport use is less responsive to price changes than other fuel users. Emissions from the other sources are only coming from the non-CO_2 GHGs. These emissions are mostly increased, except in the scenario 'Permits+profits'. Emissions from these sources seem to vary closely with the change in GDP (see below).

Table 4.7. Projected annual GHG emissions in 2008-2012 in EU-15 (million tonnes carbon equivalents) distributed on emission sources, and percentage change from baseline in four mitigation scenarios.

ES	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
1. Fuel combustion: Energy Industries	-13.3	-13.7 %	-13.6 %	-13.2 %	-13.3 %
2. Fuel combustion: Manufacturing Industries and Construction	-14.6	-16.0 %	-15.4 %	-15.2 %	-14.6 %
3. Fuel combustion: Transport	-7.1	-6.9 %	-6.0 %	-6.9 %	-7.1 %
4. Other fuel combustion	-8.6	-7.7 %	-8.3 %	-8.1 %	-8.6 %
5. Fugitive Emissions from Fuels	4.3	5.9 %	-1.0 %	1.4 %	4.3 %
6. Industrial Processes	0.4	0.5 %	-0.1 %	0.1 %	0.4 %
7. Solvent and Other Product Use	0.1	0.1 %	-0.1 %	-0.1 %	0.1 %
8. Agriculture	1.3	1.7 %	0.0 %	0.5 %	1.3 %
9. Waste	1.0	1.2 %	0.0 %	0.1 %	1.0 %
10.Other	0	0.0 %	0.0 %	0.0 %	0.0 %
TOTAL	**-8.7**	**-8.6 %**	**-8.7 %**	**-8.7 %**	**-8.7 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

The effect on CO_2 emissions from different fuel demand is presented in Table 4.8. It seems that emissions from the use of coal and heavy oil are mostly reduced, i.e., by more than 20 per cent. The explanation for this is the high carbon content of coal, and that heavy oil is quite easily substituted by other fuel types. Emissions from using coke are also reduced quite much due to a high carbon content. CO_2 emissions from using gas or middle distillates are less reduced. The carbon content of gas is less than that of coal and oil. The modest reduction in middle distillates has to do with that this fuel type is used in transportation, which is less price responsive than other activities.

Table 4.8. **Projected annual CO_2 emissions in 2008-2012 in EU-15 (million tonnes) distributed on fuel types, and percentage change from baseline in four mitigation scenarios.**

	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
Coal	128.3	-22.9 %	-21.7 %	-21.6 %	-22.3 %
Coke	23.3	-14.1 %	-13.3 %	-12.9 %	-12.9 %
Lignite	57.5	-0.3 %	-1.0 %	-0.7 %	-0.5 %
Heavy Fuel Oil	74.0	-25.2 %	-24.0 %	-24.2 %	-22.1 %
Middle Distillates	390.9	-6.0 %	-5.4 %	-6.1 %	-6.3 %
Natural Gas	226.8	-8.8 %	-9.5 %	-9.0 %	-9.6 %
Derived Gas	52.5	-8.6 %	-8.7 %	-8.1 %	-8.1 %
Electricity	0	0.0 %	0.0 %	0.0 %	0.0 %
Nuclear Fuels	0	0.0 %	0.0 %	0.0 %	0.0 %
Crude Oil	0	0.0 %	0.0 %	0.0 %	0.0 %
Steam	0	0.0 %	0.0 %	0.0 %	0.0 %
Total	**953.4**	**-10.4 %**	**-10.1 %**	**-10.2 %**	**-10.4 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

Table 4.9 shows how the total GHG emissions in each region of E3ME are changed compared to baseline in the four mitigation scenarios. We see that the emissions are most responsive to the carbon policy in Denmark and Spain, but also fairly responsive in Belgium, Austria, Italy-north and France. GHG emissions in Greece, Portugal, Italy-south and Norway are only slightly reduced - in Greece emissions are actually marginally increasing in the carbon tax scenario. These regional differences are related to the energy structure in the various regions, especially the possibilities to substitute away from carbon-intensive fuels. For instance, Denmark has a coal-intensive electricity production, and may quite easily switch over to using gas or carbon-free energy. On the other hand, Norway has a fossil-free electricity production, and thus this option is not available.

Table 4.9. Projected annual GHG emissions in 2008-2012 in Euro-19 (million tonnes carbon equivalents) distributed on regions, and percentage change from baseline in four mitigation scenarios.

	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
Belgium	36.5	-12.4 %	-11.7 %	-10.7 %	-12.3 %
Denmark	21.6	-17.9 %	-16.9 %	-16.7 %	-17.6 %
Germany (east)	60.7	-6.2 %	-6.1 %	-5.7 %	-6.7 %
Germany (west)	238.9	-7.1 %	-7.2 %	-6.8 %	-7.6 %
Greece	24.5	0.6 %	-1.8 %	-3.9 %	-0.6 %
Spain	93.3	-16.7 %	-17.3 %	-17.1 %	-15.8 %
France	133.5	-10.8 %	-10.1 %	-10.8 %	-10.7 %
Ireland	17.6	-6.8 %	-6.7 %	-6.7 %	-6.2 %
Italy (north)	115.3	-11.9 %	-11.1 %	-11.4 %	-11.3 %
Italy (south)	44.3	-3.2 %	-3.9 %	-3.1 %	-3.1 %
Luxembourg	2.0	-7.0 %	-7.8 %	-9.5 %	-7.9 %
Netherlands	58.6	-8.3 %	-8.9 %	-8.6 %	-8.5 %
Portugal	24.2	-1.0 %	-2.0 %	-2.0 %	-1.4 %
United Kingdom	192.3	-5.7 %	-5.9 %	-6.1 %	-5.8 %
Austria	20.8	-13.0 %	-12.3 %	-11.6 %	-12.2 %
Finland	24.5	-9.9 %	-10.2 %	-10.4 %	-9.8 %
Sweden	29.2	-6.2 %	-5.9 %	-6.2 %	-6.2 %
Norway	12.9	-4.1 %	-4.5 %	-4.6 %	-4.1 %
Switzerland	14.2	-5.1 %	-5.4 %	-5.6 %	-5.1 %
EURO-19	**1,165**	**-8.5 %**	**-8.6 %**	**-8.6 %**	**-8.6 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

Table 4.10 shows the corresponding results for CO_2 emissions. Since these emissions are the main target of the policy, we would expect the regional differences in Table 4.9 to be reproduced here. This is largely correct. CO_2 emissions in Denmark and Spain are reduced by more than 20 per cent, whereas emissions in Greece, Portugal and Italy-south are reduced by less than five per cent in all scenarios.

Table 4.10. Projected annual CO_2 emissions in 2008-2012 in Euro-19 (million tonnes) distributed on regions, and percentage change from baseline in four mitigation scenarios.

	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
Belgium	30.8	-14.6 %	-13.6 %	-12.5 %	-14.5 %
Denmark	17.1	-22.8 %	-21.1 %	-21.2 %	-22.3 %
Germany (east)	53.4	-7.0 %	-7.0 %	-6.5 %	-7.6 %
Germany (west)	212.0	-7.9 %	-8.0 %	-7.6 %	-8.4 %
Greece	22.2	0.4 %	-1.8 %	-4.1 %	-0.8 %
Spain	70.9	-23.0 %	-21.8 %	-22.2 %	-21.4 %
France	111.6	-13.2 %	-12.0 %	-12.9 %	-13.1 %
Ireland	10.7	-11.0 %	-10.4 %	-10.6 %	-10.1 %
Italy (north)	93.9	-14.3 %	-13.1 %	-13.4 %	-13.5 %
Italy (south)	32.8	-4.1 %	-4.8 %	-3.9 %	-3.9 %
Luxembourg	1.8	-7.9 %	-8.5 %	-10.5 %	-8.8 %
Netherlands	45.5	-10.9 %	-11.4 %	-11.1 %	-11.1 %
Portugal	17.8	-1.5 %	-2.6 %	-2.6 %	-2.0 %
United Kingdom	169.2	-6.8 %	-6.8 %	-7.1 %	-6.9 %
Austria	16.8	-16.3 %	-15.3 %	-14.4 %	-15.3 %
Finland	21.2	-11.4 %	-11.6 %	-11.9 %	-11.3 %
Sweden	25.9	-6.6 %	-6.2 %	-6.6 %	-6.6 %
Norway	8.6	-6.2 %	-6.5 %	-6.8 %	-6.1 %
Switzerland	11.7	-6.0 %	-6.4 %	-6.6 %	-6.1 %
EURO-19	**973.7**	**-10.3 %**	**-10.0 %**	**-10.1 %**	**-10.3 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

In Table 4.11 we show the change in non-CO_2 GHGs in selected parts of EU. From above we know that the overall effects in EU on these emissions are almost negligible (i.e., less than 1.2 per cent change). The regional effects seem to be somewhat bigger, but not much. In United Kingdom non-CO_2 GHG emissions are increased in all scenarios by up to 2.3 per cent; in Italy they are reduced in all scenarios by up to 2 per cent.

Table 4.11. Projected annual non-CO_2 GHG emissions in 2008-2012 (million tonnes carbon equivalents) in selected regions of EU, and percentage change from baseline in four mitigation scenarios.

	Base	Carbon tax	Permits + profits	Permits + prices	Mixed policies
Germany	34.2	-0.7 %	-1.1 %	-0.7 %	-0.8 %
France	21.9	1.8 %	-0.6 %	0.0 %	1.4 %
Spain	22.5	3.2 %	-3.0 %	-1.0 %	1.8 %
Italy	33.0	-1.4 %	-2.0 %	-1.8 %	-1.4 %
United Kingdom	23.1	2.3 %	0.2 %	0.7 %	1.9 %
Rest of EU-15	49.8	0.3 %	-0.7 %	-0.5 %	0.0 %
Eurozone EMU-11	151.3	0.4 %	-1.3 %	-0.8 %	0.0 %
non-EMU4	33.3	1.6 %	-0.4 %	0.1 %	1.1 %
EU-15 (EU)	**184.5**	**0.6 %**	**-1.2 %**	**-0.6 %**	**0.2 %**

Source: E3ME project, E3ME22 C92F7B GHG, January 2000

In Table 4.4 in section 4.1.1 we displayed how the outcome of the carbon tax scenario compares to various burden sharing rules for the member states of EU. From Table 4.9 above we saw that the outcome of the different policy scenarios were quite similar when it comes to GHG emission reductions. Thus, given that a multilateral carbon tax or a free market of emission permits within the EU is combined with an initial emission quota allocation based on a specific burden sharing rule, Table 4.4 may give useful information about the trade flows of permits within the EU.

First we look at the case where the Kyoto requirement is equal for all member states, that is, all countries must reduce GHG emissions by 8 per cent compared to the baseyear. The we see directly from column 4 in Table 4.4 that Sweden, Portugal, Finland, Italy and Ireland all must buy significant amounts of emission permits, as their GHG emissions are increasing compared to 1990/95 in the carbon tax scenario. On the other hand, Luxembourg, France, Germany and the United Kingdom will become sellers of permits, as their emissions are reduced by more than 12 per cent from the baseyear. Measured in terms of trade volumes, Germany and France will both be involved in more than one third of the total trade in EU (as sellers), whereas Italy will buy more than one third of the traded permits and Sweden one fifth.

If the suggestion from the EU environment ministers is chosen (called 'EC Burden sharing'), we must compare column 4 and 6 in Table 4.4. Then we see that Sweden, Finland, Denmark, Italy and Germany will become significant buyers of permits. For Denmark and Germany, the reason is that these two countries (together with Luxembourg) have agreed to reduce their emissions more than other member states. France, Greece, Spain and Ireland may sell large amounts of permits under this rule. In terms of trade volumes, France and Germany will both be involved in about half of the permit exchange, as respectively seller and buyer of permits within the EU. Italy (buyer) and Spain (seller) will also be large players in this market.

Finally, if we choose the last burden sharing rule called 'Equal shares', total trade volumes decrease by around two third compared to the other two rules. The reason is of course that the burden sharing is determined as equal percentage reduction from the baseline in 2008-12. In this case, countries where carbon taxes have a responsive effect on total GHG emissions will become sellers of permits, and vice versa for countries with more rigid emission levels. Consequently, the findings in Table 4.9 should be found in Table 4.4 as well. That is, Greece and Portugal must buy significant amounts of emission permits in this case, whereas Denmark and Spain will become sellers of permits. In terms of trade volumes, however, the United Kingdom and Germany will be the largest buyers of permits with each buying one third of total purchases. Spain will provide almost half the supply of permits, and France one sixth.

To conclude this burden sharing discussion, the choice of rule is very important for the member states. Total trade volumes constitute about 5 per cent of total GHG emissions in the baseyear in the two first-mentioned rules. For some countries one rule means that they will be significant sellers, whereas another rule implies that they become substantial buyers of permits.

Table 4.12 displays the macroeconomic effects of the four mitigation scenarios in EURO-19 in 2010. First of all, the tax rates and permit prices are shown. We see that these lie between 172 and 192 (1990) Euro per tonne carbon. The permit price in the two permit scenarios is lower than the tax rate (and permit price) in the two other scenarios. This is related to the impact on GDP, as we will see below.

GDP effects are 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. This is not surprising. Using carbon taxes instead of grandfathered permits gives higher revenues, which is used to reduce distortionary taxes in the economy (i.e., employer's contribution to social security). The GDP effect in the mixed policy is between the others, which is unsurprisingly. Reducing prices seems to give a better outcome than increasing profits in the sectors that receive emission permits. This is also as expected, as lower prices in general have a positive impact on GDP.

Consequently, there are certainly opportunities for double dividends of reducing CO_2 emissions in the EU, according to the E3ME model, as long as the appropriate policy is chosen. However, there may be important regional difference between the countries, especially if the chosen burden sharing is far from the outcome of the multilateral scenarios.

Since GDP is lower in the two permit scenarios, lower prices on CO_2 emissions are needed to reach the target. This explains the variation mentioned above.

Table 4.12. 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

Finally, we want to point out how important the inclusion of 6 greenhouse gases is for the EU, compared to a situation where CO_2 emissions alone were required to be reduced by 8 per cent from 1990. In the mitigation scenarios above, CO_2 emissions are reduced by merely 2-3 per cent from 1990, or by around 10 per cent from baseline. The reason is of course the dramatic fall in emissions of the other 5 GHGs. Reducing CO_2 emissions by 8 per cent from 1990 would obviously have required much tougher policy measures than the implication of the Kyoto protocol.

Since most other studies have focused on CO_2 emissions only due to lack of information of the other GHGs, our analyses suggest that these studies may have overestimated the costs and policy measures needed to comply with the Kyoto protocol.

5 Conclusions and Policy Implications

5.1 Conclusions

Including all six greenhouse gases is important in analyses of the impacts of the Kyoto protocol. In this paper we have described how the 5 non-CO_2 GHG, as well as 5 other pollutants, have been implemented into the E3ME model, and we have presented the first analyses based on the extended model.

To implement emissions calculations into the E3ME model, we have first divided the emissions into 10 different emission sources, in correspondence with our main data source DG XI (European Commission, 1999). To complement this data source, we have also used data from IPCC, CORINAIR and Eurostat among others. Emissions data in the baseyear for each gas, country and source have been linked to one or several economic variables in the model by fixed coefficients. However, these coefficients are changed over time to reflect technological change etc. For the 5 non-CO_2 GHG we have used national projections presented by IPCC for different years to calibrate the coefficients in future years (these projections are mainly based on new, expected policy measures). For SO_2, NO_x and VOC we have used the outcome of a recent European protocol for transboundary air pollution. Hence, in the baseline projection of the E3ME model several expected policy measures are implicitly included for these 8 gases. For PM_{10} and CO we have extrapolated the change in the emission coefficients from 1990 to 1994.

According to the Kyoto protocol the EU countries are required to reduce their total annual GHG emissions in the period 2008-2012 by 8 per cent compared to the baseyear (mainly 1990). In the baseline scenario of the E3ME model emissions of greenhouse gases other than CO_2 fall by 27 per cent over the same period. CO_2 emissions increase by 9 per cent. This means that total greenhouse gas emissions increase by 1 per cent before any measures against CO_2 emissions are introduced. The largest increase is in Sweden and Portugal, whereas the projections indicate major reductions in e.g. France and the United Kingdom.

The EU ministers have suggested a certain differentiation across the countries of the required reduction in the Kyoto protocol. Following that suggestion implies that Sweden will be most far from their target according to the model baseline, whereas several countries do not have to implement measures against CO_2 (e.g., France, Greece and Ireland). The choice of burden sharing is important for the trade of permits within the EU.

In order to achieve the 8 per cent reduction in GHG emissions, CO_2 emissions have to be reduced by merely 2-3 per cent compared to the 1990 level since other GHG emissions drop significantly. This means 10 per cent reduction compared to baseline. It is obvious that an 8 per cent reduction (from the baseyear) in CO_2 emissions alone would have required much tougher policy measures than in the case of the Kyoto protocol, where 6 greenhouse gases are treated together.

The paper has presented the results of four mitigation scenarios that fulfil the Kyoto requirement. It seems that if a multilateral carbon tax is introduced within the EU, with tax revenues recycled through reductions in pay-roll taxes, the overall GDP and employment effects in EU is slightly positive. If grandfathered permits are used instead, there seems to be a marginal reduction in GDP and employment. Hence, there are opportunities for double dividends of the carbon policy.

The necessary carbon taxes or permit prices lie between 172 and 192 (1990) Euro/ton carbon.

The carbon taxes or permit scheme lead to reduction of CO_2 emissions of about 10 per cent. Other greenhouse gas emissions are only slightly changed; CH_4 and N_2O emissions are either decreased or increased by up to 2 per cent. Emissions of other pollutants like SO_2 and NO_x are, however, significantly reduced.

References

Alfsen, K., T. Bye and E. Holmøy (eds.) (1996): *MSG-EE: An Applied General Equilibrium Model for Energy and Environmental Analyses*, Social and Economic Studies 96, Statistics Norway.

Bruvoll, A. and T. Bye (1998): Methane emissions and permit prices for greenhouse gases, *Economic Survey* **8**, 31-40 (Statistics Norway).

Bruvoll, A. and K. Ibenholt (1997): Future waste generation. Forecasts based on a macroeconomic model, *Resources, Conservation and Recycling* **19**, 137-49.

Camner, Per (ed.): *Particles in the ambient air as a risk factor for lung cancer.* Swedish Environmental Protection Agency, Report no. 4804.

Council of EU environment ministers (1998): Official communiqué from the 2106th Council meeting, Luxembourg, 16-17 June 1998.

Corinair 90: http://www.aeat.co.uk/netcen/corinair/corinair.html

Corinair 94: http://www.aeat.co.uk/netcen/corinair/94/

Departement für Umwelt, Verkehr, Energie und Kommunikation (1999): Swiss National Greenhouse inventory 1990-1997. Departement für Umwelt, Verkehr, Energie und Kommunikation, Switzerland.

European Commission (1995): *ExternE: Externalities of Energy*, Vol. 1-6, European Commission, DGXII, Science, Research and Development, JOULE.

European Commission (1998): *Second communication from the European Community under the UN framework convention on climate change*, European Commission, DG XI.

European Commission and EEA (1999): *Annual European Community Greenhouse Gas Inventory 1990-1996.* European Commission, DGXI, and European Environment Agency (EEA).

EUROSTAT : http://europa.eu.int/new_cronos/

Gielen, D. and T. Kram (1988): *The role of non-CO_2 Greenhouse Gases in meeting Kyoto Targets.* OECD Experts Workshop on Climate Change and Economic Modelling: Background Analysis for the Kyoto Protocol. Paris, 17-18 September 1998.

Harnisch, J., I.S. Wing, H. Jacoby and R. Prinn (1998): *Primary aluminium production: Climate policy, emissions and costs*, Report No. 44, MIT Joint Program on the Science and Policy of Global Change, Cambridge: MIT.

IPCC (1995): *IPCC Guidelines for national greenhouse gas inventories.*

IPCC (1996): *Revised 1996 guidelines for national greenhouse gas inventories: Reference Manual*, Chap. 6.

Maiss, M. and C. Brenninkmeijer (1998): Atmospheric SF_6: Trends, sources, and prospects, *Environmental Science & Technology* **32**, 20, 3077-3086.

Norconsult (1999): *Utvikling av beregningsmodell for netto utslipp av metangass fra norske deponier, historiske og framtidige utslippsmengder (Development of a simulation model for net emissions of methane from Norwegian landfills, historical and future emissions)*, March 1999, revision 2.

Reilly, J., R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov and C. Wang (1999): Multi-Gas Assesment of the Kyoto Protocol, *Nature* **401**, 549-555.

Rosendahl, K.E. (2000): Industrial benefits and costs of greenhouse gas abatement strategies: Applications of E3ME. Modelling external secondary benefits in the E3ME model, Working Paper No 9c, Cambridge Econometrics, UK.

Statistics Norway (1999): *Natural Resources and the Environment 1999.* Statistics Norway.
UNFCCC (1997): *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. 1997

United Nations (1998): *Tables of inventories of anthropogenic emissions and removals of greenhouse gases for 1990-1995 and projections up to 2020.* United Nations, Framework Convention on Climate Change, Conference of the Parties to Fourth Session in Buenos Aires, 2-13 November 1998. Item 4 (a) (i) of the provisional agenda, distributed 5 October 1998.

United Nations (1999): *8th Protocol to the UN/ECE Convention on Long-Range Transboundary Air Pollution. Signed 1 December 1999.* United Nations, Economic and Social Council.

Appendix A

Links between emission sources and economic variables

Table A.1.a. Economic variables linked to emissions of the 5 greenhouse gases, i.e., $X_{j,1}$ in equations (1) - (2).

ES	CH_4	N_2O
1. Fuel combustion: Energy and Transformation Industries	$X_{j,1}$ =FU1FRCT $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4	$X_{j,1}$ =3*FU1FRCT+FU1FROT+FU1FRGT $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4
2. Fuel combustion: Industry	$X_{j,1} = \sum_{n=2}^{11} \text{FUnFRCT}$	$X_{j,1} = \sum_{n=2}^{11} (3 * \text{FUnFRCT} + \text{FUnFROT} + \text{FUnFRGT})$
3. Fuel combustion: Transport	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05
4. Other fuel combustion	$X_{j,1}$ =FU16FRCT $X_{j,2}$ =FU17FRCT	$X_{j,1}$ =3*FU16FRCT+FU16FROT+FU16FRGT $X_{j,2}$ =3*FU17FRCT+FU17FROT+FU17FRGT
5. Fugitive Emissions from Fuels	$X_{j,1}$ =QR2 $X_{j,2}$ =QR3 $X_{j,3}$ = QR4	$X_{j,1}$ =QR3
6. Industrial Processes	$X_{j,1}$ =YRQ03+YRQ04+YRQ05 $X_{j,2}$ = YRQ010 $X_{j,3} = \text{YRQ09} + \sum_{n=12}^{22} \text{YRQ0n}$ $X_{j,4}$ = YRQ02+YRQ08	$X_{j,1}$ =YRQ03+YRQ04+YRQ05 $X_{j,2}$ =YRQ010 $X_{j,3} = \text{YRQ09} + \sum_{n=12}^{22} \text{YRQ0n}$
7. Solvent and Other Product Use	-	$X_{j,1}$ =YRQ031
8. Agriculture	$X_{j,1}$ =QR1	$X_{j,1}$ =YRQ01

Table A.1.a (cont.)

ES	CH_4	N_2O
9. Waste	$X_{j,1}=\sum_{n=1}^{4}C_n+\sum_{n=10}^{13}C_n+C_{24}$ $X_{j,2}=QRSUM$ $X_{j,3}=YRQ0SUM$ $X_{j,4}=\sum_{n=1}^{4}C_n+\sum_{n=10}^{13}C_n+C_{24}$ $X_{j,5}=QRSUM$ $X_{j,6}=YRQ0SUM$	$X_{j,1}=\sum_{n=1}^{4}C_n+\sum_{n=10}^{13}C_n+C_{24}$ $X_{j,2}=QRSUM$ $X_{j,3}=YRQ0SUM$ $X_{j,4}=\sum_{n=1}^{4}C_n+\sum_{n=10}^{13}C_n+C_{24}$ $X_{j,5}=QRSUM$ $X_{j,6}=YRQ0SUM$

Table A.1.a (cont.)

ES	HFC	PFC	SF6
1. Fuel combustion: Energy and Transformation Industries	-	-	-
2. Fuel combustion: Industry	-	-	-
3. Fuel combustion: Transport	-	-	-
4. Other fuel combustion	-	-	-
5. Fugitive Emissions from Fuels	-	-	-
6. Industrial Processes	-	$X_{j,1}=YRQ08$ $X_{j,2}=YRQ011$ $X_{j,3}=YRQ010$	$X_{j,1}=YRQ08+YRQ011$ $X_{j,2}=YRQ0SUM-YRQ08-YRQ011$
7. Solvent and Other Product Use	$X_{j,1}=YRQ0SUM$	$X_{j,1}=YRQ0SUM$	-
8. Agriculture	-	-	-
9. Waste	-	-	-

Table A.1.b. Economic variables linked to emissions of the 5 other pollutants, i.e., $X_{j,1}$ in equations (1) - (2).

ES	SO_2	NO_x
1. Fuel combustion: Energy and Transformation Industries	$X_{j,1}$ =FU1FRCT+FU1FROT $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4	$X_{j,1}$ =FU1FRCT+FU1FROT+FU1FRGT $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4
2. Fuel combustion: Industry	$X_{j,1} = \sum_{n=2}^{11}(\text{FUnFRCT} + \text{FUnFROT})$	$X_{j,1} =$ $\sum_{n=2}^{11}(\text{FUnFRCT} + \text{FUnFROT} + \text{FUnFRGT})$
3. Fuel combustion: Transport	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05
4. Other fuel combustion	$X_{j,1}$ =FU16FRCT+FU16FROT $X_{j,2}$ =FU17FRCT+FU17FROT	$X_{j,1}$ =FU16FRCT+FU16FROT+FU16FRGT $X_{j,2}$ =FU17FRCT+FU17FROT+FU17FRGT
5. Fugitive Emissions from Fuels	$X_{j,1}$ =QR3	$X_{j,1}$ =QR3
6. Industrial Processes	$X_{j,1}$ =YRQ03+YRQ04+YRQ05 $X_{j,2}$ = YRQ010 $X_{j,3} = \text{YRQ09} + \sum_{n=12}^{22} \text{YRQ0n}$ $X_{j,4}$ = YRQ02+YRQ08 $X_{j,5}$ = YRQ08+YRQ011 $X_{j,6}$ =YRQ024	$X_{j,1}$ =YRQ03+YRQ04+YRQ05 $X_{j,2}$ = YRQ010 $X_{j,3} = \text{YRQ09} + \sum_{n=12}^{22} \text{YRQ0n}$ $X_{j,4}$ = YRQ02+YRQ08 $X_{j,5}$ = YRQ08+YRQ011 $X_{j,6}$ =YRQ024
7. Solvent and Other Product Use	$X_{j,1}$ =YRQ022	$X_{j,1}$ =YRQ022
8. Agriculture	$X_{j,1}$ =QR1	$X_{j,1}$ =QR1
9. Waste	$X_{j,1} = \sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,2}$ = QRSUM $X_{j,3}$ = YRQ0SUM $X_{j,4} = \sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,5}$ = QRSUM $X_{j,6}$ = YRQ0SUM	$X_{j,1} = \sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,2}$ = QRSUM $X_{j,3}$ = YRQ0SUM $X_{j,4} = \sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,5}$ = QRSUM $X_{j,6}$ = YRQ0SUM

Table A.1.b (cont.)

ES	PM_{10}	CO	NMVOC
1. Fuel combustion: Energy and Transformation Industries	$X_{j,1}$ =10*FU1FRCT+FU1FROT	$X_{j,1}$ =FU1FR0 $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4	$X_{j,1}$ =FU1FR0 $X_{j,2}$ =QR5 $X_{j,3}$ =QR2 $X_{j,4}$ =QR2-4
2. Fuel combustion: Industry	$X_{j,1} = \sum_{n=2}^{11}(10 * \text{FUnFRCT} + \text{FUnFROT})$	$X_{j,1} = \sum_{n=2}^{11} \text{FUnFR0}$	$X_{j,1} = \sum_{n=2}^{11} \text{FUnFR0}$
3. Fuel combustion: Transport	$X_{j,1}$ =FU12FR05+FU14FR05 +FU15FR05 $X_{j,2}$ =FU13FR05	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05	$X_{j,1}$ =FU12FR05 $X_{j,2}$ =FU13FR05 $X_{j,3}$ =FU14FR05 $X_{j,4}$ =FU15FR05
4. Other fuel combustion	$X_{j,1}$ = 10*(FU16FRCT+FU17FRCT) +FU16FROT+FU17FROT	$X_{j,1}$ =FU16FR0 $X_{j,2}$ =FU17FR0	$X_{j,1}$ =FU16FR0 $X_{j,2}$ =FU17FR0
5. Fugitive Emissions from Fuels	-	$X_{j,1}$ =QR2 $X_{j,2}$ =QR3 $X_{j,3}$ =QR4	$X_{j,1}$ =QR3 $X_{j,2}$ =QR4 $X_{j,3}$ =QR5
6. Industrial Processes	$X_{j,1} = \sum_{n=2}^{5} \text{YRQ0n} + \sum_{n=8}^{22} \text{YRQ0n}$	$X_{j,1}$ = YRQ03+YRQ04+YRQ05 $X_{j,2}$ = YRQ010 $X_{j,3}$ = YRQ09+ $\sum_{n=12}^{22} \text{YRQ0n}$ $X_{j,4}$ = YRQ02+YRQ08 $X_{j,5}$ = YRQ08+YRQ011 $X_{j,6}$ =YRQ024	$X_{j,1}$ = YRQ03+YRQ04+YRQ05 $X_{j,2}$ = YRQ010 $X_{j,3}$ = YRQ09+ $\sum_{n=12}^{22} \text{YRQ0n}$ $X_{j,4}$ = YRQ02+YRQ08 $X_{j,5}$ = YRQ08+YRQ011 $X_{j,6}$ =YRQ024
7. Solvent and Other Product Use	-	$X_{j,1}$ =YRQ022	$X_{j,1}$ =YRQ022 $X_{j,2}$ =YRQ017 $X_{j,3}$ =QR10
8. Agriculture	-	$X_{j,1}$ =QR1	$X_{j,1}$ =QR1

Table A.1.b (cont.)

ES	PM_{10}	CO	NMVOC
9. Waste	-	$X_{j,1} =$ $\sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,2} = QRSUM$ $X_{j,3} = YRQ0SUM$ $X_{j,4} =$ $\sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,5} = QRSUM$ $X_{j,6} = YRQ0SUM$	$X_{j,1} =$ $\sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,2} = QRSUM$ $X_{j,3} = YRQ0SUM$ $X_{j,4} =$ $\sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}$ $X_{j,5} = QRSUM$ $X_{j,6} = YRQ0SUM$

Appendix B

DGXI and Corinair94 emission inventory

Table B.1. DGXI Emission Inventory

1	**Energy**
A	Fuel Combustion
1	Energy Industries
2	Manufacturing Industries and Construction
3	Transport
4	Other Sectors
5	Other
B	Fugitive Emissions from Fuels
1	Solid Fuels
2	Oil and Natural Gas
2	**Industrial Processes**
A	Mineral Products
B	Chemical Industry
C	Metal Production
D	Other Production
E	Production of Halocarbons and Sulphur Hexafluoride
F	Consumption of Halocarbons and Sulphur Hexafluoride
G	Other
3	**Solvent and Other Product Use**
4	**Agriculture**
A	Enteric Fermentation
B	Manure Management
C	Rice Cultivation
D	Agricultural Soils
E	Prescribed Burning of Savannas
F	Field Burning of Agricultural Residues
G	Other
5	**Land-Use Change & Forestry**
A	Changes in Forest and Other Woody Biomass Stocks
B	Forest and Grassland Conversion
C	Abandonment of Managed Lands
D	CO_2 Emissions and Removals from Soil
E	Other
6	**Waste**
A	Solid Waste Disposal on Land
B	Wastewater Handling
C	Waste Incineration
D	Other
7	**Other**

Table B.2. Corinair Emission Inventory

1	**Combustion in energy and transformation industries**
101	Public power
102	District heating plants
103	Petroleum refining plants
104	Solid fuel transformation plants
105	Coal mining, oil/gas extraction, pipeline compressors
2	**Non-industrial combustion plants**
201	Commercial and institutional plants
202	Residential plants
203	Plants in agriculture, forestry and aquaculture
3	**Combustion in manufacturing industry**
301	Comb. in boiler/gas/turb./station. engine
302	Process furnaces without contact
303	Processes with contact
4	**Production processes industries**
401	Processes in petroleum
402	Processes in iron and steel industries and collieries
403	Processes in non-ferrous metal industries
404	Processes in inorganic chemical industries
405	Processes in organic chemical industries (bulk production)
406	Processes in wood, paper pulp, food, drink and other industries
407	Cooling plants
5	**Extraction and distribution of fossil fuels / geothermal energy**
501	Extraction and 1st treatment of solid fossil fuels
502	Extraction, 1st treat. and loading of liquid fossil fuels
503	Extraction, 1st treat. and loading of gaseous fossil fuels
504	Liquid fuel distribution (except gasoline distrib. in 0505)
505	Gasoline distribution
506	Gas distribution networks
507	Geothermal energy extraction
6	**Solvent and other product use**
601	Paint application
602	Degreasing, dry cleaning and electronics
603	Chemicals products manufacturing or processing
604	Other use of solvents and related activities
605	Use of N2O
7	**Road transport**
701	Passenger cars
702	Light duty vehicles < 3.5 t
703	Heavy duty vehicles > 3.5 t and buses
704	Mopeds and motorcycles < 50 cm3
705	Motorcycles > 50 cm3
706	Gasoline evaporation from vehicles
707	Automobile tyre and brake wear

Table B.2 (cont.)

8	**Other mobile sources and machinery**
801	Other mobile & mach.- military
802	Other mobile & mach.- railways
803	Other mobile & mach. - inland waterways
804	Other mobile & mach. - maritime activities
805	Other mobile & mach. - air traffic
806	Other mobile & mach. - agriculture
807	Other mobile & mach. - forestry
808	Other mobile & mach. - industry
809	Other mobile & mach.- household and gardening
810	Other mobile & mach. - other off-road
9	**Waste treatment and disposal**
902	Waste incineration
907	Open burning of agricultural wastes (except on field 1003)
909	Cremation
910	Other waste treatment
10	**Agriculture and forestry, land use and wood stock change**
1001	Cultures with fertilizers (except animal manure)
1002	Cultures without fertilizers
1003	On-field burning of stubble, straw, ...
1004	Enteric fermentation
1005	Manure management
1006	Use of pesticides
1007	Managed deciduous forests
1008	Managed coniferous forests
1011	Luwc - wood biomass stock change/annual growth
1012	Luwc - wood biomass stock change/annual harvest
1013	Luwc - conversion/burning aboveground biomass
1014	Luwc - conversion/aboveground biomass decay
1015	Luwc - conversion/soil carbon release
1016	Luwc - managed land abandonment < 20y/aboveground biomass
1017	Luwc - managed land abandonment < 20y/soil carbon uptake
1018	Luwc - managed land abandonment > 20y/aboveground biomass
1019	Luwc - managed land abandonment > 20y/soil carbon uptake
11	**Nature**

Data sources used in E3ME for emission calculations

Table C.1. Data sources used for all pollutants and all emission sources, including disaggregation of emission sources into several economic indicators (see equations (1) - (2))

	SO_2	**NOx**	**PM_{10}**
ES1	Corinair 01	DGXI 1.A.1	Eurostat: Power Stations
$X_{j,1}$	Corinair 101 -102	Corinair 101 -102	Eurostat: Power Stations
$X_{j,2}$	Corinair 103	Corinair 103	-
$X_{j,3}$	Corinair 104	Corinair 104	-
$X_{j,4}$	Corinair 105	Corinair 105	-
ES 2	Corinair 03	DGXI 1.A.2	Eurostat: Industrial Fuel Combustion
$X_{j,1}$	Corinair 03	DGXI 1.A.2	Eurostat: Industrial Fuel Combustion
ES 3	Corinair 07+802-805	DGXI 1.A.3	Eurostat: Mobile Sources
$X_{j,1}$	Corinair 802	Corinair 802	Eurostat: Other Mobile Sources
$X_{j,2}$	Corinair 07	Corinair 07	Eurostat: Transport
$X_{j,3}$	Corinair 805	Corinair 805	-
$X_{j,4}$	Corinair 803-804	Corinair 803-804	-
ES 4	Corinair 02+801+806-810	DGXI 1.A.4-5	Eurostat: Other Combustion
$X_{j,1}$	Corinair 202+809	Corinair 202+809	Eurostat: Other Combustion
$X_{j,2}$	Corinair 201+203+ 801+806+807+808+810	Corinair 201+203+ 801+806+807+808+810	-
ES 5	Corinair 05	DGXI 1.B	-
$X_{j,1}$	Corinair 05	DGXI 1.B	-
$X_{j,2}$	-	-	-
$X_{j,3}$	-	-	-
ES 6	Corinair 04	DGXI 2	Eurostat: Industrial Processes
$X_{j,1}$	Corinair 401	Corinair 401	Eurostat: Industrial Processes
$X_{j,2}$	Corinair 404-405	Corinair 404-405	-
$X_{j,3}$	Corinair 406	Corinair 406	-
$X_{j,4}$	Corinair 402	Corinair 402	-
$X_{j,5}$	Corinair 403	Corinair 403	-
$X_{j,6}$	Corinair 407	Corinair 407	-
ES 7	Corinair 06	DGXI 3	-
$X_{j,1}$	Corinair 06	DGXI 3	-
$X_{j,2}$	-	-	-
$X_{j,3}$	-	-	-
ES 8	Corinair 10	DGXI 4-5	-
$X_{j,1}$	Corinair 10	DGXI 4-5	-

Table C.1 (cont.)

	SO_2	Nox	PM_{10}
ES 9	Corinair 09	DGXI 6	-
$X_{j,1}$	0.5990 *(Corinair 902+907+909)	0.5990 *(Corinair 902+907+909)	-
$X_{j,2}$	0.1203*(Corinair 902+907+909)	0.1203*(Corinair 902+907+909)	-
$X_{j,3}$	0.2807*(Corinair 902+907+909)	0.2807*(Corinair 902+907+909)	-
$X_{j,4}$	0.343*(Corinair 910)	0.295 *(Corinair 910)	-
$X_{j,5}$	0.1971*(Corinair 910)	0.2115 *(Corinair 910)	-
$X_{j,6}$	0.4599*(Corinair 910)	0.4935 *(Corinair 910)	-
ES 10	Residual	DGXI 7/ Residual	Eurostat: Miscellaneous/Residual
Projections	Emission ceilings for 2010 in United Nations (1999)	Emission ceilings for 2010 in United Nations (1999)	Extrapolation

Table C.1 (cont.)

	CO	NMVOC	CH_4
ES1	DGXI 1.A.1	DGXI 1.A.1	DGXI 1.A.1
$X_{j,1}$	Corinair 101 -102	Corinair 101 -102	Corinair 101 -102
$X_{j,2}$	Corinair 103	Corinair 103	Corinair 103
$X_{j,3}$	Corinair 104	Corinair 104	Corinair 104
$X_{j,4}$	Corinair 105	Corinair 105	Corinair 105
ES 2	DGXI 1.A.2	DGXI 1.A.2	DGXI 1.A.2
$X_{j,1}$	DGXI 1.A.2	DGXI 1.A.2	DGXI 1.A.2
ES 3	DGXI 1.A.3	DGXI 1.A.3	DGXI 1.A.3
$X_{j,1}$	Corinair 802	Corinair 802	Corinair 802
$X_{j,2}$	Corinair 07	Corinair 07	Corinair 07
$X_{j,3}$	Corinair 805	Corinair 805	Corinair 805
$X_{j,4}$	Corinair 803-804	Corinair 803-804	Corinair 803-804
ES 4	DGXI 1.A.4-5	DGXI 1.A.4-5	DGXI 1.A.4-5
$X_{j,1}$	Corinair 202+809	Corinair 202+809	Corinair 202+809
$X_{j,2}$	Corinair 201+203+ 801+806+807+808+810	Corinair 201+203+ 801+806+807+808+810	Corinair 201+203+ 801+806+807+808+810
ES 5	DGXI 1.B	DGXI 1.B	DGXI 1.B
$X_{j,1}$	Corinair 501	Corinair 501-504	DGXI 1.B.1
$X_{j,2}$	Corinair 502-503	Corinair 506	Corinair 502-504
$X_{j,3}$	Corinair 506	Corinair 505	Corinair 506
ES 6	DGXI 2	DGXI 2	DGXI 2
$X_{j,1}$	Corinair 401	Corinair 401	Corinair 401
$X_{j,2}$	Corinair 404-405	Corinair 404-405	Corinair 404-405
$X_{j,3}$	Corinair 406	Corinair 406	Corinair 406
$X_{j,4}$	Corinair 402	Corinair 402	Corinair 402
$X_{j,5}$	Corinair 403	Corinair 403	-
$X_{j,6}$	Corinair 407	Corinair 407	-
ES 7	DGXI 3	DGXI 3	-
$X_{j,1}$	DGXI 3	Corinair 601+604	-
$X_{j,2}$	-	Corinair 602	-
$X_{j,3}$	-	Corinair 603	-
ES 8	DGXI 4-5	DGXI 4-5	DGXI 4-5
$X_{j,1}$	DGXI 4-5	DGXI 4-5	DGXI 4-5

Table C.1 (cont.)

	CO	**NMVOC**	**CH_4**
ES 9	DGXI 6	DGXI 6	DGXI 6
$X_{j,1}$	0.5990 *(Corinair 902+907+909)	0.5990 *(Corinair 902+907+909)	0.5990 *(Corinair 902+907+909)
$X_{j,2}$	0.1203*(Corinair 902+907+909)	0.1203*(Corinair 902+907+909)	0.1203*(Corinair 902+907+909)
$X_{j,3}$	0.2807*(Corinair 902+907+909)	0.2807*(Corinair 902+907+909)	0.2807*(Corinair 902+907+909)
$X_{j,4}$	0.295 *(Corinair 910)	0.295 *(Corinair 910)	0.343*(Corinair 910)
$X_{j,5}$	0.2115 *(Corinair 910)	0.2115 *(Corinair 910)	0.1971*(Corinair 910)
$X_{j,6}$	0.4935 *(Corinair 910)	0.4935 *(Corinair 910)	0.4599*(Corinair 910)
ES 10	DGXI 7/ Residual	DGXI 7/ Residual	DGXI 7/Residual
Projections	Extrapolation	Emission ceilings for 2010 in United Nations (1999)	IPCC projections 2000-2020

Table C.1 (cont.)

	N_2O	HFC	PFC	SF_6
ES1	DGXI 1.A.1	-	-	-
$X_{j,1}$	Corinair 101 -102	-	-	-
$X_{j,2}$	Corinair 103	-	-	-
$X_{j,3}$	Corinair 104	-	-	-
$X_{j,4}$	Corinair 105	-	-	-
ES 2	DGXI 1.A.2	-	-	-
$X_{j,1}$	DGXI 1.A.2	-	-	-
ES 3	DGXI 1.A.3	-	-	-
$X_{j,1}$	Corinair 802	-	-	-
$X_{j,2}$	Corinair 07	-	-	-
$X_{j,3}$	Corinair 805	-	-	-
$X_{j,4}$	Corinair 803-804	-	-	-
ES 4	DGXI 1.A.4-5	-	-	-
$X_{j,1}$	Corinair 202+809	-	-	-
$X_{j,2}$	Corinair 201+203+ 801+806+807+808+810	-	-	-
ES 5	DGXI 1.B	-	-	-
$X_{j,1}$	DGXI 1.B	-	-	-
$X_{j,2}$	-	-	-	-
$X_{j,3}$	-	-	-	-
ES 6	DGXI 2	-	0.85*Total IPCC	DGXI 2
$X_{j,1}$	Corinair 401	-	0.6*Total IPCC	DGXI 2.C
$X_{j,2}$	Corinair 404-405	-	0.15*Total IPCC	DGXI 2.A-B + DGXI 2.D-F
$X_{j,3}$	Corinair 406	-	0.1*Total IPCC	-
$X_{j,4}$	-	-	-	-
$X_{j,5}$	-	-	-	-
$X_{j,6}$	-	-	-	-
ES 7	DGXI 3	Total IPCC	0.15*Total IPCC	-
$X_{j,1}$	DGXI 3	Total IPCC	0.15*Total IPCC	-
$X_{j,2}$	-	-	-	-
$X_{j,3}$	-	-	-	-
ES 8	DGXI 4-5	-	-	-
$X_{j,1}$	DGXI 4-5	-	-	-

Table C.1 (cont.)

	N_2O	HFC	PFC	SF_6
ES 9	DGXI 6	-	-	-
$X_{j,1}$	0.5990 *(Corinair 902+907+909)	-	-	-
$X_{j,2}$	0.1203*(Corinair 902+907+909)	-	-	-
$X_{j,3}$	0.2807*(Corinair 902+907+909)	-	-	-
$X_{j,4}$	0.295 *(Corinair 910)	-	-	-
$X_{j,5}$	0.2115 *(Corinair 910)	-	-	-
$X_{j,6}$	0.4935 *(Corinair 910)	-	-	-
ES 10	DGXI 7/ Residual	Residual	Residual	Residual
Projections	IPCC projections 2000-2020	IPCC projections 2000-2020	IPCC projections 2000-2020	IPCC projections 2000-2020

C.1 Specific exceptions or data problems for each region

- Belgium (be): HFC: 1995 only. No projections of HFC, PFC and SF_6. CH_4 and N_2O to 2005 only.
- Denmark (dk): PM_{10}: Emissions from Mobile Sources only. HFC and PFC: 1995 only. No projections of HFC, PFC and SF_6. CH_4 and N_2O to 2010.
- Germany (do + dw): In the E3ME-model, Germany is divided into two regions, Germany West (dw) and Germany East (do). We only have data for the national totals. The emission coeffisients (α and β) in the model baseyear are calculated on the basis of the sum of the economic variables for do and dw. These average coeffisients is then used to divide total emissions for Germany on do and dw. If the actual emission coeffisient between the two regions are not too different, the relative distribution in the model could be a reasonable indication on the division of actual emissions.
- Greece (el): PM_{10}, HFC, PFC and SF_6: No data or projections available. Corinair data: Aggregates (1-11) reported only. The average distribution for the other countries is used to find the distribution on subcategories (e.g 101-105). CH_4 and N_2O: No projections. NO_x and NMVOC: No reported emission ceiling. SO_2: Emission ceiling from the 1994-protocol.
- Spain (es): PM_{10}: Mobile Sources 1990 only. HFC, PFC and SF_6: No data or projections available. Corinair data: Same treatment as for Greece. CH_4 and N_2O projections to 2000 only. NO_x and NMVOC: No reported emission ceiling. SO_2: Emission ceiling from the 1994-protocol.
- Ireland (ir): PM_{10}: 1990 only. HFC, PFC and SF_6: No data or projections available. CH_4 and N_2O to 2010.
- Italy (in + is): In the E3ME-model, Italy is divided into two regions, Italy North (in) and Italy South (is). We only have the national totals. Same treatment as for Germany. No Italian data or projections for emissions of HFC, PFC and SF_6. PM_{10}: 1990 only. Corinair data: Same treatment as for Greece. CH_4 and N_2O to 2010.
- Luxembourg: PM_{10}, HFC, PFC and SF_6: No data or projections available. NO_x and NMVOC: No reported emission ceiling. SO_2: Emission ceiling from the 1994-protocol.
- Netherlands: PM_{10}: 1990 only; only emissions from Mobile Sources.
- Portugal: PM_{10}, HFC, PFC and SF_6: No data or projections available. Corinair data: Same treatment as for Greece. CH_4 and N_2O to 2010. SO_2: Emission ceiling from the 1994-protocol.
- United Kingdom: HFC, PFC and SF_6: Projections to 2010 only.
- Austria: PM_{10}: 1990 only. HFC, PFC and SF_6: 1995 only. No projections for CH_4, N_2O, HFC, PFC and SF_6. NO_x and NMVOC: No reported emission ceiling. SO_2: Emission ceiling from the 1994-protocol.
- Finland: Corinair data: Same treatment as for Greece.
- Sweden: PM_{10} 1995: Table 6 in Camner (ed.). PM_{10} 1990: Eurostat reports total emissions. Same percentage distribution is assumed for 1990 as in 1995. SF_6 1995 emissions only. CH_4, N_2O, HFC, PFC and SF_6: Projections to 2010.

- Norway: Data from Statistics Norway for all gases. To see Norwegian inventory, see Statistics Norway (1999), table C.5. IPCC projections to 2020.
- Switzerland: HFC, PFC and SF_6: IPCC data and 1995 only (no projections). CH_4, N_2O, NMVOC, CO and NO_x: Data from Departement für Umwelt, Verkehr, Energie und Kommunikation (1999). The inventory is identical with DGXI. CH_4 and N_2O: IPCC projections to 2010.

Methane emissions from landfills

Organic waste degrades over time. Thus methane emissions from landfills in a certain year stem from previously landfilled waste amounts. In principle, a model of methane emissions should therefore include pervious years landfilled amounts over about 30 years. However, it is not realistic to gather this detailed data for all countries included in the model.

Another approximation is to estimate the methane gas potential, or the total future emissions, from the landfilled waste in a certain year, and then calibrate these with the countries reported methane gas emissions. Given a constant growth in landfilled waste, the calibrated potential methane gas emissions equals the actual emissions. This method corresponds with one out of IPCCs two guidelines (IPCC 1996, "theoretical gas yield methodology", see. ch. 3.1.1 in Norconsult 1999), and is the basis for our modelling.

There are several factors that are important for the growth in methane emissions from landfills. First of all, the growth in waste production is the driving force behind these emissions. Here we distinguish between household waste and commercial waste. The reason is that there may be different waste intensities for the two sources (i.e., waste amount per economic value), and there may also be different emission intensities (i.e., methane emission per waste amount). Household waste is related to consumption activities in the model, whereas commercial waste is partly related to material input to the production process and partly to the output of production. For instance, in an industry generating a type of waste that corresponds closely with the product (e.g. paper waste in paper industry), waste is mostly linked to production. As we don't have such detailed data for each industry, we use a single factor here. This is based on waste forecasts in Norway, where 30 percent of the waste is explained by production (Bruvoll and Ibenholt 1997).

We also use Norwegian data to distinguish between household and commercial waste. According to Norconsult (1997) household waste constitutes 38 per cent of all landfilled waste. Moreover, the proportion of waste that is landfilled as opposed to burned is 56 per cent for household and 82 per cent for commercial waste (Norconsult 1997). These factors are used to calculate emissions related to waste incineration.

Finally, there are several factors that affect the amount of methane emissions from a ton of landfilled waste. For instance, the type of waste (i.e., the share of degradable organic material) and the amount of transformation from CH_4 to CO_2 is important. Here, too, we use different factors for household and commercial waste based on Norwegian results (Norconsult 1999), i.e. one ton landfilled household waste causes 25 per cent more methane emissions than one ton landfilled commercial waste.

Following equation (1) in section 3.1, we are now ready to specify the landfill methane emissions in region j as follows (the exogenous part is excluded):

$$\text{(E1)} \qquad ESY_{ES9,j}^{CH4} = \alpha_{ES9,j}^{CH4} \cdot \gamma_{ES9,j}^{CH4} \cdot X_j$$

where X_j denotes a weighted sum of the following economic variables in the model[7]:

---

[7] In the model emissions from waste incineration (only marginal for methane) is included in the same equation with the same set of economic variables (but other β's).

(E2) $$X_j = \beta_{ES9,j}^{CH4,1}\left(\sum_{n=1}^{4} C_n + \sum_{n=10}^{13} C_n + C_{24}\right) + \beta_{ES9,j}^{CH4,2} QRSUM + \beta_{ES9,j}^{CH4,3} YQR0SUM$$

The first part includes all relevant consumption variables in the model, whereas the two other parts include total output in the industries and total material input in the industries. The β's and α are calibrated for each region by using the total methane emissions from landfills in the baseyear combined with the information presented above. This information implies that 43 per cent of methane emissions should be linked to consumption, 17 per cent to output and 40 per cent to material input.

Several of the non-economic factors above will change over time, e.g. the proportion of waste that is landfilled and the transformation from CH_4 to CO_2 (due to new waste treatment at landfills). This factors may in principle be specified directly in the equations and changed over time. However, in the current version this is not done, as we have rather calibrated the parameters for future years based on the IPCC projections for future emissions (as with the rest of the GHG emissions).

Appendix E

Changes in emission intensities 1990-1994

Table E.1. Weighted[a] annual growth rates for emission intensities in major emission sources, 1990-1994[b]

	Growth rate	% of total emissions
CH_4		
Fugitive Emissions from Fuels (ES 5)	-2.1 %	16 %
Agriculture (ES 8)	-2.7 %	43 %
Waste (ES 9)	-4.3 %	38 %
		Sum 96 %
N_2O		
Industrial Processes (ES 6)	-5.3 %	27 %
Agriculture (ES 8)	-2.7 %	56 %
		Sum 82 %
SO_2		
Fuel Comb: Energy and Transformation Ind. (ES 1)	-2.1 %	60 %
Fuel Comb: Industry (ES 2)	-16.6 %	19 %
		Sum 79 %
NO_x		
Fuel Comb: Energy and Transformation Ind. (ES 1)	-5.2 %	19 %
Fuel Comb: Transport (ES 3)	-3.0 %	56 %
		Sum 75 %
CO		
Fuel Comb: Transport (ES 3)	-5.2 %	65 %
Other Fuel Combustion (ES 4)	-5.4 %	18 %
		Sum 83%
PM_{10}		
Fuel Comb: Energy and Transformation Ind. (ES 1)	-0.2 %	16 %
Fuel Comb: Transport (ES 3)	0.0 %	35 %
Other Fuel Combustion (ES 4)	6.6 %	20 %
		Sum 70 %
NMVOC		
Fuel Comb: Transport (ES 3)	-6.1 %	38 %
Fugitive Emissions from Fuels (ES 5)	-8.3 %	11 %
Solvent and Other Product Use (ES 7)	-4.4 %	30 %
		Sum 79 %
HFC		
Industrial Processes (ES 6)	2.2 %	100 %
PFC		
Industrial Processes (ES 6)	-13.4 %	87.7 %
SF_6		
Industrial Processes (ES 6)	-1.5 %	100 %

[a] Weights are determined by regional total emissions for each ES.
[b] 1990-1995 for HFC, PFC and SF_6.

Appendix F

Classification of Industries, Fuel Users and Fuel Types in the E3ME model

Table F.1. Industries, Y

1	Agriculture etc
2	Coal & Coke
3	Oil & Gas Extraction
4	Gas Distribution
5	Refined Oil
6	Electricity etc
7	Water Supply
8	Ferrous & Non-F Metal
9	Non-metallic Min.Pr.
10	Chemicals
11	Metal Products
12	Agri. & Indust. Mach.
13	Office Machines
14	Electrical Goods
15	Transport Equipment
16	Food, Drink & Tobacco
17	Tex., Cloth. & Footw.
18	Paper & Printing Pr.
19	Rubber & Plastic Pr.
20	Recycling/Emiss Abate
21	Other Manufactures
22	Construction
23	Distribution etc
24	Lodging & Catering
25	Inland Transport
26	Sea & Air Transport
27	Other Transport
28	Communications
29	Bank. Finance & Ins.
30	Other Market Serv.
31	Non-market Services
32	Unallocated

Table F.2. Fuel Users, FU

1	Power Generation
2	Iron & Steel
3	Non-ferrous Metals
4	Chemicals
5	Mineral Products
6	Ore-extraction
7	Food, Drink & Tobacc
8	Tex., Cloth. & Footw
9	Paper & Printing
10	Engineering etc
11	Other Industry
12	Rail Transport
13	Road Transport
14	Air Transport
15	Inland Navigation
16	Households
17	Other Final Use

Table F.3. Fuel Types, FR

1	Coal
2	Coke
3	Lignite
4	Heavy Fuel Oil
5	Middle Distillates
6	Natural Gas
7	Derived Gas
8	Electricity
9	Nuclear Fuels
10	Crude Oil
11	Steam

Emission ceilings 2010 for SO_2, NO_x and NMVOC

Table G.1. Emission ceilings in the 8th Protocol to the UN/ECE Convention on Long-Range Transboundary Air Pollution signed on 1 December 1999 (United Nations 1999). Numbers are in thousands of tonnes per year

	SO_2			NO_x			NMVOC		
	Emission level 1990	**Emission ceiling 2010**	**%-change in 2010 (1990 baseyear)**	**Emission level 1990**	**Emission ceiling 2010**	**%-change in 2010 (1990 baseyear)**	**Emission level 1990**	**Emission ceiling 2010**	**%-change in 2010 (1990 baseyear)**
Belgium (BE)	372	106	-72 %	339	181	-47 %	324	144	-56 %
Denmark (DK)	182	55	-70 %	282	127	-55 %	178	85	-52 %
Germany (DO+DW)	5313	550	-90 %	2693	1081	-60 %	3195	995	-69 %
Greece (EL)	509	546	7 %	343	344	0 %	373	261	-30 %
Spain (ES)	2182	774	-65 %	1113	847	-24 %	1094	669	-39 %
France (FR)	1269	400	-68 %	1882	860	-54 %	2957	1100	-63 %
Ireland (IR)	178	42	-76 %	115	65	-43 %	197	55	-72 %
Italy (IN+IS)	1651	500	-70 %	1938	1000	-48 %	2213	1159	-48 %
Luxembourg (LX)	15	4	-73 %	23	11	-52 %	20	9	-55 %
Netherlands (NL)	202	50	-75 %	580	266	-54 %	502	191	-62 %
Portugal (PO)	362	170	-53 %	348	260	-25 %	640	202	-68 %
United Kingdom (UK)	3731	625	-83 %	2673	1181	-56 %	2555	1200	-53 %
Austria (AT)	91	39	-57 %	194	107	-45 %	351	159	-55 %
Finland (FI)	260	116	-55 %	300	170	-43 %	209	130	-38 %
Sweden (SE)	119	67	-44 %	338	148	-56 %	526	241	-54 %
Norway (NO)	53	22	-58 %	218	156	-28 %	310	195	-37 %
Switzerland (CH)	43	26	-40 %	166	79	-52 %	292	144	-51 %
Total	**16532**	**4092**	**-75 %**	**13545**	**6883**	**-49 %**	**15936**	**6939**	**-56 %**

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