JUNE 1998 ECN-C--98-040

POST-KYOTO

Effects on the Climate Policy of the European Union

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Acknowledgement

This research is commissioned by the Dutch Ministry of Economic Affairs and is registered at ECN under number 7.7143. The study has been translated by Mr B. Blasweiler and Mr E.T.E. Reijn at R & B Textueel in Amsterdam.

Abstract

In March 1997, a differentiated greenhouse gas (GHG) emission reduction agreement was reached within the EU, based on a total reduction of 10% for the aggregate of three GHGs (CO_2, CH_4 and N_2O). Earlier studies indicated that the cost implications of this agreement raised serious questions. At COP-3 several elements were introduced in the Kyoto protocol. Three new GHGs (PFCs, HFCs and SF_6) and land use change related sinks had been added, and in addition the reduction target for the EU as a whole was changed to -8%. Consequently, the March 1997 differentiation conference has to be revisited.

This study considers the costs and emission targets for EU Member States (MS) in a number of cases: flat rate, equal marginal costs and equal costs per unit of GNP. In addition, a modified March 1997 allocation is studied which combines the March97 emission targets for each MS with the projections for the three new GHGs and sinks.

The data on which the study is based are taken from various sources. Emission data, projections and abatement costs for CO_2 are derived from ETSAP and COHERENCE studies, with some updates and modifications. Emission data and projections for the other GHGs and the sinks are those presented by EU MS in recent EU discussions. Abatement costs for non-CO_2 GHGs are based on a number of different studies. While absolute cost estimates and projections should be treated with some caution, relative cost levels of the different MS vis-à-vis each other are more robust and comparable with other studies. The projections show that EU emissions in 2010 will be more or less stabilised. This is explained by a relatively low growth rate of CO_2 emissions (mainly as a consequence of the decrease in CO_2 emissions in Germany) and by the decrease of the two other major non-CO_2 GHG emissions, CH_4 and N_2O.

Abatement costs of the most efficient distribution, equal marginal costs, which would result from a system of tradable emission permits or from a uniform GHG charge (at the appropriate level), are more than six times lower than abatement costs of the modified March97 distribution. In the equal marginal costs or equal costs per unit of GNP case (which are fairly similar in this case), Germany, the UK and France have to reduce most, with Germany having to reduce about 25% relative to 1990/1995 emissions. The southern COHESION countries are all allowed to increase their emissions, although Spain and Portugal have to reduce emissions more than their commitment in the (modified) March97 case. Depending on which is the case, reduction of non-CO_2 GHGs account for one third to one half of the total reductions required to meet the EU target.

In the case of the equal costs per unit of GNP, the Netherlands would be allowed to increase emissions with 5.5% over the reference level, as against a reduction of 8% in

the modified March97 distribution. Costs per capita would be reduced with more than a factor 7 than for the modified March97 target (8% reduction).

CONTENTS

1. INTRODUCTION

1.1 Background

In the preliminary stages of the UNFCCC/CoP-3 conference in Kyoto several quantitative studies were conducted by the Unit Policy Studies of the Netherlands Energy Research Foundation (ECN-BS) to inform the participants in the negotiation process. Among others, the Burden Sharing costs of the differentiated reduction target, as agreed by the European Union in March 1997, was evaluated. Also the possible influence of the introduction of a system of Tradable Emission Permits (TEP) on the total reduction costs and its subsequent division over the Annex 1 parties was examined, depending on the choice of an initial allocation of emission rights. The studies mentioned aimed exclusively on energy related CO_2 emissions.

The outcome of the CoP-3, as has been determined in the Kyoto Protocol, holds a number of new elements. Consequently, because of the altered EU target a reconsideration of the Dutch contribution becomes relevant. Partly in view of new EU negotiations led by the current British chairmanship, ECN-BS has been commissioned by the Ministry of Economic Affairs to make a calculation of the Kyoto results.

1.2 Target and starting points

The main target of this study is to provide insight in the alternative possibilities of dividing the EU greenhouse gas reduction goal among the member states. An 8% greenhouse gas reduction goal, compared to the reference year, has been laid down in the Kyoto Protocol. This is the so-called ‘Burden Sharing’ problem.

In particular, conform the Kyoto agreements, the six (groups of) greenhouse gases and the emissions/sinks which are related to land use changes (LUC) have been taken into account. As yet, these LUCs (limited to afforestation and deforestation since 1990), will keep the main focus. The six gases are: CO_2, CH_4, N_2O, PFCs, HFCs and SF_6.

In the Protocol, there are several options for geographic flexibility in order to achieve the emission targets (Joint Implementation, Tradable Emission Permits and the Clean Development Mechanism). Anticipating these options, and in view of the general endeavour for cost-effectiveness and a fair Burden Sharing, the study emphasises EU distributions that lead to equal burdens (equal reduction costs per unit of GNP), or to equal marginal reduction costs. Theoretically, the latter is per definition the most cost-effective distribution. That is to say, with no other distribution the EU target could be achieved against less costs for the EU as a whole.

Important elements in the ECN analyses are the cost estimates for future emission reductions, based on the most consistent, detailed, and technical analyses available. In view of the existing uncertainties, only limited value can be placed on the results in the absolute sense. However, it turns out that in particular, in the mutual relations between the Member States a clear insight could be made available.[1] Therefore, based on this type of analysis, workable conclusions with regard to Burden Sharing can be drawn.

1.3 Structure of the report

The structure of the report is as follows. Chapter 2 elaborates on the used methodology, which closely follows the approach of the previous ECN studies. The emission data that were used are described in chapter 3. Subsequently, in chapter 4 the results of the analysis are expounded. Finally, chapter 5 draws a conclusion and offers some subjects for discussion.

[1] In the study *Burden sharing and cost-effectiveness of CO_2 emission reduction targets for EU member states (in Dutch),* ECN-C-97-033, Kram e.a. 1997, several emission reduction studies have been compared. It becomes clear that the relative position of countries concerning reduction costs between the studies are comparable. However, the reported absolute cost levels show a considerable dispersion.

2. METHODOLOGY

2.1 Introduction

This chapter explains the methodology. To that end, the followed approach will be elaborated first. Subsequently, the examined variants will be elucidated.

2.2 Approach

The approach followed in this study is based upon the approach followed in the ECN study of Tradable Emission Permits [1], in the sense that the spreadsheet programme that was developed for the latter has been adjusted to examine the combined effect of the 6 greenhouse gases.

In the present study autonomous emission trends are given for the period between the reference year (cq. 1990/95, depending on the gas type) and a future year (2010 as representative of the period 2008-2012). Emission reduction cost curves are determined, which represent marginal and total emission reduction costs in 2010.

For each greenhouse gas separate estimates and the curves of the reduction costs are drawn and are subsequently combined into an overall curve for the basket of six gases.

These cost curves are construed on the basis of detailed, technological analyses. On this basis it is possible to calculate the (direct, social) costs that are connected to a specific emission reduction target for a particular member state. Moreover, the burden and cost implications of a proposed Burden Sharing scheme can be mapped. It is also possible to determine an optimal distribution that may result for instance, in an equal burden for all Member States, or that leads to the most cost effective distribution in which the marginal cost level is the same for all Member States.

ECN-BS has developed a number of mathematical programmes that are operationally available for analyses and evaluation of Burden Sharing schemes that are to be agreed on in the EU.

As for the TEP study, the projections and cost curves for CO_2 emissions in the energy sector are largely derived from ETSAP [2,3] and COHERENCE [4,5] (described in more detail in [1]). It should be noted that the emission levels that were reported in these studies do not always concur with statements in the National Communications to the FCCC, not even for the reference year 1990. For some countries these projections have been adjusted to more recent information and insights.

In the case of non-CO_2 greenhouse gases and land use change (LUC) emissions and sinks (converted into Mton CO_2 equivalents) the most recent data, as presented by the individual Member States during the EU conference on the post-Kyoto reduction targets, have been used. However, one should take into account that (net) emissions and reduction costs and potentials of non-CO_2 gases and LUC sources are somewhat doubtful[2]. The costs of emission reductions of non-CO_2 greenhouse gases are based on several sources that are briefly described in Appendix 2.

In chapter 3 the levels of the emission data for CO_2 and non-CO_2 greenhouse gases used in this study are considered in more detail. Ireland, Austria and Luxembourg have been left out of the analysis because of the lack of reliable information on the costs of CO_2 reduction. The contribution of these three countries to the total of EU-15 emissions in the year of reference is 3.6%.

2.3 Examined variants

Three different emission reduction objectives have been analysed in this study, each of which lead to meeting the overall EU target of 8% reduction. The three examined variants are:

- Distribution on the basis of a flat rate of 8% of all Member States[3].
- Distribution on the basis of an equal burden per unit of GNP.
- Distribution on the basis of equal marginal reduction costs (resultant of a TEP system with 6 greenhouse gases and LUC/sinks within the EU)[4].

The effects of an adjusted March97 differentiation have been considered as well. The adjustment refers to the specific new elements in the Kyoto protocol: the extension with the three gases HFCs, PFCs and SF_6 and the ‘sink allowance’ connected with land use changes. The March97 differentiated target only referred to the gases CO_2, CH_4 and N_2O. The followed approach entails that for the latter the original target for 2010 remains unchanged. The reference value in 1995 and the projection for 2010 for the three new gases is placed on top of that, while 2010 ‘sink allowance’ is subtracted. This will lead to new values for the reference level as well as the 2010 projection, and thus to an adjusted target for 2010 with respect to 1990/95.

The variants under study will be analysed on the basis of general indicators such as total cost of reduction, cost per capita of reduction, Burden Sharing and the differentiation of the marginal costs of reduction. The relative contribution of the different greenhouse gases in the total emission reduction will be considered in more detail as well.

2 For further information see Appendix 2.A.
3 Except Germany for which the 2010 projection is less than the flat rate.
4 Maximum cost efficiency.

3. EMISSION DATA

Table 3.1 shows a survey of the emission levels in the reference year[5] and in 2010[6] as were used in this study, based on the sources as described in chapter 2.

Table 3.1 *Emission level of greenhouse gases 1990/95 and 2010 [Mton CO_2 equivalents]*

	CO_2		CH_4		N_2O		PFCs		HFCs		SF_6		LUC
	1990	2010	1990	2010	1990	2010	1995	2010	1995	2010	1995	2010	2010
Netherlands	161	210	27.1	14.9	19.8	21.1	2.4	1.0	6.7	9.3	1.5	2.0	-0.1
Belgium	106	121	13.3	10.0	9.6	10.4	0.1	0.0	0.6	2.0	0.5	0.5	-0.1
Germany	1,003	845	119.3	57.9	70.1	48.7	1.7	0.8	3.2	18.3	6.0	5.4	-0.4
Italy	410	479	48.9	66.7	51.0	53.1	0.1	0.1	3.1	4.4	0.3	0.5	-0.6
Sweden	56	64	6.8	5.5	2.9	3.9	0.4	0.6	0.2	0.9	1.2	1.2	-0.2
Finland	53	72	5.2	4.0	5.6	7.3	0.0	0.0	0.1	0.2	0.1	0.1	0.0
Denmark	52	60	8.8	7.6	10.5	8.7	0.0	0.0	1.0	2.0	0.4	0.4	-0.2
France	378	415	63.4	53.0	56.3	36.0	0.7	0.9	1.9	9.5	0.5	0.5	-2.0
Greece	84	127	9.3	10.4	5.4	5.4	0.7	0.3	1.0	4.0	0.4	0.4	0.0
Portugal	45	63	16.9	15.0	4.3	4.7	0.0	0.0	0.9	3.0	0.4	0.4	-0.9
Spain	208	265	45.8	50.4	29.2	29.1	4.5	2.5	6.5	10.3	0.2	0.3	-6.0
UK	580	589	92.6	58.9	63.0	44.1	0.6	0.7	15.4	6.1	0.7	1.0	-1.1
Total	3,137	3,310	457	354	328	272	11.0	6.7	40.5	69.9	12.2	12.6	-11.6

This Table clearly shows that the CO_2 emissions account for the largest contribution to the total greenhouse gas emissions, followed by the CH_4 and N_2O emissions. Figure 3.1 shows the different contributions in the reference year in percentages.

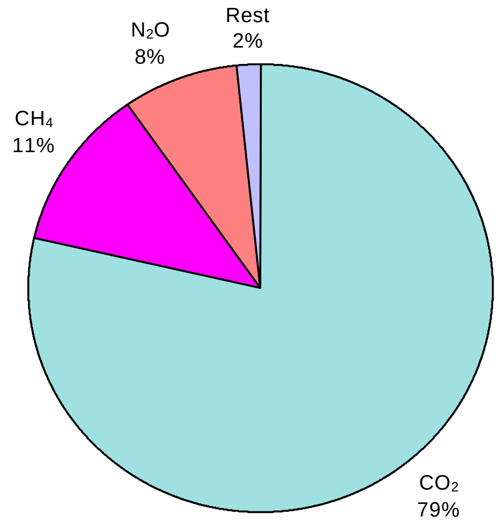

Figure 3.1 *The greenhouse gas contributions in the reference year*

[5] Conform the Kyoto Protocol, 1990 has been used as reference year for CO_2, CH_4 and N_2O. 1995 is used as the reference year for the fluorine compounds PFCs, HFCs and SF_6.

[6] Representative of the budget period 2008-2012.

Additionally, Table 3.1 gives insight in the emission progress per gas until the year 2010. The following histogram shows the emission levels for the gases in the reference year and in 2010.

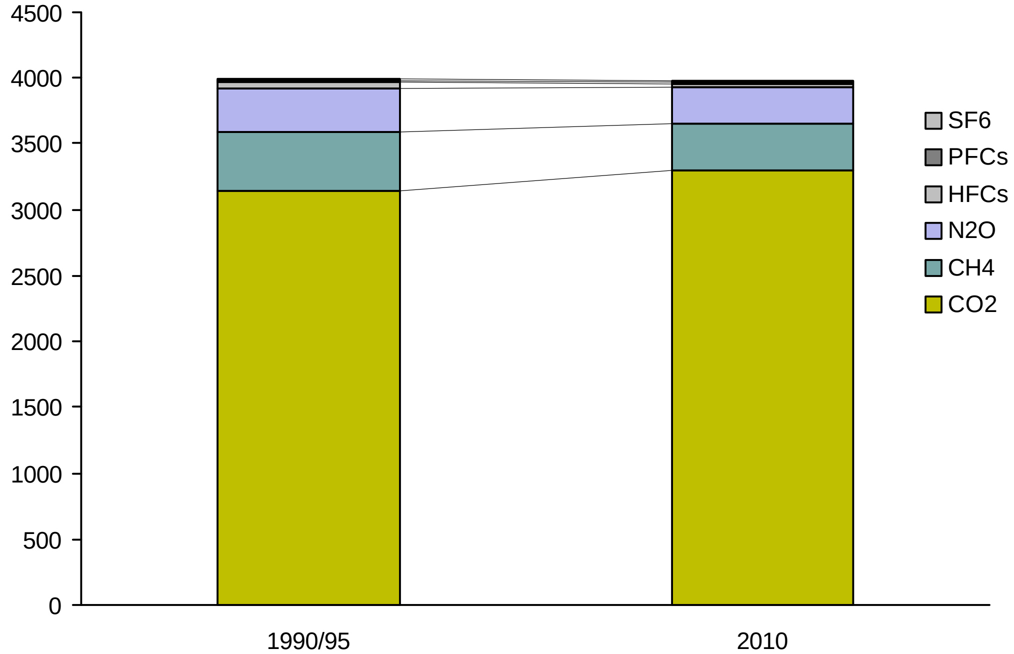

Figure 3.2 *Emission projections [Mton CO_2 equivalents]*

Figure 3.2 shows that the total greenhouse gas emissions remain stable until 2010, compared to the reference year. The CO_2 emissions (including sinks) show an increase until the year 2010. This increase is compensated by the decrease of the N_2O, and especially of the CH_4 emissions.

Several remarks on the used data

The emission value of 2010 is not based on a perfect baseline, since either some of the executed policies or cost-effective options have already been incorporated in the data. This has been considered in determining the reduction costs.

In the projection for 2010, the 50% cost free HFC emission reduction has been taken into account as well. Therefore, in 2010, for this group of gases the effective starting level will be half of the projection as was given by the Member States (see Table 3.1). For a number of countries, the CO_2 projections were adjusted in relation to the original ETSAP and COHERENCE studies. For Germany and United Kingdom, the most recent projections were adopted because these fit in better with the current situation. Revised figures, based on a higher economic growth (3.3% instead of about 2% per year) are used for the Netherlands, which coincides with a stronger increase of the energy consumption. Using this relatively high growth scenario (GC scenario) implies that, as far as emissions and reduction costs are concerned, for the Netherlands the upper limit has been reached.

In connection with prolonging the life-span of nuclear power stations to 40 years, the CO_2 emission projection for Sweden has been adjusted in comparison to ETSAP numbers. Consequently, in 2010 the emissions will amount to 64.2 Mtons (the old estimates amounted to 80.9 Mtons). A MARKAL cost curve that is consistent with this, is not (yet) available. Therefore, for the time being, the old curve will be used. Most likely, this will lead to an underrating of the reduction costs for Sweden.

Recently, France has handed over a new CO_2 projection that amounts to 465 Mtons in 2010. It seems difficult to reconcile this with the trend as has been reported until the year 2000, with previous estimates, and with model studies and the cost curves derived from these studies[7]. Therefore, for the time being, a smaller growth of the CO_2 emission (415 Mtons in 2010) will be taken into account in this study.

It is remarkable that in 1990 for a number of energy related CO_2 emissions there are deviations between the reports recently issued to the EU, the numbers in the FCCC National Communications and the baseline year as used in the model studies. In a number of cases, this is clearly caused by process emissions from (mainly cement) industry. Although these should occur in the total emission reports, they are left out of the energy model calculations. Partly due to the fact that no strong increase in the cement production is expected in the EU, this does not lead to any significant deviations in the calculations. The total CO_2 report in the National Communication for the United Kingdom amounts to 610 Mtons. This value is close to the most recent EU statement of 614 Mtons. However, according to the same National Communication, that total includes 30 Mtons emissions caused by land use changes that are left out of the current Kyoto Protocol. Possibly, a misunderstanding lies at bottom of this difference. This is the reason why the original estimate is still maintained by ECN. A similar, relatively large deviation exists for Italy: 443 Mtons in the EU report versus 410 Mtons in the MARKAL calculation. On the basis of the National Communication, it appears that again the explanation has to be found in the differences of definition. According to that National Communication the energy related emission amounts to 402 Mtons. The 10% difference consists of industrial emissions, the use of solvents, waste disposal and land use changes.

Originally, the CO_2 emissions for the year 1990 reported by the Netherlands and Denmark included temperature corrections. This means that the actual registered energy consumption (and its derived CO_2 emissions) has been corrected to the deviation of the temperature in relation to a long-term average. This is particularly relevant for applications such as spatial heating. Besides, the (net) export from Denmark to Norway of electricity generated by fossil fuels depends on the yearly fluctuating weather conditions. Both countries have also indicated that the agreed EU targets of March 1997 (‘Pre-Kyoto') are valid for the corrected levels (see also paragraph 4.4). In connection herewith, in this study these corrections have been taken into account in the adjusted March97 differentiation. Conform the international agreements, for the reference year 1990 the unadjusted values are maintained.

[7] For example, in 2010 COHERENCE results in 370 Mtons after deployment of a (unrealistically) high potential on cost effective savings.

4. RESULTS OF THE ANALYSIS

4.1 Introduction

This chapter deals with the results of the analysis. In paragraph 4.2 projections and reduction cost curves will be presented. In this context, projections should be taken as the emissions in the year 2010, that result from autonomous developments of already started or determined policy and from cost free (from the perspective of climate policy) technical reductions. Subsequently, paragraph 4.3 deals with the results of the differentiated emission reduction distribution for the European Union. Finally, in paragraph 4.4 these results are queried.

4.2 Projections and reduction cost curves

Table 4.1 shows the projections until 2010 for the individual Member States expressed in a percentage of the year of reference, considering the six greenhouse gases and LUC/sinks. At the same time, the projections for CO_2 emissions en non-CO_2 emissions have been entered into the table. The table shows the occurrence of very large differences between the Member States. The considerable reduction in the total greenhouse gas emission in Germany and United Kingdom is noteworthy. Particularly the Cohesion countries (Greece, Spain and Portugal) and Finland show a strong growth. The projection for the basket of six gases until 2010 for the EU in total is -0.15%.

Table 4.1 *Projections per country*

	1990/95	2010	Projection total[1]	Projection CO_2[2]	Projection non-CO_2
	[Mtons CO_2 equivalent]		[% mutation in respect reference year]		
Netherlands	218.9	253.5	15.8%	30.0%	-24.1%
Belgium	130.0	142.8	9.9%	14.1%	-8.8%
Germany	1203.2	966.1	-19.7%	-15.8%	-39.1%
Italy	513.8	600.8	16.9%	16.6%	18.4%
Sweden	67.0	75.7	13.0%	15.3%	1.8%
Finland	63.9	83.2	30.2%	35.3%	5.6%
Denmark	73.1	77.5	6.1%	14.4%	-14.8%
France	500.8	508.1	1.5%	9.3%	-22.6%
Greece	100.7	145.4	44.4%	51.2%	10.3%
Portugal	67.5	83.7	23.9%	38.1%	-4.4%
Spain	294.2	346.4	17.8%	24.5%	1.4%
UK	752.3	695.9	-7.5%	1.4%	-37.5%
Total	3985.2	3979.2	-0.15%	5.2%	-19.8%

[1] Including the cost free HFC measures (circa 35 Mtons CO_2 equivalent).
[2] Including sinks.

The table indicates that the total projection for 2010, after deducting LUC/sinks and taking into account the supposed 50% cost free reduction of HFC emissions, nearly reaches the reference level of 1990/95. Although CO_2 emissions increase by over 5%, this increase will be more than compensated by a decrease of approximately 20% in the non-CO_2 greenhouse gases. The CO_2 result has been influenced considerably by the substantial decrease in Germany, which was in 1990 still good for nearly one third of all CO_2 emissions. In the United Kingdom, which contributed nearly 20% of the CO_2 emissions of the EU, there is hardly any increase. These two developments, interrelated with a substantial reduction in the use of coal and the re-unification with the DDR, largely compensate the considerable increase of CO_2 emissions by an average of 20% in the other Member States. Of the non-CO_2 gases there is a great difference between the Member States (also see Table 3.1) in the supposed development. There is a considerable net decrease which is largely caused by a reduction of CH_4 emissions by a 100 Mtons CO_2 equivalent and of N_2O emissions by more than 50 Mtons. As Table 3.1 and Figure 3.1 show, next to CO_2 these two gases are the major contributors in de total emission of greenhouse gas emissions in the European Union.

In Figure 4.1 the reduction cost curves of respectively CO_2 emissions and the basket of six greenhouse gases are represented.

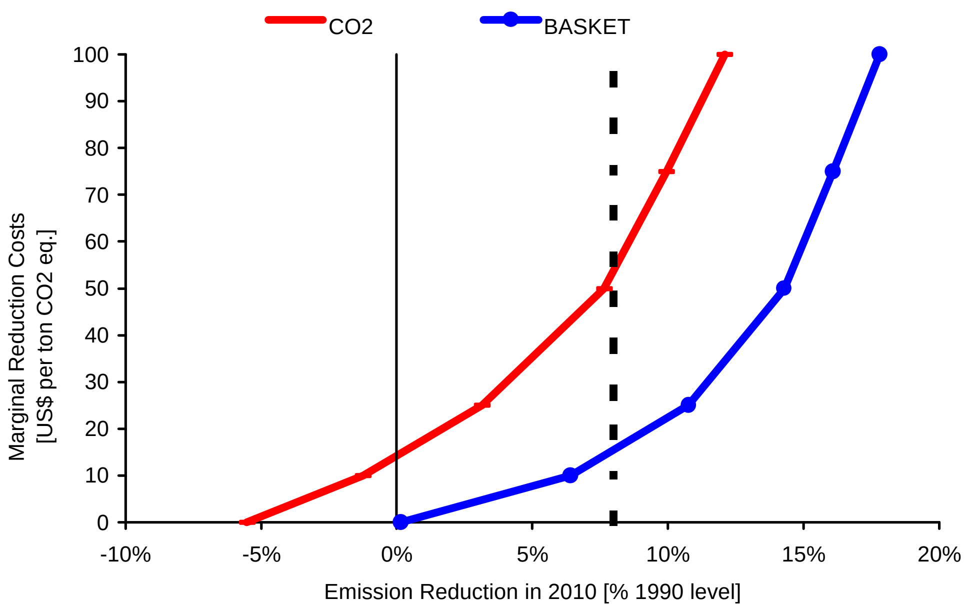

Figure 4.1 *Marginal reduction cost curves for the EU*

This figure shows that the reduction costs curve of the basket of six greenhouse gases is at a considerably lower level than the EU reduction costs curve for CO_2 emissions. This has two causes. Firstly, the reduction starting point of the six gases together is at a lower level than of CO_2 because the emission level of the six gases in 2010 is more or less equal to the level in 1990, while the CO_2 emissions increase. Secondly, the cost curve of the six gases initially has a flatter path as a result of relatively cheap reduction options for CH_4, N_2O en HFCs.

4.3 Differentiated emission reduction distribution in the EU

4.3.1 Results for the EU

Table 4.2 presents the results of the three studied emission reduction objectives:

- Distribution on a basis of a flat rate of 8% for all Member States.
- Distribution on a basis of equal burden per unity GNP.
- Distribution on a basis of equal marginal reduction costs.

For comparison the adjusted March97 distribution is added to the table.

Table 4.2 *Emission reduction distribution for six gases and LUC/sinks EU [% reference year]*

		Projections	Flat rate[8]	Equal burden per unity GNP	Marginal costs	Adjusted March97 distribution
Netherlands		15.8%	-8.0%	5.5%	3.4%	-8.0%
Belgium		9.9%	-8.0%	1.1%	-0.6%	-9.5%
Germany		-19.7%	-19.7%	-26.6%	-25.8%	-23.7%
Italy		16.9%	-8.0%	8.4%	9.6%	-6.7%
Sweden		13.0%	-8.0%	5.8%	9.1%	5.9%
Finland		30.2%	-8.0%	18.2%	12.1%	0.3%
Denmark		6.1%	-8.0%	-1.2%	0.1%	-15.2%
France		1.5%	-8.0%	-9.7%	-8.0%	0.6%
Greece		44.4%	-8.0%	36.7%	26.5%	30.5%
Portugal		23.9%	-8.0%	15.6%	9.6%	39.1%
Spain		17.8%	-8.0%	7.3%	3.0%	15.1%
United Kingdom		-7.5%	-8.0%	-12.0%	-10.8%	-11.1%
Total		-0.15%	-11.5%	-8.0%	-8.0%	-8.4%
Total costs	Total[9]		16923	2347	2028	12388
	Per capita[10]		46	6.3	5.5	33
Marginal costs[11]	Average[12]		71	18	16	45
	Range		0-252	6.5-39	-	0-251
	St. dev.		80	10	0	50

If one compares the variants that are represented in Table 4.2, certain issues stand out. Firstly, if a distribution based on equal burden is used, Germany, the United Kingdom, and to a certain extend France, would have to reduce (considerably) more than when a flat rate reduction of 8% is used. The other Member States would have to reduce their emission by a much lesser extend if a distribution based on equal burden is used. Secondly, the flat rate reduction scheme will lead to approximately 11.5% reduction instead of 8% reduction, as a result of the substantial decrease in the pro-

8 The projection of Germany is less than 8% flat rate. Because of this, the reduction for the total EU is more than 8%.

9 In $MUS\$_{95}$.

10 In $US\$_{95}$ per capita.

11 In $US\$_{95}$ per ton.

12 Not weighted.

jection for Germany (-19.7%). Even the adjusted March97 distribution leads to a somewhat larger reduction than required: 8.4%. Like the flat rate distribution, this distribution deviates strongly from the distribution based on equal burden or equal marginal costs.

Table 4.2 also presents a survey of the total reduction costs of the studied variants. The table shows that the reduction costs are the highest in the case of a flat rate distribution. Even the adjusted March97 distribution leads to much higher costs than the distribution based on equal burden or equal marginal costs.

One needs to take into consideration that the cost numbers represented here are the direct, social costs conform the definitions and conventions for this type of energy models. The absolute amount can therefore not be simply compared to other analyses en calculations. In general, it could be stated that the reported total cost and the reported burden turn out to be less than for instance the results based on end user costs or economic losses in macro-economic studies. The relations between the Member States and between the variants, however, are internally consistent.

The marginal reduction costs also differ widely between the variants, both considering the average level and the distribution. In both the flat rate and the adjusted March97 distribution these range from zero to 250 US$ per ton CO_2 equivalent. The highest level amounts to a levy of 100 US$ per barrel crude oil.

Not only the total costs and the average per capita, but also the assignment of costs over the inhabitants of the EU Member States is relevant to the Burden Sharing discussion. These indicators are represented in Table 4.3, together with statistical data on the dispersal. This table clearly confirms that the adjusted March97 distribution, as does the flat rate distribution, leads to a very unequal distribution of the burden over the EU Member States.

Table 4.3 *Number of inhabitants and the burden per capita for the EU member state in 2010 [US$$_{95}$/cap]*

	Inhabitants 2010 [mln]	Flat rate of 8%	Equal burden per unity GNP	Adjusted March97 distribution
Netherlands	16.7	59.7	8.0	59.7
Belgium	10.2	31.0	6.9	38.5
Germany	80.3	0.0	7.7	2.2
Italy	60.0	189.6	5.6	161.6
Sweden	9.2	58.8	7.5	7.3
Finland	5.2	97.8	6.4	49.6
Denmark	5.3	40.0	8.9	97.1
France	62.2	4.6	7.3	0.0
Greece	10.8	148.5	2.4	7.7
Portugal	9.5	0.0	2.5	0.0
Spain	40.8	26.7	3.8	0.2
UK	60.2	0.1	6.4	3.1
Average[13]		54.7	6.1	35.6
Least		0	2.4	0
Highest		190	8.9	162
Standard dev.		62	2.2	50

Finally, Figure 4.2 shows the contribution of the different greenhouse gas emissions in the total reduction obligation of the European Union of 8%. The equal burden per unity GNP variant has been the starting point.

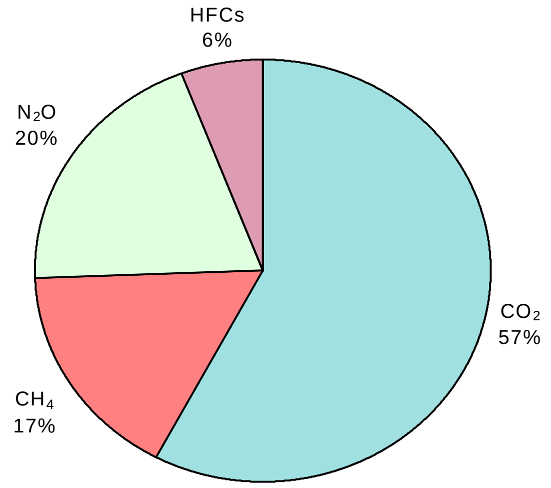

Figure 4.2 *Contribution of greenhouse gases in 8% EU reduction target*

[13] Not weighted average, deviates from costs per capita (weighted) in Table 4.2.

4.3.2 Results for the Netherlands

In this paragraph the consequences of the considered ratios of distribution for the Netherlands will be gone into further[14]. The table below shows per variant[15] the required reduction (in % en Mtons). De total emission reduction is divided by greenhouse gas.

Table 4.4 *Consequences for the Netherlands*

	Flat rate/adjusted March97 distribution		Equal burden per unity GNP	
	% of reference year	Reduction 2010 [Mton]	% of reference year	Reduction 2010 [Mton]
CO_2	6.8	37.7	22.7	12.0
CH_4	-53.3	2.2	-53.3	2.2
N_2O	-31.8	7.6	-31.8	7.6
PFCs	-58.2	0.0	-58.2	0.0
HFCs	-100.0	4.7	-41.5	0.7
SF_6	34.2	0.0	34.2	0.0
Total	-8.0	52.2	5.5	22.5
Marginal reduction cost ($US\$_{95}$/ton)	68.8		12.4	

Table 4.4 shows that in the year 2010 the Netherlands would have to reduce over 52 Mtons[16] for a reduction of 8%, as is required both in the flat rate variant as in the adjusted March97 distribution. This overall reduction leads to marginal costs of 69 $US\$_{95}$ per ton CO_2 equivalent and will be achieved mainly by reducing CO_2 emissions by nearly 38 Mtons. More than halve of the remaining 14.5 Mtons is contributed by industrial N_2O reduction. In the case of a distribution on an equal burden basis (as % of the GNP in 2010), emissions in the Netherlands could grow another 5.5% compared to the reference year. The reduction compared to the 2010 projection would then be 22.5 Mtons. Again, the lion's share is contributed by CO_2 and N_2O. The related level of marginal reduction costs amounts to 12 $US\$_{95}$. De relatively large contribution of N_2O, in particular its low cost level in the equal burden variant, coincides with the relatively substantial contribution by the industrial sector to the emissions (about 40%) in the Netherlands. Most of it (90%) could be reduced at very little expense (up to 10 $US\$_{95}$ per ton CO_2 equivalent) (see Appendix 2.C).

Figures 4.3 en 4.4 show how the structure of the total reduction in 2010 (of 52.2 respectively 22.5 Mtons CO_2 equivalents) arranged by the gases[17] would turn out. The figures illustrate that a relatively large contribution to the attainment of the Dutch tar-

14 In Appendix 1 information on other EU-member states has been included.

15 The flat rate and the adjusted March97 distribution have been aggregated, as both emission reduction objectives result in an 8% reduction target for the Netherlands.

16 In addition to the supposed cost free 50% reduction of HFCs (4.7 Mtons CO_2-equivalent).

17 There are no supposed reduction possibilities for PFCs and SF_6 against acceptable costs.

get could be made by non-CO_2 greenhouse gases, specifically in the case of less far reaching national targets such as shown in Figure 4.4.

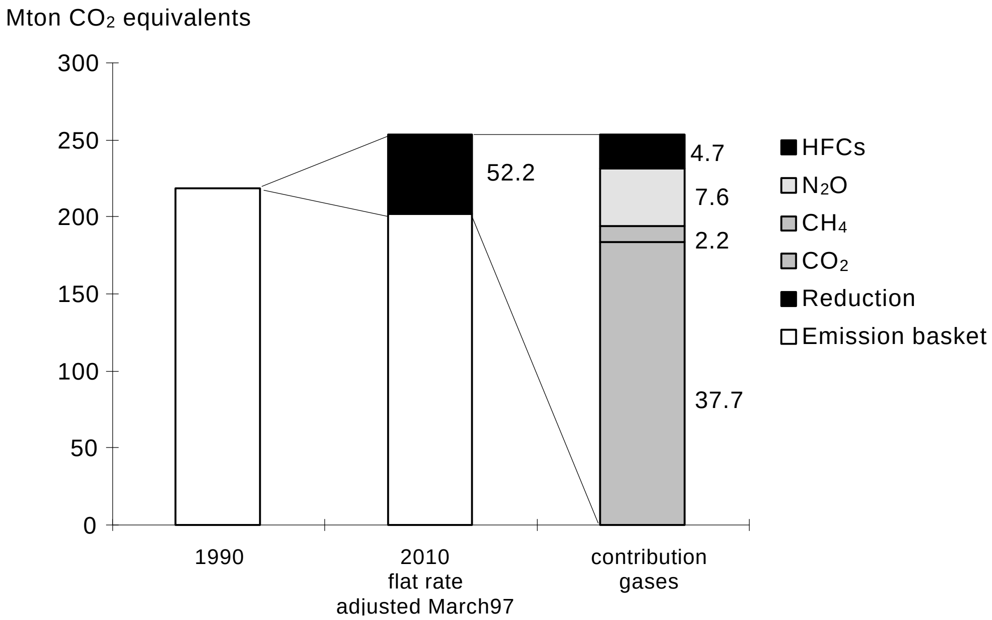

Figure 4.3 *Consequences for the Netherlands (Flat rate and adjusted March97 variant)*

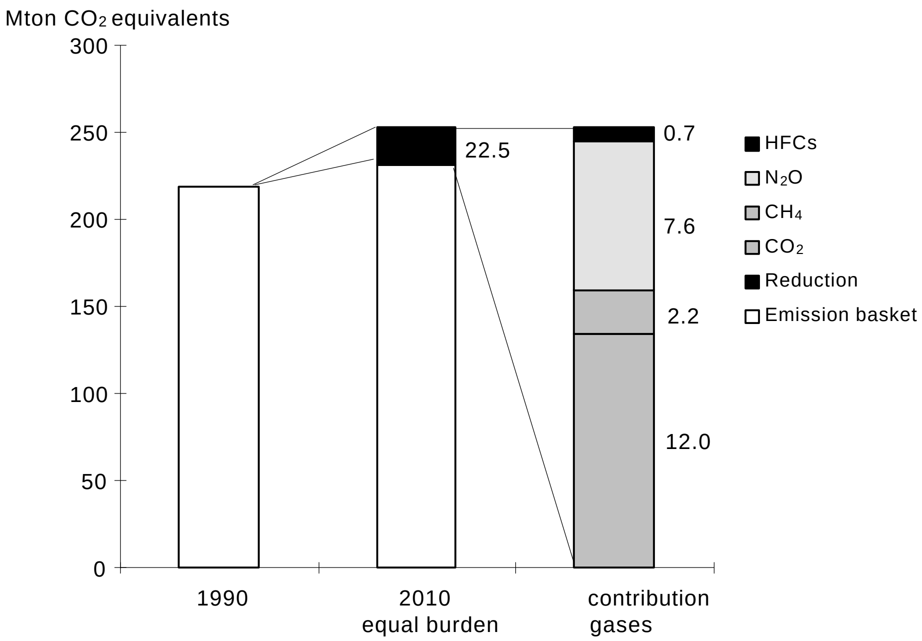

Figure 4.4 *Consequences for the Netherlands (Equal burden per unity GNP variant)*

Table 4.5 also shows how the costs of emission reductions in the Netherlands in the year 2010 depend on the targets that are set for that year. Next to the EU variants that have been examined, four other percentages were added in order to get a fuller picture. As mentioned before, the costs that are reported here cannot simply be compared to other studies and reports, because here it concerns the direct social costs conform model definitions and assumptions. For equal sets of reduction measures, other cost approaches could turn out several times higher. Universal conversion factors, however, are not applicable. Therefore, the numbers can only be used in a comparative sense within the frame of this study.

Table 4.5 *Costs per capita for the Netherlands with divergent targets*

Target in 2010 [% compared to 1990/95]	-10%	-8%	-6%	-3%	0%	+3.4%	+5.5%
Costs [US$$_{95}$/cap]	80	60	44	29	20	12	8

4.4 Several remarks

The results presented above rest on a basis projection for France of 415 Mtons CO_2 in 2010. Matters change if one starts from the basis projection of 465 Mtons as has been reported by France. In this situation the other Member States have to make an extra effort to compensate for the higher emission of France. This will lead to extended reduction obligations and higher expenses per capita in the equal burden and equal marginal costs distributions. For example, the Netherlands would only be allowed to grow 4.5% in case of equal burden (instead of 5.5% at the lesser French CO_2 increase as is maintained in the basis projection) and would carry an expense of 9.8 US$$_{95}$ per capita (instead of 8 US$$_{95}$).

In the original statements for Denmark and the Netherlands, temperature adjusted CO_2 emissions were used for 1990. However, in later EU deliberation it was decided that non-temperature adjusted numbers would be used for all countries. This was also the starting point for this study. The distribution on the basis of equal burden per unity GNP would turn out differently, particularly for the Netherlands and Denmark, if temperature adjusted emission numbers were to be used. The Netherlands, for instance, would only be allowed to grow 3 percent in case of the equal burden variant, in contrast to the 5.5% growth with the non-temperature adjusted numbers. Denmark would have to realise a reduction of 7.1% instead of 1.2% with a temperature adjusted numbers.

During the preparations for the EU conference on Burden Sharing several emission numbers, in particular those for the non-CO_2 greenhouse gases, have been downwardly, respectively upwardly readjusted compared to the National Communications. Some of these adjustments are:

- The CH_4 emissions for Italy in the reference year have been downwardly readjusted: 50 Mtons CO_2 equivalent instead of 81.9 Mtons CO_2 equivalent.
- The CH_4 emission values of Portugal have been upwardly readjusted to a considerable extend: 16.9 en 15 Mtons CO_2 equivalent in 1990 and 2010 compared to 4.8 and 4 Mtons.
- The Danish N_2O numbers for 1990 have been readjusted from 3.2 to 10.5 Mtons.
- The N_2O and the HFC data for the United Kingdom have been upwardly readjusted both for 1990 as 2010.

In spite of these readjustments, their net result on the basis projection for the entire EU is relatively minor. On the other hand, larger differences occur per country. For instance, the above mentioned upward readjustment for Portugal leads to a decrease in the total projection until 2010 from 31.3% to 23.9%. However, there seem to be few arguments in favor of such a high emission level in Portugal, as CH_4 emissions mainly emerge from livestock industry (of relatively low intensity in Portugal) and from waste disposal (which is not to be estimated at a high level in view of the number of inhabitants and the level of prosperity).

5. CONCLUSIONS AND DISCUSSION

In the present study a number of EU emission reduction distributions have been examined. The main purpose is to provide insight in alternative possibilities for dividing the required EU 8% greenhouse gas reduction compared to the reference year over de Member States (Burden Sharing), as was laid down in the Kyoto Protocol. The variants that were examined are:

- Distribution on the basis of a flat rate of 8% for all Member States.
- Distribution on the basis of equal burden per unity GNP.
- Distribution on the basis of equal marginal reduction costs.
- Adjusted March97 distribution.

Firstly, it becomes clear that in an analysis of a basket of 6 greenhouse gases and sinks the burden of greenhouse gas reduction for the EU is considerably less than in the case of an exclusive greenhouse gas CO_2 analysis. On the one hand this is the result of a decrease of the emission level of CH_4 and N_2O until 2010, and on the other hand the presence of relatively inexpensive reduction options for CH_4, N_2O and HFCs.

Furthermore, the results show that the distribution on the basis of equal burden per unity GNP and equal marginal costs (the most cost effective distribution) show no substantial differences. However, these distributions show a substantial deviation from a flat rate distribution of 8% reduction for all Member States and from an adjusted March 1997 EU distribution.

For the EU, with equal burden and equal marginal costs variants the total reduction costs are considerably less than with the other two distribution variants. The total costs for the most efficient distribution (equal marginal costs) are no less than 8 times smaller than the reduction costs of the March97 differentiation. With the distribution on the basis of equal burden per unity GNP and equal marginal costs, in the different EU Member States the reduction costs per capita are relatively close, while the costs per capita with the other variants could differ considerably per country.

Although the outcome is susceptible to the baseline data that are used and which are liable to uncertainties (see also the following discussion), the trends that were discovered turned out to be quite stable. However, the absolute values (reduction percentages, total costs and the per capita costs) as are reported here, should be considered with all due caution. Nevertheless, the indicated trends concerning the Burden Sharing position for Member States with equal burden per unity GNP and the equal marginal costs distributions are rather solid.

The acquired insight could contribute to the formulation which can be used for negotiations on EU Burden Sharing. A better co-ordination with the general considerations on cost efficiency (equal marginal costs) and fair Burden Sharing (equal reduction costs per unity GNP) is not only valuable in its own right, but it also offers a more balanced starting point for the EU Member States with a possible introduction of international policy instruments such as Joint Implementation, Tradable Emission Permits and the Clean Development Mechanism. After all, an unbalanced starting position could lead to a situation in which one EU member state, by means of flexible instruments, is still able to take measures in another member state, or to buy emission rights from other Member States.

The support for community policy could also be increased by a more balanced division of efforts and expenses. After all, if one country still has to make a considerable effort to accomplish its ‘own’ targets, while for other Member States considerable less additional measures will suffice, it will prove difficult to introduce Policy & Measures on an EU level.

It is of the utmost importance for the outcome of the present study that the starting points and the current and future estimated data are reliable and representative. Especially in the field of non-CO_2 greenhouse gases, and most certainly of the fluorine compounds PFCs, HFCs and SF_6 there are yet many and major uncertainties. However, with the exception of -possibly- the future contribution of HFCs, these compounds have a relatively small magnitude. Nevertheless, it is desirable to gain a deeper insight in sources, more uniformity in emission inventory, and a better knowledge on alternatives and reduction measures. Many of the data currently used within the EU Burden Sharing raise questions concerning consistency (between Member States) and comparability (with other sources and estimates). This does not only apply to the relatively recently added fluorine compounds, but also to CO_2, CH_4 and N_2O. Only with regard to the ‘allowable land use change sinks' the UK chairmanship seems to have made a serious attempt for harmonisation. During the execution of this study, ECN pointed out that there are some extremes in the emission data that urgently need further study and analysis. Anticipating such actions, based on the analyses as they have been carried out thus far, with continuously actualised data, it might be put that the mutual positions of the EU Member States for equal burden and equal marginal costs distributions will not change drastically. Such distributions are and will be deviating strongly from the, either or not adjusted, March97 distribution.

For the Netherlands, the effects of the distribution on the basis of equal burden per unity GNP highly deviate from the flat rate and the March97 ratio of distribution. The emissions in the Netherlands are allowed to grow with 5.5% in case of the equal burden distribution, while with the flat rate as well as with the adjusted March97 distribution the Netherlands would have to reduce of 8%. These differences are mirrored in the costs per capita. In de equal burden variant, in the Netherlands the costs per head of population are 8 US$ against 60 US$ in the flat rate and in the March97 distribution.

The non-CO_2 greenhouse gases make an important contribution to the realisation of the Dutch target, especially to the less far-reaching national targets. In the flat rate variant of 8% reduction, over one fourth[18] of the required 52 Mtons reduction is achieved by non-CO_2 emissions. In the equal burden variant the contribution of non-

[18] A cost free 50% reduction of HFCs has already been included in this calculation. If values without this cost free reduction are assumed, the total required reduction amounts to 57 Mtons and the non-CO_2 greenhouse gases contribute no less than one third of the required reduction.

CO_2 greenhouse gases amounts to almost half of the more than 22 Mtons reduction that is required. With both distributions the CO_2 emission grows in comparison with the reference year 1990, respectively with 7% and 23%.

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APPENDIX 1. GAS RESULTS PER COUNTRY

Table A.1 *VARIANT: Adjusted March97 distribution*

[% mutation compared to the reference year]

	Netherlands	Belgium	Germany	Italy	Sweden	Finland	Denmark	France	Greece	Portugal	Spain	UK
CO_2	6.8	-6.2	-18.7	-6.1	10.1	1.9	-9.3	9.1	37.3	40.0	24.9	0.5
CH_4	-53.3	-36.1	-56.8	16.2	-31.3	-34.1	-26.9	-17.7	-5.3	-11.2	5.7	-45.9
N_2O	-31.8	-2.0	-49.0	-19.1	24.4	17.6	-25.9	-37.6	-10.0	7.1	-2.8	-45.7
PFCs	-58.2	-100.0	-53.2	-43.6	53.8	166.7	-100.0	21.4	-53.8	-	-45.0	21.0
HFKs	-100.0	-100.0	186.4	-100.0	-100.0	-100.0	-100.0	150.0	74.8	66.7	-21.1	-93.6
SF_6	34.2	0.0	-10.0	19.9	-3.2	40.0	0.0	0.0	0.0	0.0	50.0	43.8
Total (% reference year)	-8.0	-9.5	-23.7	-6.7	5.9	0.3	-15.2	0.6	30.5	23.9	15.1	-11.1
Total reduction (Mton)	52	25	48	121	5	19	16	4	14	0	8	27
Price (US$$_{95}$/ton)	68.8	43.0	7.4	250.6	27.8	36.1	68.9	1.0	11.9	0.0	2.6	20.1

[reduction in 2010 in Mton CO_2 equivalent]

	EU	Netherlands	Belgium	Germany	Italy	Sweden	Finland	Denmark	France	Greece	Portugal	Spain	UK
CO_2	240.8	37.7	21.6	28.6	93.7	3.1	17.7	12.6	2.6	11.7	0.0	5.1	6.4
CH_4	35.8	2.2	1.5	6.4	9.9	0.8	0.6	1.1	0.8	1.6	0.0	1.9	8.8
N_2O	47.5	7.6	1.0	13.0	11.8	0.4	0.7	0.9	0.8	0.5	0.0	0.7	9.9
PFCs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFCs	11.7	4.7	1.0	0.0	2.2	0.5	0.1	1.0	0.0	0.3	0.0	0.0	2.0
SF_6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A.2 *VARIANT: Equal burden per unity GNP*

[% mutation compared to the reference year]

	Netherlands	Belgium	Germany	Italy	Sweden	Finland	Denmark	France	Greece	Portugal	Spain	UK
CO_2	22.7	6.1	-20.7	11.7	10.1	23.0	9.7	0.4	43.5	32.4	17.7	-0.5
CH_4	-53.3	-36.1	-58.7	15.9	-31.3	-32.6	-26.9	-28.9	0.4	-22.2	-6.5	-45.9
N_2O	-31.8	-2.0	-55.5	-19.3	24.4	19.3	-25.9	-50.5	-6.6	-1.7	-10.2	-45.7
PFCs	-58.2	-100.0	-53.2	-43.8	53.8	166.7	-100.0	21.4	-53.8	-	-45.0	21.0
HFCs	-41.5	40.4	-50.4	-77.6	-100.0	25.0	-68.8	-76.0	100.0	66.7	-21.5	-100.0
SF_6	34.2	0.0	-10.0	32.9	-3.2	40.0	0.0	0.0	0.0	0.0	50.0	43.8
Total (% 1990)	5.5	1.1	-26.6	8.4	5.8	18.2	-1.2	-9.7	36.7	15.6	7.3	-12.0
Total reduction (Mton)	23	11	83	44	5	8	5	56	8	6	31	34
Price ($US\$_{95}$/ton)	12.4	12.6	22.4	20.2	28.0	8.7	20.4	23.6	6.6	8.3	10.1	39.1

[reduction in 2010 in Mton CO_2 equivalent]

	EU	Netherlands	Belgium	Germany	Italy	Sweden	Finland	Denmark	France	Greece	Portugal	Spain	UK
CO_2	180.5	12.0	8.6	49.2	20.5	3.1	6.5	2.6	35.5	6.4	3.4	20.2	12.3
CH_4	52.1	2.2	1.5	8.7	10.0	0.8	0.5	1.1	8.0	1.0	1.9	7.6	8.8
N_2O	61.7	7.6	1.0	17.5	11.9	0.4	0.6	0.9	8.1	0.4	0.4	2.9	9.9
PFCs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFCs	18.5	0.7	0.2	7.6	1.5	0.5	0.0	0.7	4.3	0.0	0.0	0.0	3.0
SF_6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX 2. REDUCTION OF NON-CO_2 GHG EMISSIONS[19]

2.A Uncertainty in non-CO_2 GHG emission data

The uncertainty regarding non-CO_2 GHG emissions in 1990 is higher than the uncertainty regarding CO_2 emissions. The higher uncertainty is caused by the different accounting practice CO_2 emissions are in proportion with the consumption of fossil energy carriers (plus some corrections). Energy statistics are well established for all Western European countries. The uncertainty in CO_2 emissions is estimated to be in the range of 2-5%. The emissions for the other greenhouse gases are process emissions. They are either calculated on the basis of the consumption of substances (part of the HFC emissions, SF_6) or they are calculated on the basis of a proportionality to certain process inputs or outputs (CH_4, N_2O, PFC, part of the HFC emissions). Emissions (and storage) caused by land use change are based on land-use statistics and biomass growth estimates.

The emissions related to consumption (HFCs and SF_6) are measured according to different methods. In some cases/countries, the apparent consumption is measured (Tier 1-A method). In other cases/countries, the apparent consumption is adjusted for imports and exports of the substances within products (extended Tier 1-A method). Finally, some countries report estimates for actual emissions (on the basis of leakages and/or waste product statistics) (Tier 2 method). Different methods result in different estimates. If different countries use different calculation methods, the comparability is limited. Assuming that the actual emission is the 'accurate' value, the difference between the accounted and the reported emission may be a factor 2-5. In the following analysis, the actual emission is selected as accounting guideline, because it is thought to be in line with the IPCC guidelines.

Emissions related to process activities can be influenced by the specific emission coefficient. The different emission categories will be discussed separately.

The PFC emissions for new or refurbished aluminium smelters with point-feeders is one order of magnitude lower than the emissions from older types of smelters. Some countries account for such differences, while other countries use a more crude emission estimate. The emission is further influenced by the housekeeping of the smelter (control of the smelting bath composition). This adds another factor 2 to the uncertainty. The total uncertainty is a factor 3-4.

The most important N_2O sources are agriculture, transport and industry. The use of nitrogen fertiliser in the agricultural sector is a source of 30-50% of the total emission. This emission depends highly on the soil type. The application of fertilisers on grassland with high groundwater levels (like parts of the Netherlands) result in emissions

19 From: D.J. Gielen and T. Kram, *The consequences of the Kyoto agreement for energy related CO_2 policies in the European Union - analysis of non-CO_2 GHG emissions*, ECN Policy Studies, February 1998, ECN paper.

that are one order of magnitude higher than the emissions from the same fertilisers. applied on dry cropland. It is not clear to which extent these differences are accounted for in the current national emission estimates. It is estimated that the uncertainty regarding N_2O from agriculture is a factor 2-3. Regarding industrial emissions, the production of adipic acid and the production of nitric acid (HNO_3) are major emission sources. To some extent these emissions depend on the applied technology. Emissions can be reduced by end-of-pipe technology. The uncertainty in the emission estimates is a factor 1.5. Regarding emissions from transportation, the use of catalytic converters will result in increasing emissions. The uncertainty is estimated to be a factor 1.5. In conclusion, the uncertainty in the total N_2O emission is a factor 2.

The main CH_4 emission sources are agriculture, waste and volatile fuel. The uncertainty is not as high as for the other non-CO_2 GHGs. It is estimated that the uncertainty is 25%. It is interesting to note the different accounting practices for CH_4 from landfill use. The Netherlands use a time dependent first order model to estimate emissions. Most other countries use a time independent zero order model. As a consequence the emissions cannot be compared. Again, such differences are neglected in the current discussion.

Regarding carbon storage due to land use change, the forestry statistics are well established. It is thought that the uncertainty is 20%.

Given the composition of the non-CO_2 GHG emissions and of their sources in the EU Member States, the uncertainties regarding non-CO_2 GHG emissions are in the range of a factor 1.5-2. Table A.3 shows the relative importance of the non-CO_2 GHGs in the total CO_2 equivalent emissions of all the GHGs, which gives an indication of the relative weight of the uncertainty range for non-CO_2 GHGs for total GHG emissions.

Table A.3 *Function of CO_2 and non-CO_2 GHG emissions [1990/1995]*

	CO_2	Non-CO_2
Belgium	82%	18%
Denmark	71%	29%
Finland	83%	17%
France	75%	25%
Germany	83%	17%
Greece	83%	17%
Italy	80%	20%
Netherlands	74%	26%
Portugal	67%	33%
Spain	71%	29%
Sweden	83%	17%
United Kingdom	77%	23%
Total	79%	21%

2.B Additional emission reduction options and their costs for non-CO_2 GHGs

CH_4

Waste

Costs for methane recovery from waste disposal sites (landfills) range from 0.12 to 0.49 ECU per kg methane (i.e. 6-23 ECU/t CO_2 equivalents). The maximum recovery efficiency for the whole landfill life cycle is 55% [6]. The closer the drainage pipes, the higher the efficiency, but the higher the costs. Total potential in the EU: 150 PJ (70 Mtons CO_2 equivalents) (based on [7]).

Agriculture

Agricultural emissions represent one third to two thirds of the CH_4 emissions in the individual countries. Ruminants and manure storage are main emission sources. A split of the emissions over both categories is not available. Worldwide, the ratio of the emissions from ruminants and manure storage is 8:1.5. In the Netherlands, the ratio is 4:1 [8]. This ratio is probably also valid for Western Europe.

Methane emissions associated with enteric fermentation in ruminants range from 3-8% of gross feed intake. For the vast majority of the world's domestic ruminants consuming a wide range of diets under common production circumstances, CH_4 emissions are equivalent to 6% of the gross energy fodder intake. Opportunities for reducing CH_4 emissions from intensively managed cattle are generally aimed at higher product yields per unit of food intake [9]:

- genetic improvement (-10%),
- use of bovine growth hormones (-10%),
- improved feed formulation (-10%),
- a higher protein gain/fat gain ratio (-20%).

Together, these measures are thought to decrease CH_4 emissions from ruminants by 30%. Most of these measures will have limited costs once they are developed. However, genetic improvements and growth hormones face major consumer opposition in Europe. As a consequence, the potential for Europe is thought to be limited to a 10% improvement (3% of total CH_4 emissions) at zero cost. One must add that this is a fairly optimistic estimate for 2010.

Concerning manure storage, covered lagoons pose a major reduction option. Approximately 40% emission reduction is possible. However, the potential for total CH_4 emissions is limited to 2-3%. Centralized biogas plants exclusively based on the digestion of animal manure are not profitable under the present technological and economic conditions [10]. If 10-25% easily convertible organic matter is added, the plants can achieve break-even conditions, as examples in Denmark show. However, the profitability depends critically on the electricity revenues. In other countries with lower electricity prices the situation is less favourable [11].

Mining

Fossil fuel related emissions are mainly accounted for by deep coal mining. The emissions are in the range of 5-15 kg CO_2/GJ coal, depending on the mine depth (higher for deeper mines). Mine closures in Germany and the UK are considered in the emission estimates. The remaining (relatively insignificant) emissions from deep mines can be reduced by 80-90% before, during, or after the mining of the coal.

N_2O

Industrial N_2O emissions are related to the production of nitric acid (HNO_3) and the production of adipic acid, an intermediate in the nylon 6.6 production. Emissions can be reduced by catalytic conversion of N_2O. Emission reduction costs are in the range of 1-3 ECU/t CO_2 equivalent (see Appendix 2.C).

PFCs

PFC emissions are predominantly related to primary aluminium production. These emissions arise during periods when the alumina concentration in the smelter bath is too low. This causes short-circuiting of the cell, the so-called 'anode effect'. Improved control of the alumina concentration can reduce the anode effect by one order of magnitude. Modern smelters use so-called point feeders for improved alumina concentration control. Autonomous replacement of existing aluminium smelters or upgrading the existing smelters will result in a considerable reduction of these emissions. On the long run, the development of inert anodes can reduce PFC emission to zero. However, successful development of inert anodes before 2010 seems unlikely. The average life of an aluminium smelter is between 25 and 30 years. An autonomous reduction by 75-90% in the next two decades seems likely in the countries with existing smelters.

HFCs

HFC emissions can be split into emissions in production (the bulk of HFC-23 emissions) and emissions during use (from refrigerators, air conditioning equipment etc.). These emissions can be reduced significantly through reduction of leakages and through substitution of cooling agents. For example the high HFC emission for the Netherlands is accounted for by HFC-23, by-product from HCFC-22 production. The emission can be reduced by 90% through installation of cracking installations and after-burners [12].

SF_6

The bulk of SF_6 is used for high voltage equipment. The emissions are caused by leakages and waste handling of old equipment. The introduction of new sealing materials, the chemical and mechanical treatment of flanges and the improvement of shield welding techniques should help to decrease this leakage rate. Moreover, it is possible to install SF_6 leakage detection cameras. Integrated chain management strategies can be developed for old equipment. The potential for emission reduction is 20-40%. However, cost data have not been encountered. These options have not been considered in the analysis.

Land use change

Land use change refers to the carbon storage in soil and trees. The costs are accounted for by land costs, plantation costs and carbon storage potentials. Costs and potentials will depend on the future land use (production forests or sec carbon storage). The carbon storage option seems more likely, if the surplus wood situation in Europe is considered. Assuming 50 years of carbon storage, 5-10 ton CO_2 storage per ha per year, 1000 ECU/ha/year, costs are 100-200 ECU/ton CO_2. This measure does not seem cost-effective within the framework of the Kyoto agreement. However, one must emphasise that new forests can provide major secondary benefits. Wood production, recreation and erosion control are examples of secondary benefits. The distribution of forestry costs between these categories can significantly reduce emission reduction costs.

2.C Reduction of industrial N_2O emissions

The countries of the European Union (excluding Italy, Spain, Portugal) reported for 1990 an industrial N_2O emission of 306 Gigagrams [13]. This emission equals 95 Mtons CO_2 equivalents (compared to a total emission of approximately 4500 Mtons CO_2 equivalents). Two industrial processes account for the bulk of these process emissions. The first one is the production of nitric acid. The second one is the production of adipic acid.

Nitric acid production

Western European nitric acid (HNO_3) production amounted to 18.3 Mtons in 1989. The process emission is approximately 3 ton CO_2 equivalents per ton HNO_3. The total Western European emission from this source is approximately 60 Mtons CO_2 equivalents per year [14].

The N_2O concentration in the off-gases is in the range of 500-3000 ppm. Emissions can be reduced by more than 90% through end-of-pipe equipment, based on catalytic conversion. The concentration of N_2O in the off-gases is so low that special ovens must be installed to heat the off-gases to the minimum temperature of 300 ^{0}C.

Emission abatement costs can be calculated on the basis of a case study for a specific plant [15]. A nitric acid plant produces 80.000 m^3 off-gases per hour, containing 500 ppm of N_2O. This equals a total emission of 0.68 kt N_2O per year. Based on a GWP of 310, this equals 210 kt CO_2 equivalents per year. The investment for an installation that achieves 90% emission reduction amounts to 1-2 million ECU. Annual costs for catalysts, labour, etc. amount to 200-350 thousand ECU. Assuming a plant life of 25 years and an interest rate of 10%, total costs amount to 310-570 thousand ECU per year. Emission abatement costs amount to 1.5-2.7 ECU per ton CO_2 equivalent.

Current research at ECN focuses on the optimisation of the N_2O conversion efficiency through improved selection of catalysts and temperature optimisation.

Adipic acid production

Western European adipic acid production amounted in 1992 to 650 kt [16]. Adipic acid is produced in 10-20 industrial plants. Adipic acid is an intermediate in the production of nylon 6.6. Its chemical structure is $COOH(CH_2)_4COOH$. It is produced from cyclohexane, that is converted into a mixture of cyclohexanol and cyclohexenone by catalytic oxidation. The mixture is catalytically converted into adipic acid. Two catalyst systems are applied. One uses HNO_3, the other one uses oxygen. In the system that uses HNO_3, significant amounts of N_2O are generated as by-product. The N_2O- concentration in the off-gases is 20 volume %. The N_2O emission amounts to 180 kg/t adipic acid (based on [-16th 17]). This equals a CO_2 emission of 60 t/t adipic acid. For the whole of Western Europe, the emission equals 40 Mtons CO_2. If oxygen is used, no N_2O is produced. However, this new process is not yet widely applied. Other new process routes start from butadiene. In conclusion, alternative process routes can on the long term easily reduce the N_2O emissions in adipic acid production.

On the mid-term (the next 10 years), catalytic reduction of N_2O in exhaust gases poses the most attractive alternative. The catalysts are available, the main technological problem is the heat that is produced. Cooling is required to prevent overheating of the equipment [-15th].

The annual costs of catalytic conversion equipment are estimated to be lower than for nitric acid plants, because the oven costs can be saved. Assuming costs of 1 million ECU per plant and assuming an emission of 1 Mton per plant, emission reduction costs are 1 ECU/t CO_2 equivalents.

Conclusions

The total of N_2O emissions for HNO_3 production and for adipic acid production, based on bottom-up estimates, is 100 Mtons per year, N_2O abatement constitutes for both processes a cost-effective option for greenhouse gas emission reduction. Emission reduction costs are between 1 and 2.7 ECU/t CO_2 equivalents. The catalysts are available, retrofit of existing production plants is feasible before 2010. Retrofit can reduce the emissions by more than 90%. Additional research focuses currently on the optimisation of the N_2O conversion efficiency.

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