Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change

Summary Report for Policy Makers

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http://europa.eu.int/comm/environment/enveco

http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

Preface

This report summarises the results of a two year project performed by a team of experts from ECOFYS (NL), AEA Technology (UK) and the National Technical University of Athens (NTUA, GR). The project resulted in both a bottom-up (with the GENESIS database) and a top-down (with the PRIMES model) analysis of the allocation of objectives for different sectors and greenhouse gases, that would enable the European Union to meet its Kyoto target at the least-cost.

This Policy Maker's Summary is based on the following two reports:

- The 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change: Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU' written by ECOFYS and AEA Technology and in turn based on various sector reports.
- The 'Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU' written by NTUA.

During the preparation of the underlying reports the project team received significant input from a considerable number of experts. In particular, several panels of experts in Brussels discussed draft versions of the sector reports on November 24, 1999 and on March 29 and 30, 2000, and made a number of specific and more general comments and suggestions. Also, after the workshops, many experts and industry organisations – such as Ceramunie, CEPI, CEFIC, Eurofer, Europia, EAA, EISI, CPIU and others – gave their comments on the adapted version of these reports. Furthermore, the project team received many constructive comments from representatives of the European Commission, notably Matti Vainio of the DG Environment. The authors would like to thank all these people for their valuable input to this project. For this summary their suggestions were considered wherever possible in the text. However, specific comments can be found in the bottom-up and top-down reports as well as in the sector studies.

The project team[*)] consisted of the following people:

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The authors would like to thank all team members for their constructive input and co-operation.

Utrecht, February 2001

[*)] The contents, conclusions and recommendations of this study are made by the project team and do not necessarily reflect the views of the European Commission, or the experts that gave their comments to draft versions of the study.
Due to a technical inaccuracy, section concerning methane emissions was incorrect. In this version that section is changed (p. 14), and marked in red colour.

EXECUTIVE SUMMARY

Background

This report summarises the results of a two year study to identify a least-cost allocation of objectives for different sectors and greenhouse gases that allows the European Union to reduce its greenhouse gas emissions by 8% by 2008 – 2012 compared to 1990 emissions. This is the level stipulated by the commitments in the Kyoto Protocol. This approach will fully maintain the environmental integrity of the Kyoto Protocol, while identifying those policies and measures that achieve the Kyoto target in a manner that minimises the cost. Simply, the intention is to identify a least-cost allocation so that the cost of production of energy and other goods would increase as little as possible.

An important back-drop to this study is the fact that often, a reduction target is allocated uniformly to different sectors (i.e. an –8% reduction is allocated to all sectors). This is done because the regulator has no information on the reduction potential in the individual sectors and is consequently forced to use a "one-size-fits-all" approach. However, this approach can prove to be very costly. In a recent European Commission study[1] it was shown that the cost of reaching the Kyoto target would more than double if each sector had to attain the same percentage emission reductions. In short, following a least-cost route, the EU Member States could make annual savings of € 11.5 billion compared to a situation where each sector has a uniform objective. There are different pathways to reach the Kyoto target and the objective of this study is to identify the cheapest one.

Caveats and coverage of the study

Even if the potentially cheapest allocation is identified, it does not automatically mean it should be adopted. Two of the most important reasons for deviating from an identified least cost allocation are that: *i)* some options may not be politically or otherwise feasible e.g. due to strong lobby group pressure or due to technical or social difficulties; and *ii)* choosing a longer time horizon than used in this study (2008-2012) could give rise to a different allocation, since the longer-term potential of technological progress is taken into account. Such consideration of allocations was beyond the scope of this study.

Some options, such as fuel cells, have not been included in this study because of their technological limitations and expected development up to 2010. Thus, deviations from the least-cost objectives set out in this study may be reasonable, if there is evidence that setting tougher objectives for a particular sector would induce further technological development that would pay off in the subsequent commitment periods.

While the results of this study are based on a state-of-the-art methodology and the input data was extensively examined, it is possible that some mitigation options have been omitted, or that the potential of some measures has been over or under-estimated. Thus, the results presented should be used with care. This caveat applies

[1] See "The Economic Effects of EU-wide Industry-Level Emission Trading to Reduce Greenhouse Gases - Results from PRIMES model", available at: http://europa.eu.int/comm/environment/enveco/.

even more when considering the results for separate Member States. This is because, for instance, it has not been possible to take into account all local circumstances when mitigation options have been defined. However, it is felt that the results by Member State are an important additional input to the EU endeavours to reach the Kyoto target most cost-effectively.

Due to the extensive coverage of all gases and due to the unavailability of detailed data in some sectors (e.g. aviation) it has not been possible to cover all sectors equally deeply. Thus, due to such information constraints it is possible that some reduction opportunities are missed. This would introduce a bias which would lead to an overestimation of total compliance costs and to a lower reduction objective for the sector where data is not available.

As the coverage of this study is wide there are more uncertainties attached to the results of this study than if the scope had only been for e.g. energy related CO_2 emissions. However, due to a rigorous and consistent analytical treatment of all greenhouse gases, it is believed that this study is relatively unbiased and thus an important contribution to understanding the costs of mitigation options of greenhouse gases.

This report is the first time that all greenhouse gases have been included in an EU wide study. However, due to paucity of data, land-use change and the corresponding changes in biological sinks have not been included. Furthermore, for the purposes of this study, it was assumed that the EU would reach its target without using the flexible mechanisms[2].

Methodologies and examination of input data

The study combines a “top-down” and a “bottom-up” methodological approach and compares them as far as possible. As both approaches have their strengths and weaknesses, they complement each other, and increase understanding of different cost-effective greenhouse gas mitigation options.

1. In the “top-down” approach, the PRIMES model is used in which all options are analysed simultaneously. Here, it is more difficult to separate distinct options from one another. Thus, it is unclear what exactly the results imply from a policy point of view. Also, the “top-down” approach is less detailed compared to the “bottom-up” approach. However, the advantage of the top-down approach is that the results are 100% consistent within the model. The “top-down” approach and the detailed results of the analysis are described in a separate report, prepared by the National Technical University of Athens[3].

2. In the “bottom-up” approach, different technological options for the reduction of greenhouse gas emissions were identified, their investment and operation costs calculated and, finally, the cost per ton of CO_2 equivalent determined. The

[2] These flexible mechanism are International Emissions Trading, Joint Implementation and Clean Development Mechanism. The EU would most likely pay other Parties of the Kyoto Protocol so that they would take action to reduce their greenhouse gas emissions and correspondingly, the EU would need to mitigate less within its area. In such a case the least-cost allocation would change to some extent. It was beyond the scope of this study to analyse such cases.

[3] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down analysis of greenhouse gas emission reduction possibilities in the EU, National Technical University of Athens, Athens, March 2001

"bottom-up" approach and the results of the analysis are described in a separate report[4] and in several sector reports, which were prepared by Ecofys Energy and Environment and AEA Technology Environment. The advantage of the "bottom-up" approach is that the options for reducing greenhouse gas emissions are clear and easy to understand. However, it can not dynamically analyse simultaneous or behavioural changes[5] in demand and supply of energy, as is the case in the PRIMES model.

The assumptions and the data used in this study were examined in detail by industry and NGO experts as well as the European Commission staff. The examination was carried out in seven workshops, four of which were held in November 1999 and three in March 2000, as well as with bilateral contacts. Given the extensive coverage of this study, it has not been possible to include all suggestions arising from the workshops in the final analysis. Where this has not been possible, or in cases where differences of opinion have ensued (e.g. concerning forecasts of sector growth), the issues have been highlighted in a transparent manner in the sector specific reports to allow possible follow-up work.

EU-wide results

For non-CO_2 greenhouse gases and process emissions of CO_2 only the bottom-up approach was used. This study reports the base year emissions for 1990 or 1995 (the latter is used for the fluorinated gases - HFCs, PFCs and SF_6), the baseline emissions in 2010 and identifies available mitigation options. These options were combined with the top-down analysis for energy related CO_2 emissions, resulting in the main findings of the study (Table A, full details in Annex 1). The marginal cost for emission reduction would be $€_{99}$ 20 per tCO_2 eq., taking a successful implementation of the ACEA agreement into account[6].

Instead of each sector having to reduce its greenhouse gas emissions by 8% from 1990 emission levels, the least cost allocation methodology implies that some sectors need to reduce their emissions by more than 8%. These sectors are energy supply (11%), fossil fuel extraction (46%), industry (26%), agriculture (8%) and waste (28%). It should be noted that since the projected growth of greenhouse gas emissions in these sectors is negative (with the exception of energy supply), the real effort needed to make the required reductions is less than it appears. Taking this into account, the real reductions that these sectors would need to make from their projected 2010 emissions are much lower: for fossil fuel extraction (16%), industry (12%), agriculture (4%) and waste (13%). Emissions in the remaining sectors would need to be reduced from their projected levels in 2010 as follows: transport (4%) (this includes the full implementation of the ACEA agreement), households (6%), commercial and public services (15%). The overall weighted reduction remains at 8% from 1990.

[4] C. Hendriks, D. de Jager, K. Blok et al. (2001): Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU, Ecofys and AEA Technology, Utrecht, March 2001

[5] For instance, if the price of oil increased, renewable energy would become more attractive, and power generators would shift towards renewables. The larger the increase in the price of oil, the more there would be a shift towards substituting energy sources. In a top-down approach based on an energy systems model like PRIMES, these changes can be analysed but a detailed "bottom-up" approach can handle such changes only partially.

[6] See footnote 7 in the main text.

Table A Summary of the EU-wide allocation of least-cost objectives for different sectors to reach the Kyoto target of –8% in 2010

EU-15 **Emission breakdown per sector *(top-down)***	**Direct emissions (Mt CO2 eq.)**				
	Emissions in 1990/95	*Baseline emissions in 2010*	***Cost-effective objective 2010***	*Change from 1990*	*Change from 2010 baseline*
Energy supply[1/2/]	1190	1206	**1054**	-11%	-13%
Non-CO_2 fossil fuel[3/]	95	61	**51**	-46%	-16%
Industry[2/]	894	759	**665**	-26%	-12%
Transport[4/]	753	984	**946**	26%	-4%
Households	447	445	**420**	-6%	-6%
Services	176	200	**170**	-3%	-15%
Agriculture	417	398	**382**	-8%	-4%
Waste	166	137	**119**	-28%	-13%
Total	**4138**	**4190**	3807	**-8%**	**-9%**

Note: The ACEA agreement is included in the baseline, the marginal cost is €$_{99}$ 20 per tCO_2 eq.

[1/] Energy supply comprises power and steam production and refineries.

[2/] Eurostat definition of sectors: Industrial boilers are allocated to industrial sectors.

[3/] Non-CO_2 greenhouse gas emissions from fossil fuel extraction, transport and distribution.

[4/] Due to data inavailability, emission data for the transport sector include international aviation, which is excluded in the IPCC inventory methodology.

Source: This study

According to the least-cost allocation of sectoral objectives EU-wide, the compliance costs for the EU would be €$_{99}$ 3.7 billion per annum for the period 2008-2012 (0.06% of EU GDP in 2010)[7]. Compared to the baseline, the cost increase will be limited for most sectors: the average electricity and steam generation costs would increase by 10%, energy costs for most energy demand sectors would increase by 5% at most. For example, costs for all household energy services and related equipment will increase by about €$_{99}$ 56 per household, per year.

The six most important ways for the EU to reach the Kyoto target in the most cost-effective manner are identified as being:

- Decarbonisation of energy supply
  - Further switching from coal to gas.
  - More efficient generation of power (e.g. increasing the share of Combined Heat and Power).
  - Increase in the use of renewable energy (notably biomass and wind energy).
- Improvement of energy efficiency, particularly in industry, households (retrofitting) and the services sector.
- Further reduction of nitrous oxide from the adipic acid industry and implementation of reduction options in the nitric acid industry.

[7] With the ACEA/JAMA/KAMA agreement incorporated in the baseline; full flexibility scenario, i.e. a European-wide allocation of least-cost objectives for different sectors. If the ACEA agreement was excluded from the baseline, the compliance costs would be €$_{99}$ 2.9 billion higher.

- Reduction of methane emission in coal mining, the oil and natural gas system as well as waste and agriculture sectors.
- Reduction of fluorinated gases in specific applications, e.g. industrial processes, mobile air conditioning and commercial refrigeration.
- Energy efficiency improvement measures in the transport system.

Results per Member State

Table A shows an EU-wide allocation of least-cost objectives for different sectors. If each Member State fulfils their target individually according to the Burden Sharing Agreement, the least-cost allocation changes by coincidence so little, that the percentages in Table A would not be altered significantly. However, the marginal abatement costs would increase from $€_{99}$ 20/tCO_2 eq. to $€_{99}$ 42/tCO_2 eq. (weighted EU average). Thus, the total compliance cost of all EU Member States would increase from $€_{99}$ 3.7 billion to $€_{99}$ 7.5 billion per annum. The marginal abatement cost in each Member State would range from $€_{99}$ 1/tCO_2 eq. to over $€_{99}$ 100/tCO_2 eq. Annex 2 disaggregates the results to each Member State, taking into account the Burden Sharing Agreement.

One way of interpreting the difference between the EU-wide allocation and the Member State based allocation approach is to identify this as a potential for EU-wide emission trading[8]. An alternative way to interpreted the difference is a recommendation for the allocation of a specific number of permits to those sectors that would be given the possibility to participate in emission trading and specific objectives to those sectors that are subject to other policies and measures. These interpretations are useful to keep in mind when using this study to identify policies and measures either at the EU level, i.e. in the Working Groups of the European Climate Change Programme, or in Member States.

Table B summarises the results:

Table B Marginal abatement and total compliance costs for both an EU-wide and a Member State allocation of least-cost objectives to reach the EU Kyoto target of –8% in 2010

	Marginal abatement cost in 2010	Total compliance cost in 2010
EU-wide allocation of least cost sectoral objectives ('full flexibility case')	$€_{99}$ 20/tCO_2 eq.	$€_{99}$ 3.7 billion/yr
Allocation of least cost sectoral objectives in each Member State ('burden sharing case')	$€_{99}$ 42/tCO_2 eq.	$€_{99}$ 7.5 billion/yr

Note: in both cases the amount of greenhouse gases reduced is exactly the same (331 Mt of CO_2 eq from 1990)

[8] In this case it would be (unrealistically) assumed that emission trading would be possible across all sectors and all greenhouse gases. Thus, EU-wide emission trade could save as much as half of EU Member States total compliance costs.

Recommendations

The objective of this study was not only to identify the least cost allocation of sector specific objectives but also to define which policies and measures would be most appropriate to realise such an allocation. In the context of this study, it was not possible or meaningful, to give recommendations on policies and measures to be undertaken to realise each reduction option identified. An attempt has been made in this summary for policy makers to suggest relevant policies and measures when appropriate. They are given in some cases in the sector specific chapters but mainly collected at the end of this summary. The highlights of the recommendations are:

1. Emission trading among all Member States in well defined sectors holds the potential for significant cost reductions (up to half of total compliance costs) in reducing greenhouse gas emissions to 8% less than 1990/1995 emissions levels. It is recommended to include not only energy related CO_2 emissions but also, when measurable, other greenhouse gases. Such gases would be process emissions of CO_2 in the cement, iron and steel, and chemical industries, PFC emissions from aluminium production, N_2O emissions from adipic and nitric acid production, HFC emissions from chemical industry (by-product of HCFC22 production) and process emissions of CH_4 in the oil and natural gas industry.
2. It is vital to fully implement all policies and measures, both at EU and Member State level, that are assumed to reduce greenhouse gas emissions. Examples are the ACEA agreement to reduce the average CO_2 emissions of new cars, the reductions of methane due to the implementation of the Landfill Directive and the action plan of the White Paper on Renewable Energy Sources. For combined heat and power, specific policies would need to be designed, preferably at the EU level, in order to increase its share option and to limit the possible negative impacts of the liberalisation on the European energy markets.
3. As the energy markets in the EU are currently undergoing liberalisation this may render more difficult the implementation of some CO_2 emission reduction options, in particular in combined heat and power. Therefore, the European Commission and the Member States should ensure that the transition period towards liberalised energy markets is as short as possible and, if required, additional policies and measures are designed to reduce possible negative impacts on emission reduction of greenhouse gases.
4. As energy consumption in public, commercial and residential buildings in the EU is still relatively high in comparison to attainable consumption levels, an EU-wide approach to reduce energy consumption is recommended. Such an approach might include the dissemination of information about successful policy instruments, further labelling of equipment and materials (e.g. for lighting and glazing) and research and development (e.g. concerning integrated approaches to low-energy and zero-energy buildings for the various climate zones in the EU). Retrofitting existing buildings for increased efficiency of energy use, better management of energy use in office buildings, carrying out energy audits of dwellings when they are handed over to new owners/tenants and building more energy efficient (both in terms of cooling and heating) new buildings are some options which offer significant reduction potentials.
5. The low cost options identified in the non-CO_2 gases in energy supply, industry, transport, agriculture and waste sectors should be fully exploited.

6. While beyond the remit of this study, it is clear that further reductions in the cost of compliance are possible thanks to research and development. Thus, research and development of emission reduction technologies should be further supported both at the EU and Member State levels. Such technologies could be made available before, during or after the first Kyoto commitment period. Examples include, fuel cells, renewable energy sources, CO_2 storage and catalysts for nitrous oxide emission reduction in the nitric acid industry and the transport sectors as well as reductions of HFC emission in cooling applications.

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INTRODUCTION

In 1997, the countries that are Parties to the United Nations Framework Convention on Climate Change agreed upon the Kyoto Protocol. In this protocol, industrialised countries committed themselves to limit and reduce greenhouse gas emissions in the period 2008 – 2012 to 5.2% less than the 1990 (or 1995) level. The Member States of the European Union jointly committed themselves to reduce their emissions by 8% compared to 1990 in this period. In 1998, the Member States agreed to share the 8% target so that some Member States would commit to a higher reduction target while others were allowed to increase their emissions[1].

The 8% reduction target applies to all important greenhouse gases that are emitted through human activity and not covered by the Montreal Protocol[2]: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF_6. For the latter three categories, 1995 can be taken as a base year instead of 1990. Changes in land use were included as options in the Kyoto Protocol but these and the corresponding changes in biological sinks (forests and soils) have not been included in this study, mainly due to the uncertainty in political positions regarding the use of these options in the Protocol ratification process. In the Kyoto Protocol, the Parties agreed that targets could be reached in a flexible manner but for the purpose of this study, it was assumed that the EU would reach its target without using these mechanisms[3].

The cost-effectiveness of mitigation options is an important criterion in developing policies to reduce greenhouse gas emissions. For the European Union as a whole, it is worthwhile focusing on those emission reduction options that show the lowest costs per unit of greenhouse gas avoided, disregarding the country, the sector or the type of gas. To date, an extended overview of costs of emission reduction options was lacking and this study is the first comprehensive and integrated attempt to cover the whole range of greenhouse gases, sectors and Member States in the European Union.

Purpose and methodology

According to the terms of reference set out for this study, the main objectives were:

- to determine the most cost-effective distribution of emission reductions between different sectors and gases to meet the EU quantitative reduction objective for greenhouse gases under the Kyoto protocol; and
- to identify cost-effective policies and measures for all sectors and gases in order to meet the emission reduction goals.

[1] Council conclusions of 16/6/1998

[2] The Montreal Protocol phases out the use of CFCs and HCFCs which deplete stratospheric ozone. These gases are also potent greenhouse gases.

[3] These flexible mechamisms are International Emissions Trading, Joint Implementation and Clean Development Mechanism. The EU would most likely pay other Parties of the Kyoto Protocol so that they would take action to reduce their greenhouse gas emissions and correspondingly, the EU would need to mitigate less within its area. In such a case the least-cost allocation would change to some extent. It was beyond the scope of this study to analyse such cases.

In order to fulfil these objectives two methodologies were used:

1. A top-down approach, which uses an integrated energy-economy model, PRIMES, that simulates the European Union energy system[4].
2. A bottom-up approach, which makes an engineering-economic analysis of individual emission reduction options using the GENESIS database[5].

Both top-down and bottom-up methodologies were used to analyse energy related CO_2 emissions. An attempt was made to compare the results of these two methodologies. As the PRIMES model includes only energy related CO_2 emissions, only the bottom-up approach was used for non-CO_2 gases and for process related CO_2 emissions. The top-down analysis builds on the baseline developed in the "Shared Analysis" project[6].

Methodological summaries of the top-down and bottom-up are given at the beginning of the sections where results of the approaches are given. An overall methodologial description is included in Annex 4.

It should be noted that the results of this report are sensitive to the assumptions affecting the growth of greenhouse gas emissions in the baseline. Several industry organisations have suggested that the PRIMES model baseline assumptions should be amended either up (e.g. aluminium production) or down (e.g. cement and fertilisers). These issues need to be kept in mind with the baseline is updated.

Representation of emissions

The sectoral emission breakdown as presented in this study is not in complete accordance with the IPCC guidelines. This notably applies to energy related CO_2 emissions from autoproduction which is allocated to the energy supply sector in this study and not to the sectors where emissions actually occur (see Annex 3 for details). Furthermore, due to data unavailability, emission data for aviation includes both domestic and international aviation. However, according to the IPCC guidelines only domestic aviation should be included in national inventories. As the growth rate of international aviation is most likely higher than domestic, the growth of emissions of aviation are likely to be overestimates, compared to the national inventories. These differences need to be taken into account when comparing the results of this study with IPCC (detailed) inventory data.

In this study, CO_2 emissions from electricity and steam production and refineries are allocated either to the energy supply sector (as *direct emissions* of that sector), or to the energy end-use sectors as *indirect emissions*. The sum of all indirect emissions addd up to the direct CO_2 emissions of the energy supply sector. The bottom-up analysis presents total (direct and indirect) emissions only (see Annex 3).

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[4] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down analysis of greenhouse gas emission reduction possibilities in the EU, National Technical University of Athens, Athens, March 2001

[5] C. Hendriks, D. de Jager, K. Blok et al. (2001): Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU, Ecofys and AEA Technology, Utrecht, March 2001

[6] P. Capros: European Union Energy Outlook to 2020, European Commission – Directorate General for Energy special issue of "Energy in Europe", catalogue number CS-24-99-130-EN-C, ISBN 92-828-7533-4, 1999.

Structure of the report

In this summary for policy makers, the 1990 emission level and the projected 2010 baseline emissions are first described. The main results of the analysis of the top-down and bottom-up approaches are then presented. This is followed by a sector-by-sector breakdown identifying the main options for cost-effective reduction of greenhouse gases. Finally, conclusions are drawn and recommendations are given for policies and measures to attain the least-cost allocation that has been identified in this study. Annexes 1 and 2 to this summary give detailed tables at EU and Member State level, by sector and greenhouse gas. Unless otherwise stated, all monetary figures in this study refer to euros (€) in 1999 price level.

GREENHOUSE GAS EMISSIONS IN 1990 AND BASELINE EMISSIONS IN 2010

In Table 1 an overview is given of 1990 emissions of carbon dioxide, methane, nitrous oxide and for the other three categories of greenhouse gases for 1995. The total emissions amount to 4,138 Mt of CO_2 equivalent. This estimate does not include changes in atmospheric CO_2 levels due to land use change and forestry but it does include emissions from international aviation (transport sector).

Table 1 Overview of **direct** emissions of greenhouse gases in 1990 in the European Union and the projected baseline emissions in 2010 (including the ACEA agreement). All quantities are given in Mt of CO_2 equivalent (calculated with a time horizon of 100 years).

1990/1995 Mt CO_2-eq.	CO_2 Energy related	CO_2 Other	CH_4	N_2O	HFCs	PFCs	SF6	**Total**
Energy supply[1/]	1132	0	12	42	0	0	4	**1190**
Non-CO_2 fossil fuel emissions[2/]	0	0	95	0.3	0	0	0	**95**
Industry[1/]	561	157	0.4	113	51	10	1	**894**
Transport[3/]	735	0	5	12	1	0	0	**753**
Households	447	0	0	0	0	0	0	**447**
Services	176	0	0	0	0	0	0	**176**
Agriculture	17	0	194	206	0	0	0	**417**
Waste	0	8	155	4	0	0	0	**166**
Total 1990/1995	**3068**	**164**	**462**	**376**	**52**	**10**	**5**	**4138**

2010 baseline Mt CO_2-eq.	CO_2 Energy related	CO_2 Other	CH_4	N_2O	HFCs	PFCs	SF6	**Total**
Energy supply[1/]	1161	0	12	29	0	0	4	**1206**
Non-CO_2 fossil fuel emissions[2/]	0	0	60	0.3	0	0	0	**61**
Industry[1/]	450	176	0.4	53	52	25	3	**759**
Transport[3/]	919	0	3	38	25	0	0	**984**
Households	444	0	0	0	2	0	0	**445**
Services	194	0	0	0	6	0	0	**200**
Agriculture	26	0	178	194	0	0	0	**398**
Waste	0	8	126	4	0	0	0	**137**
Total 2010	**3193**	**183**	**380**	**317**	**84**	**25**	**7**	**4190**

[1/] Eurostat definition of sectors: Industrial boilers are allocated to industrial sectors.

[2/] Non-CO_2 greenhouse gas emissions from fossil fuel extraction, transport and distribution.

[3/] Due to data inavailability, emission data for aviation include international aviation, which is excluded in the IPCC inventory methodology.

In 1998, CO_2 emissions from the EU were at approximately the same level as in 1990[7]. In the baseline of this study, (i.e. a projection without the inclusion of additional policies directed at CO_2 emission reduction[8]) which includes the impact of the so called ACEA agreement[9], CO_2 emissions increase by about 4% from 1990 to 2010. The emissions of methane and nitrous oxide are projected to decrease because of, for example, measures taken in landfills and adipic acid production. The emissions of HFCs increased since 1990 and are expected to increase as these agents are used more and more as replacements for CFCs and HCFCs that are to be phased out under the Montreal Protocol. Total greenhouse gas emissions in the baseline scenario for the year 2010 (which is used as an indicative year for the first commitment period 2008 to 2012 of the Kyoto Protocol) are expected to increase slightly, by about 1%.

It must be noted that in the baseline a number of expected changes are already included, e.g. some degree of energy efficiency improvement, a substantial shift to natural gas in the power sector and some application of renewable energy sources. As it is by no means certain that these changes will occur it is very important that those measures that are included in the baseline are also implemented fully.

THE OVERALL PICTURE: INTEGRATED ANALYSIS OF EMISSION REDUCTION OPTIONS

The first of the two approaches that were used to determine emission reduction possibilities utilises an integrated modelling analysis of the energy system and the associated emissions: PRIMES, which is an integrated model of the energy and economic systems (a partial equilibrium model). The complete energy system, including all supply and demand sectors, were modelled in connection with the modelling of the economic system. Technologies were explicitly modelled giving significant emphasis to the power and steam supply sector.

The model simulates future behaviour by taking a representative agent of a sector that performs a stepwise set of decisions to configure production and energy use in that sector. Levels of physical production, degrees of recycling and possible structural changes in sub-sectors were calculated. In addition, technologies for each energy use were chosen, the capital replacement procedure managed and the fuels selected. The behaviour of agents was simulated using sector-specific discount rates as follows: industrial sectors, services and agriculture 12%; households and passenger transport 17.5%; public transport 8%; aviation, navigation, trucks 12%; power and steam generation 8%.

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[7] M. Ritter and B. Gugele: Annual European Community Greenhouse Gas Inventory 1990-1998. Submission to the secretariat of the UNFCCC; European Environment Agency, Copenhagen, May 2000.

[8] For energy related CO_2 emissions the PRIMES baseline is used, for process emissions of CO_2 and non-CO_2 greenhouse gas emissions new baseline data were developed from the bottom-up study, which are in compliance with the PRIMES baseline for CO_2.

[9] The European Commission concluded in 1998 and 1999 agreements with European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturers to lower the average fleet consumption of new cars to 140 g/km by 2008 and 2009. As North American car manufacturers are all present in the EU, the ACEA agreement covers also them. This study estimated that the ACEA agreement reduces annual CO_2 emissions by about 80 Mt in 2008-2012. Without the ACEA agreement the baseline emissions would increase by 35% (and not by 25% as used in this study).

The baseline development used as a starting point in this study was developed in the extended Shared Analysis project. The 2010 baseline (including the ACEA agreement) for energy related CO_2 emissions shown in Table 1 are taken from this project.

In the baseline, the monetary value of CO_2 emissions was set at zero. By attaching a value to reducing emissions of CO_2, the choices made by actors will change. The PRIMES model was re-run using several values of emission reduction and presents the sectoral and/or Member State breakdown of emissions under that constraint as well as the marginal cost of carbon dioxide emission abatement. The results can be interpreted as the effect of a carbon tax in an economy with no market barriers and no market failures.

An example of these results is shown in Annex 4 which gives an indication of the sensitivity of carbon dioxide emissions to the value of carbon dioxide avoided. The results show a gradual decrease of emissions in the case of increasing value attached to carbon dioxide mitigation. A reduction of carbon dioxide emissions of 8% would be achieved at an avoided carbon dioxide value of $€_{99}$ 34 per tCO_2 eq. (ACEA agreement included in the baseline).

The analysis of energy-related CO_2 emissions of the PRIMES model are complemented by the GENESIS bottom-up estimates of non-energy related CO_2 emissions as well as by non-CO_2 greenhouse gases (see next section for details) in the 'meta-analysis' that combines the two approaches. The adoption of various technologies was analysed using a 4% discount rate. Hence, the non-CO_2 greenhouse gases were integrated into the PRIMES model in an ad hoc manner. As most major emission reduction options for non-CO_2 greenhouse gases are independent from the energy sector, the results are judged to be sufficiently reliable.

From the model calculations in the 'meta-analysis' it is concluded that a reduction of 8% in all greenhouse gases by the year 2010 can be achieved at a value of $€_{99}$ 20 per tCO_2 equivalent avoided carbon dioxide. The breakdown of the direct and total (direct and allocated indirect) emissions by sector and by gas is given in Table 2. The full, more detailed table can be found in the annexes of this report.

From it can be seen that compared to the 1990/1995 level, energy related carbon dioxide emissions only need to be reduced by 5% (instead of the 8% average required) and methane and nitrous oxide have to decrease by about 25%. However, for the reduction effort the comparison with the 2010 baseline is analytically more correct as this wil show the additional <u>effort</u> that the sector needs to undertake to reach the Kyoto target cost-effectively. Compared to the baseline level for the year 2010 both energy related carbon dioxide emissions and methane and nitrous oxide emissions need to be decreased by about 10% (8-11%). Compared to the 2010 baseline the remaining three gas categories (HFCs, PFCs, SF_6) need to be decreased by 27% to 53%.

Table 2 Distribution of direct and total (direct and indirect) emissions of greenhouse gases in 1990/1995, in the 2010 baseline and in the most cost-effective solution for 2010 where emissions are reduced by 8% compared to the 1990/1995 level. Results of the **meta-analysis** incorporating the PRIMES top-down approach for energy related CO_2 emissions and the bottom-up information on non-CO_2 greenhouse gases and process emissions of CO_2. The top table gives the breakdown into sectors and the bottom table the breakdown into gases.

EU-15 **Emission breakdown per sector (*top-down*)**	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990/95	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*	*Emissions in 1990/95*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*
Energy supply[1/2/]	**1190**	**1206**	**1054**	**-11%**	**-13%**	**58**	**45**	**42**	**-27%**	**-6%**
CO_2 (energy related)	1132	1161	1011	-11%	-13%					
autoproducers	*124*	*278*	*229*	*85%*	*-18%*					
utilities	*836*	*772*	*667*	*-20%*	*-14%*					
other	*172*	*111*	*115*	*-33%*	*4%*					
Non-CO_2	58	45	42	-27%	-6%	58	45	42	-27%	-6%
Non-CO_2 fossil fuel[3/]	**95**	**61**	**51**	**-46%**	**-16%**	**95**	**61**	**51**	**-46%**	**-16%**
Industry[2/]	**894**	**759**	**665**	**-26%**	**-12%**	**1383**	**1282**	**1125**	**-19%**	**-12%**
Iron and steel	196	158	145	-26%	-9%	253	200	183	-28%	-9%
Non-ferrous metals	24	22	13	-47%	-40%	66	42	30	-54%	-28%
Chemicals	243	121	81	-66%	-33%	362	257	201	-44%	-22%
Building Materials	201	212	208	3%	-2%	237	240	232	-2%	-3%
Paper and Pulp	29	22	20	-32%	-9%	69	106	92	34%	-13%
Food, drink, tobacco	46	35	26	-42%	-24%	89	107	91	2%	-15%
Other industries	155	189	172	11%	-9%	308	331	295	-4%	-11%
Transport	**753**	**984**	**946**	**26%**	**-4%**	**778**	**1019**	**975**	**25%**	**-4%**
CO_2 (energy related)	735	919	887	21%	-4%	760	953	916	21%	-4%
road	*624*	*741*	*724*	*16%*	*-2%*	*624*	*741*	*724*	*16%*	*-2%*
train	*9*	*2*	*2*	*-83%*	*-8%*	*34*	*36*	*31*	*-10%*	*-14%*
aviation [4/]	*82*	*150*	*135*	*65%*	*-10%*	*82*	*150*	*135*	*65%*	*-10%*
inl. navigation	*21*	*27*	*26*	*26%*	*-2%*	*21*	*27*	*26*	*26%*	*-2%*
Non-CO_2 (road)	18	65	59	222%	-10%	18	84	143	681%	70%
Households	**447**	**445**	**420**	**-6%**	**-6%**	**792**	**748**	**684**	**-14%**	**-9%**
Services	**176**	**200**	**170**	**-3%**	**-15%**	**448**	**500**	**428**	**-4%**	**-14%**
Agriculture	**417**	**398**	**382**	**-8%**	**-4%**	**417**	**398**	**382**	**-8%**	**-4%**
Waste	**166**	**137**	**119**	**-28%**	**-13%**	**166**	**137**	**119**	**-28%**	**-13%**
Total	**4138**	**4190**	**3807**	**-8%**	**-9%**	**4138**	**4190**	**3807**	**-8%**	**-9%**

Breakdown per gas	*Emissions in 1990/95*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990/95*	*Change from 2010 baseline*
CO_2 - energy related	3068	3193	2922	-5%	-8%
CO_2 - other	164	183	182	11%	-1%
Methane	462	380	345	-25%	-9%
Nitrous oxide	376	317	282	-25%	-11%
HFCs	52	84	54	3%	-36%
PFCs	10	25	19	87%	-27%
SF_6	5	7	3	-41%	-53%
Total	**4138**	**4190**	**3807**	**-8%**	**-9%**

[1/] The direct CO_2 emissions of energy supply are allocated to the energy demand sectors in the right part of the table representing direct and indirect emissions. Refineries are included in the energy supply sector.

[2/] Industrial boilers are allocated to industrial sectors.

[3/] Non-CO_2 greenhouse gas emissions from fossil fuel extraction, transport and distribution.

[4/] Due to data inavailability, emission data for aviation include international aviation, which is excluded in the IPCC inventory methodology.

In the transport sector the least cost objective would suggest that the growth of direct greenhouse gas emissions would be limited from +31% to +26%, compared to the 1990/1995 level. In the least cost allocation, the emissions of all other sectors would decrease, either moderately (less than about 10%; agriculture, services, households and the energy supply sector) or quite substantially (industry, waste and fossil fuel extraction, transport and distribution emissions).

Again, a quite different picture is seen when the reduction effort is compared to the 2010 baseline: moderate (4-6%) reduction efforts for agriculture, transport and households and stronger (12-16%) reduction efforts for industry, energy supply, waste, the services sector and fossil fuel related emissions.

EMISSION REDUCTION OPTIONS CONSIDERED IN MORE DETAIL: THE ENGINEERING-ECONOMIC ANALYSIS OF GENESIS

The second approach is the engineering-economic analysis of individual emission reduction options. This approach comprised the following steps:

- For each sector (or sub-sector) the various processes that cause energy use and greenhouse gas emissions (of both CO_2 and non-CO_2 greenhouse gases) were identified.
- For the relevant processes available technical emission reduction options were inventoried.
- Options that could make a contribution to emission reduction in the year 2010 were characterised according to the following aspects: emission reduction potential, investment costs, operation and maintenance costs, operational benefits (e.g. energy cost savings) and lifetime.

The information was then collected in the GENESIS database. The information on the individual options can be used to calculate total emission reduction potentials and associated mitigation costs by sector, by country and by gas.

The GENESIS database contains technology and cost information on over 250 reduction options (56 for the energy supply sector, 24 for fuel related emissions, 91 for industry, 17 for transport, 32 for households and services, 18 for agriculture and 13 for the waste sector). It should be noted that even this level of detail does not cover the full variety of options that are available. The potential and costs often depend on local conditions that can not be covered in a general database. However, differences between the Member States were taken into account, if relevant. For instance, differences in climate makes building insulation more effective in reducing emissions in Finland than in Spain. In considering these differences the study gives a reliable approximation of the emission reduction potentials and associated costs to the sector, Member State and on the European Union level.

The assembled information was used to generate an overview of emission reduction options, taking into account the following:

- The total potential for emission reduction was given, including the fraction of this reduction potential that is expected to occur autonomously. This was done to provide a complete overview of all the options. Also for the options for which autonomous implementation is expected, it will be important to monitor whether this actually is happening.
- For the calculation of the specific mitigation a 4% discount rate was used as the central rate (and varied to see if the results are sensitive to that rate), according to DG Environment cost guidelines.

A breakdown of the emission levels by sector and by gas under Kyoto target conditions is presented in Table 3. Emission reductions were calculated for the sector in which the emission reduction measure should be taken (for instance, electricity conservation in households is allocated to households and not to the energy sector where the actual emission reduction would occur). This means that no breakdown in direct and indirect emissions is presented and that the energy related CO_2 emissions of the energy supply sector are allocated to the sector where the energy is used (end-use sector).

Despite the different approach and economic parameters (discount rates for example), the distribution of total emissions per sector and gas show a similar pattern as the results of the top-down analysis. The bottom-up analysis shows a somewhat larger emission reduction potential in the energy end-use sectors (especially households) and a slightly higher emission reduction for CO_2 at the expense of methane. Note that the results of the top-down meta-analysis in Table 2 (incorporating bottom-up information on reduction options for non-CO_2 greenhouse gases and process emissions of CO_2) are not strictly comparable with the bottom-up results in Table 3 since the meta-analysis allocates industrial boilers to the industry sector, whereas the bottom-up approach is in accordance with the PRIMES/Shared Analysis approach in which these installations are allocated to the energy supply sector. For this reason the breakdown per sector is slightly different in between the tables. Box 1 shows a comparison of the two models using the same allocation methodology.

Table 3 Distribution of **total** emissions of greenhouse gases in 1990/1995 and in the most cost-effective solution for 2010 under Kyoto target conditions, by sector and by greenhouse gas. Results of the GENESIS **bottom-up approach**. The total figures relate to the sum of **direct** and **indirect** emissions.

EU-15 **Emission breakdown per sector (*bottom-up*)**	**Total (direct and indirect) emissions (Mt CO2 eq.)**[1/]		
	Emissions in 1990/95	*Cost-effective objective 2010*	*Change from 1990/95*
Energy supply - Non-CO_2 emissions	58	42	-27%
Non-CO_2 Fossil fuel emissions[2/]	95	51	-46%
Industry	1466	1113	-24%
Transport [3/]	775	1069	38%
Households	748	567	-24%
Services	413	434	5%
Agriculture	417	382	-8%
Waste	166	144	-14%
Total	**4138**	**3801**	**-8%**

Breakdown per gas	*Emissions in 1990/95*	*Cost-effective objective 2010*	*Change from 1990/95*
Carbon dioxide - energy related	3068	2893	-6%
Carbon dioxide - other	164	182	11%
Methane	462	370	-20%
Nitrous oxide	376	282	-25%
HFCs	52	53	1%
PFCs	10	19	87%
SF_6	5	3	-41%
Total	**4138**	**3801**	**-8%**

[1/] Primes / Shared Analysis definition of sectors: Industrial boilers are allocated to energy supply (the sectoral emission breakdown differs from other tables)

[2/] Non-CO_2 greenhouse gas emissions from fossil fuel extraction, transport and distribution.

[3/] Due to data inavailability, emission data for the transport sector include international aviation, which is excluded in the IPCC inventory methodology.

Box 1: Comparison of the PRIMES top-down and the GENESIS bottom-up approach

EU-15 Emission breakdown per sector	Total (direct and indirect) emissions (Mt CO2 eq.) [1/]										
		Top-down (1) (incl. ACEA)		*Top-down (2) (excl. ACEA)*		*Bottom-up (3)*		*Difference (1)-(3)*		*Difference (2)-(3)*	
	Emissions in 1990/95	*Cost-effective objective 2010*	*Change from 1990/95*	*Cost-effective objective 2010*	*Change from 1990/95*	*Cost-effective objective 2010*	*Change from 1990/95*	*Mt CO_2*	*% points*	*Mt CO_2*	*% points*
Energy supply - Non-CO_2	58	42	-27%	42	-27%	42	-27%	0	0%	0	0%
Non-CO_2 fossil fuel	95	51	-46%	51	-46%	51	-46%	0	0%	0	0%
Industry	1466	1129	-23%	1103	-25%	1113	-24%	16	1%	-11	1%
Transport	775	975	26%	1037	34%	1069	38%	-94	-12%	-31	-12%
Households	748	682	-9%	663	-11%	567	-24%	115	15%	97	15%
Services	413	426	3%	409	-1%	434	5%	-7	-2%	-25	-2%
Agriculture	417	382	-8%	382	-8%	382	-8%	1	0%	0	0%
Waste	166	119	-28%	119	-28%	144	-14%	-24	-15%	-24	-15%
Total	**4138**	**3807**	**-8%**	**3807**	**-8%**	**3801**	**-8%**	**6**	**0%**	**6**	**0%**

[1/] Primes / Shared Analysis definition of sectors: Industrial boilers are allocated to energy supply (the sectoral emission breakdown differs from other tables presented in this Policy Maker's Summary). The direct CO_2 emissions of energy supply are allocated to the energy demand sectors.

Despite the differences in approaches in the integrated modelling approach of PRIMES and the bottom-up analysis in the GENESIS database a comparison is possible to some extent. The table above shows the distribution of total emissions under Kyoto target conditions according to the top-down analysis (with and without the ACEA agreement incorporated in the baseline and using sector specific discount rates) and the bottom-up analysis (4% discount rate). The compliance costs in the top-down analysis are $€_{99}$ 20 (incl. ACEA) and $€_{99}$ 32 (excl. ACEA) per tCO_2-eq. respectively, whereas the bottom-up analysis gives marginal abatement costs of $€_{99}$ 25 per tCO_2-eq. If the bottom-up analysis uses the sector specific discount rates of the top-down approach, these costs increase to about $€_{99}$ 90 per tCO_2-eq.

As the ACEA agreement requires the implementation of measures with higher costs than the compliance costs given above, the cost-effective objective of the transport sector is higher in the 'excl. ACEA' case than in the 'incl. ACEA' case (62 Mt CO_2-eq. difference). The bottom-up results should be compared to the 'excl. ACEA' case. For most sectors the differences are small, except for transport, households and waste. The latter differences are the consequence of incorporating the effects of the Landfill Directive in the baseline but not in the bottom-up analysis: part of the associated options has relatively high costs and is therefore higher than the compliance cost level in the bottom-up analysis.

The top-down analysis uses the bottom-up information on emission reduction options for non-CO_2 greenhouse gases and process emissions of CO_2. Except for some differences in the applied baseline (as for the waste sector), the differences in the results should be explained by looking at the energy related CO_2 emissions. The information available in the GENESIS database indicates that the energy demand sectors may be modelled in PRIMES in a way that underestimates their reduction potential. Alternatively, the information from the PRIMES model shows that the GENESIS database does not consider all structural changes, modal split changes in transportation, shifts from primary to secondary materials, nuclear energy and other energy supply options. As a consequence, the cost-effective objective for the energy supply sector is lower in the top-down cases than in the bottom-up (e.g. 1029 Mt CO_2 for the energy related CO_2 emissions in the 'excl. ACEA case' and 1298 Mt CO_2 in the bottom-up analysis).

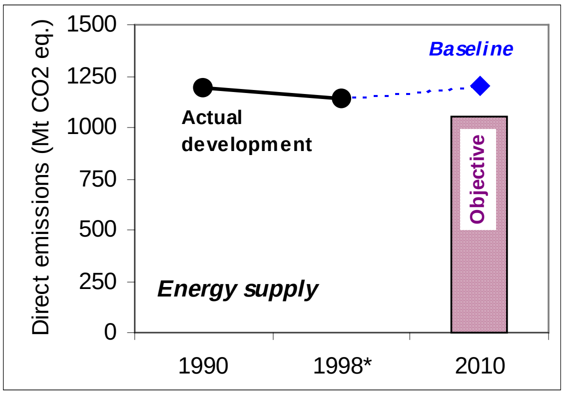
This explains the low cost-effective objective for households in the bottom-up results and slightly higher objective in the transport sector. The objectives for industry and services are approximately equal. However, in the top-down analysis this is as a result of the effect of significant emission reductions in the energy supply sector that are allocated to these sectors, whereas in the bottom-up case this level is reached with a higher share of energy efficiency improvement options.

THE EMISSION REDUCTION OPTIONS DISCUSSED BY SECTOR

In this section the main findings of this study will be discussed by sector, and possible policy consequences will be identified[10]. The main findings are the results of the 'meta-analysis' in which the top-down analysis for energy related CO_2 emissions is combined with the bottom-up analysis for non-CO_2 greenhouse gases and process emissions of CO_2 (see Table 2 and Annex 1). In the accompanying tables and graphs the 1990 emissions, the 2010 baseline emissions and the sectoral cost-effective objectives for 2010, the results of the meta-analysis, are depicted. Furthermore, the graphs show the emission levels in 1998. However, these figures are indicative, as for some non-CO_2 emission sources and sectors, data is not yet available[11].

Energy supply sector

Energy supply	**Direct emissions (Mt CO2 eq.)**				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	1132	1161	1011	-11%	-13%
industrial generators	124	251	203	64%	-19%
other generators	0	28	26	-	-7%
utilities	836	772	667	-20%	-14%
boilers	115	55	63	-45%	13%
refineries	74	42	51	-31%	19%
district heating	41	13	12	-71%	-9%
fuel extraction and refining	57	55	53	-8%	-4%
Non-CO_2	58	45	42	-27%	-6%
CH_4	12	12	12	0%	0%
N_2O	42	29	27	-36%	-6%
SF_6	4	4	3	-20%	-20%
Total	1190	1206	1054	-11%	-13%



The energy supply sector includes the production of electricity and steam for industrial processes and electricity production by utilities, as well as by refineries[12]. The energy supply sector is one of the important emitters of carbon dioxide. Furthermore, power trans-formers are a source of SF_6. In the baseline, emissions from this sector are expected to stabilise, despite a 30% projected growth of electricity production compared to 1995. This is mainly caused by a strong shift towards natural gas combined-cycle power plants and co-generation.

[10] It is important to note that by this sector-by-sector treatment cross-sectoral policies are overlooked. Example of such policies are carbon taxation and emission trading.
[11] Notably for fluorinated gases no sectoral breakdown is available. See also footnote 21. 1998 data are presented in Annex 1.
[12] Note that in the presentation of the results of the meta-analysis in this study the emissions of industrial boilers are allocated to the industry sector (unless stated otherwise).

The cost-effective objective implies a further emission reduction of about 150 Mt CO_2 (about 13% compared to the baseline). This is caused by a further shift towards the use of options above as well as the increased implementation of renewable energy sources. This is represented in Figure 1 which shows the development of electricity production by energy form for the year 1995, the 2010 baseline and the 2010 level under Kyoto target conditions. Figure 2 shows the changes in electricity and steam production by different sources. These figures clearly show that the increase in the use of natural gas is at the cost of solid and liquid fuel.

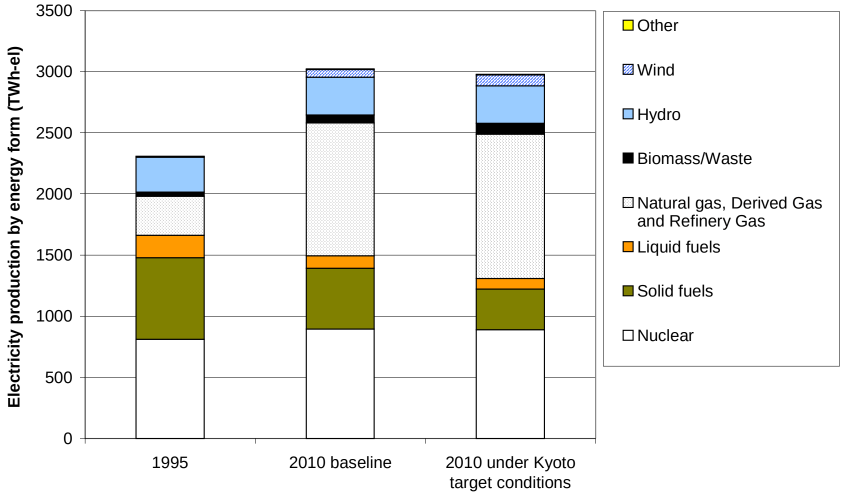


Figure 1 Electricity production by energy form in 1995, the 2010 baseline and the 2010 level under Kyoto target conditions

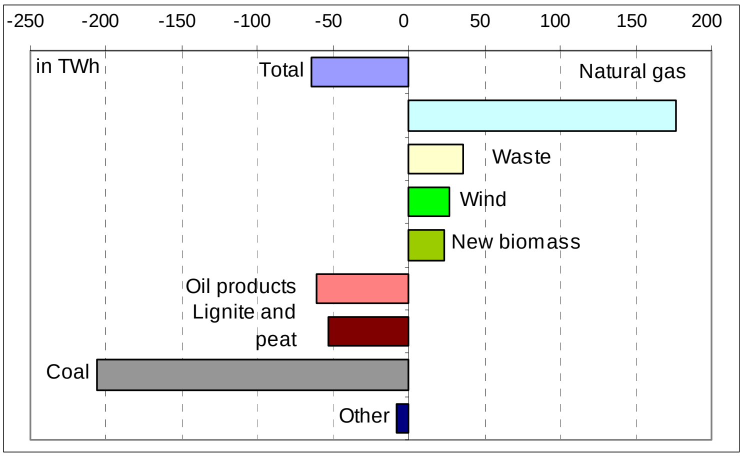


Figure 2 Impact on electricity and steam production of the achievement of the Kyoto target with least cost, compared to the 2010 baseline (full flexibility scenario, including ACEA agreement)

The cost-effective emission reduction potential from fuel shift is not boundless. Thus, during the second commitment period (i.e. after 2012) fuel shift is unlikely to be a significant option, and therefore more expensive reduction measures will be required. In order to reach the –8% target, according to the meta-analysis, the share of renewables in electricity and steam production would need to be about 10% (excluding waste) in 2010 (compared to about 8.7% in 1995 and 8.8% in the 2010 baseline). The greatest increase is seen in biomass (both electricity and heat production) and wind energy. Thus, in the least cost solution to reach the Kyoto target, the share of renewables in energy production would increase by 1.2 percentage points compared to the baseline[13].

The increase in natural gas consumption would be 13% above the baseline increase, which is considered quite manageable in terms of availability of gas in the EU and the neighbouring countries as well as in terms of the capacity to import gas.

Options outside the power and steam sector are energy efficiency improvement measures in refineries. According to a preliminary analysis of the bottom-up study, which needs to be further assessed in detail by experts in refineries, a reduction potential of about 23 Mt CO_2 equivalent is available, partly at zero or net negative costs (e.g. through the application of improved catalysts in refineries). However, reduction potential and costs are hard to determine as these options concern a limited number of refineries with large differences between them.

Important policy consequences are:

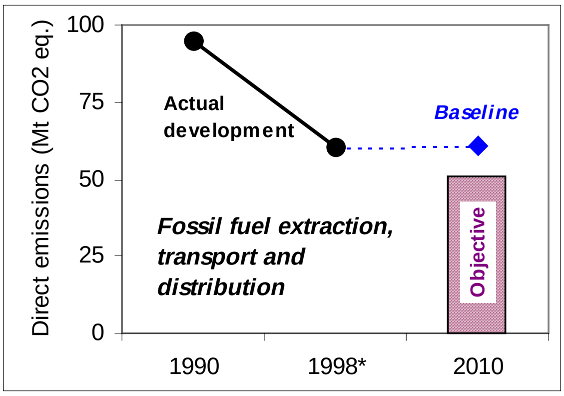
- One of the major conclusions to emerge from this analysis is the crucial role that the electricity and steam generation need to play in reducing emissions. Orchestrating this role may prove quite difficult in the circumstances of liberalised, mostly privately owned and competitive markets. It is important to recall that the reduction in emissions from these sectors are not only due to market forces, such as the relative prices of gas and coal, but also to a number of other factors, many of which are influenced by policy. Removal of all explicit or hidden subsidies to domestic coal and lignite (already initiated in the 2010 Baseline scenario) and transparency on fuel costs are of great importance. These include non-fossil fuel obligations, subsidies for renewables (or other measures in support of renewables), the difficulty of insuring nuclear plants, fair tariffs for co-generation and R&D support for promising generation technologies.
- The total potential of emission reduction options in the energy supply sector can keep emissions well below 1990 levels; a large fraction of the options can be assigned to the cost-effective packages. The meta-analysis shows that in order to reach the cost-effective objective the energy supply sector has to reduce its emissions by 11% compared to 1990 levels, at costs below $€_{99}$ 20/tCO_2 eq. In the longer term, additional biomass resources, offshore wind energy and CO_2 removal and storage are important options with significant reduction potentials.
- Fuel shift to natural gas is the most important option for the first commitment period. Although part of this shift is still expected to occur autonomously (i.e. without further policy interventions), realisation of the complete fuel shift can not be taken for granted, given the uncertain conditions in the European power market. It might be that substantial intervention will be needed to realise the full potential of the shift and to resolve most implementation barriers that occur during the transition phase towards complete liberalisation. For the same reason, the realisation of the potential for combined heat and power generation may require substantial policy support.
- Additionally, the inclusion of the energy supply sector in emission trading schemes, both at the Member State and the EU level, or an imposition of carbon taxes on energy supply would further support the shift to low-carbon fuels.

[13] Note that the target in the White Paper on Renewable Energy Sources (COM (97)599 final) is 12% of total gross inland consumption.

- Renewable energy sources have a high potential for emission reduction but are often expensive. In developing renewable energy policies, it needs to be considered that renewable energy is the key option in the longer term. Important additional benefits of renewable energy policies are the “learning-by-doing” effects that drive the cost of renewable energy sources down in the long term. Instruments with dynamic cost-effectiveness incentives, such as 'green' or renewable energy certificates, could become important and should be supported on a EU level. The implications of the co-existence of green certificates and CO_2 certificates should be examined.

Fossil fuel extraction, transport and distribution

Fossil fuel extraction, transport and distribution	**Direct emissions (Mt CO2 eq.)**				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
Non-CO_2					
CH_4	94.6	60.5	50.8	-46%	-16%
N_2O	0.3	0.3	0.3	0%	0%
Total	94.9	60.8	51.1	-46%	-16%



Methane emissions related to fossil fuel extraction, transport and distribution occur through coal mining, oil and natural gas upstream activities and the natural gas transport and distribution network. In the baseline, these emissions of methane are expected to decrease from 95 to 61 Mt of CO_2 equivalent, mainly due to the expected decrease in coal production in the EU. In total, an additional reduction potential of 34 Mt of CO_2 eq. is identified, of which 10 Mt CO_2 eq. is included in the cost-effective objective for this sector (which is 46% below 1990 emission levels). The most important reduction options are:

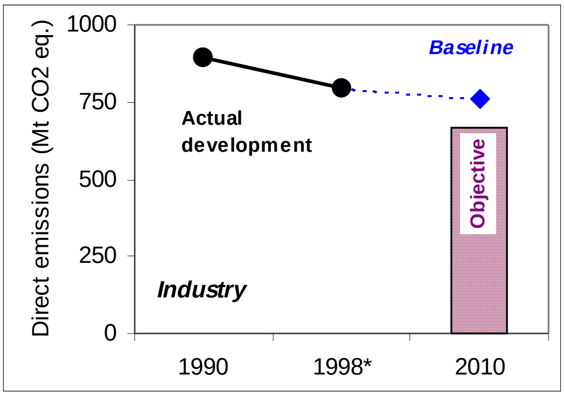
Methane emissions related to fossil fuel extraction, transport and distribution occur through coal mining, oil and natural gas upstream activities and the natural gas transport and distribution network. In the baseline, these emissions of methane are expected to decrease from 95 to 61 Mt of CO_2 equivalent, mainly due to the expected decrease in coal production in the EU. In total, an additional reduction potential of 34 Mt of CO_2 eq. is identified, of which 10 Mt CO_2 eq. is included in the cost-effective objective for this sector (which is 46% below 1990 emission levels). The most important reduction options are:

- Methane emission reduction from coal mining (almost 9 Mt of CO_2 equivalent) at near zero costs.
- Methane emission reduction from the natural gas system. From this amount about 1 Mt is inexpensive to implement. About 25 Mt (from which about 20 Mt in the distribution) is more expensive to implement (>€$_{99}$50/tCO_2).

Industry sector

Industry	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	561	450	416	-26%	-8%	1051	973	875	-17%	-10%
CO_2 (other)	157	176	175	11%	-1%	157	176	175	11%	-1%
CH_4	0.4	0.4	0.4	0%	0%	0.4	0.4	0.4	0%	0%
N_2O	113	53	26	-77%	-50%	113	53	26	-77%	-50%
HFC	51	52	30	-42%	-43%	51	52	30	-42%	-43%
PFC	10	25	19	87%	-27%	10	25	19	87%	-27%
SF_6	1	3	0	-100%	-100%	1	3	0	-100%	-100%
Total	894	759	665	-26%	-12%	1383	1282	1125	-19%	-12%

Note: the grown of baseline emissions depends on external assumptions of the growth of output in sectors. Some industry organisations have commented the baseline used inthis study being too high (e.g. fertiliser and cement) or too low (aluminium).



The manufacturing industry consists of a variety of sectors. From the point-of-view of greenhouse gas emissions, a number of energy-intensive sectors, including iron and steel production, the chemical industry and the cement industry are most important. Apart from energy-related CO_2, some process related CO_2 emissions are relevant. These include carbon dioxide from cement production; nitrous oxide from adipic acid and nitric acid production; and PFCs from aluminium production.

Energy-related direct emissions of carbon dioxide included in the baseline are expected to decrease by about 20% from 1990 levels. Some process-related emissions are likely to go down, especially nitrous oxide emissions from adipic acid production, which is already strongly reduced due to an ongoing inter-industry initiative. According to the 'meta-analysis' the overall cost-effective objective for the industry sector (including industrial boilers, but excluding industrial autoproduction in this sector) would be 665 Mt of CO_2 eq., i.e. down by 261 Mt of CO_2 eq. (or 26%) from 1990.

According to the bottom-up analysis, implementing all identified options with costs below €$_{99}$ 20/tCO_2 eq. would result in an emission level of about 17% below the 1990 total direct and indirect emissions[14].

A range of technologies that can improve energy efficiency is most important for CO_2 emission reduction. Some important options are: improved pressing and heat recovery in pulp and paper production, vapour recompression, de-bottlenecking in the petrochemical industry[15], and the application of thin slab casting techniques in iron and steel production. Capacity expansion and the replacement of existing plants, which may occur effectively autonomously, may lead to additional reductions.

Important emission reduction options for non-CO_2 greenhouse gases include:

[14] This includes emission reductions achieved in the energy sector through energy efficiency improvement of electricity and steam use as well as measures taken in the energy supply sector.

[15] It should be noted that de-bottlenecking does not result in energy efficiency improvements in all cases.

- N_2O emission reduction in the remaining adipic acid plants and in nitric acid production.
- Emission reduction of HFC-23 in HCFC-22 production;
- PFC emission reduction in the aluminium industry and in the semiconductor industry.

It is important to consider that from the meta-analysis we see that additional to these process-oriented measures, structural changes (e.g. the fact that industry is producing higher value added goods which require less energy) will lead to additional emission reductions in the industry sector. In addition, increased recycling of steel and other energy-intensive commodities and the limitation of total material use (e.g. through more efficient use of materials in final products) give rise to new technologies which are better adapted for recycled materials.

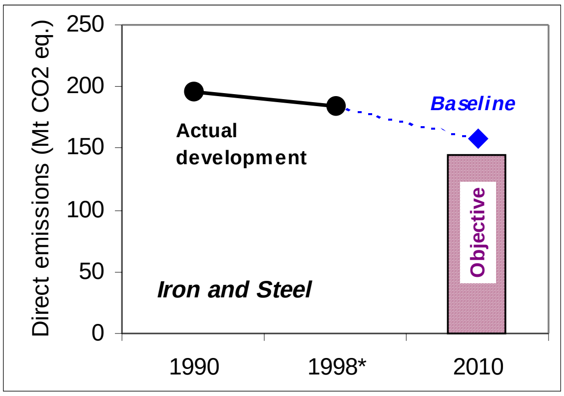
Important policy recommendations are:

- Industrial energy efficiency is an important source of low-cost emission reductions; target setting for industrial energy efficiency is hard to attain on the level of individual measures but can be better set at the level of sub-sectors.
- Emission standards can be set for a limited number of industrial sources of non-CO2 greenhouse gases where relatively cheap emission reductions can be attained.
- Further research is required to determine how adaptations in material production and consumption systems can contribute to the reduction of greenhouse gas emissions.
- Inclusion of well defined and verifiable industrial greenhouse gas emissions as part of an EU wide and/or national emission trading scheme is recommended.

The results of the analysis for the industrial subsectors are presented below:

Iron and steel industry

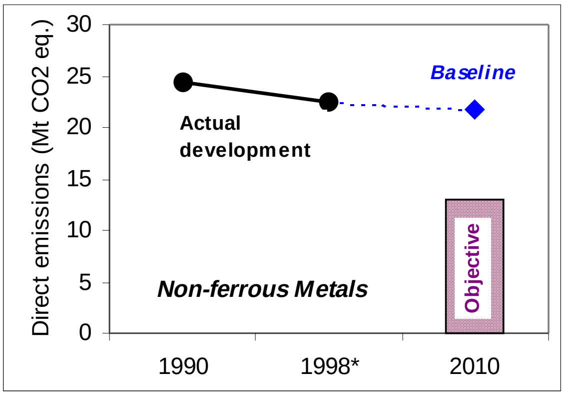
Iron and steel	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	173	134	120	-30%	-10%	229	176	158	-31%	-10%
CO_2 (other)	23	24	24	4%	0%	23	24	24	4%	0%
CH_4	0.2	0.2	0.2	0%	0%	0.2	0.2	0.2	0%	0%
Total	196	158	145	-26%	-9%	253	200	183	-28%	-9%



Emissions in the iron and steel industry are projected to decrease substantially in the baseline mainly as a result of the projected shift from integrated steelworks using blast-furnace plants to further application of electric arc furnaces. Limited technology improvement is projected at the specific process level. The cost-effective objective would imply a further reduction of 14 Mt of CO_2. Thus, the overall objective for the iron and steel industry would be a reduction of 26% from the 1990 emission level. Taking electricity consumption of this sector into account, the cost-effective reduction objective would result into a similar decrease from total emissions, equal to 70 Mt of CO_2.

Non-ferrous metals industry

Non-ferrous metals	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	15	12	12	-21%	-4%	57	32	29	-48%	-10%
PFC	8	6	1	-87%	-85%	8	6	1	-87%	-85%
SF_6	1	3	0	-100%	-100%	1	3	0	-100%	-100%
Total	24	22	13	-47%	-40%	66	42	30	-54%	-28%



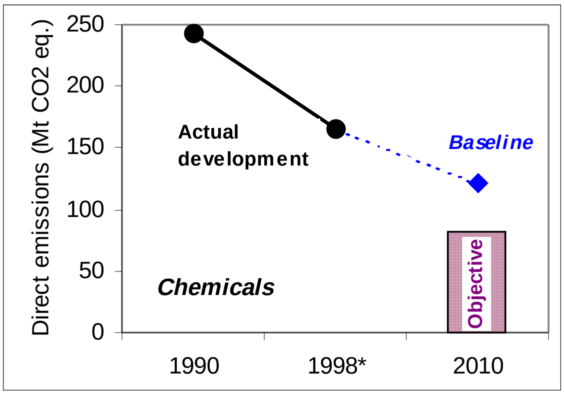
Direct emissions from the non-ferrous metals industry are relatively small compared to other industrial sectors (24 Mt CO_2 eq. in 1990). However, indirect emissions related to electricity consumption are almost twice as high as the direct emissions. In the baseline, emissions are projected to decrease, mainly as a consequence of a shift from primary to secondary aluminium production[16]. Limited technology improvement is projected at the specific process level. The cost-effective objective implies a further attainable reduction of 9 Mt of CO_2 eq. or 47% below the 1990

[16] According to the PRIMES model baseline (which is based on the Shared Analysis), compared to 1995 production levels, primary aluminium production is projected to decrease with 35%, whereas secondary aluminium production will increase with 60%. European Aluminium Association does not consider such development realistic and thus suggests that the emission growth projected in PRIMES is an underestimate.

emission level, with an important contribution of measures in the aluminium and magnesium industry that limit PFC formation and SF_6 consumption respectively.

Chemical industry

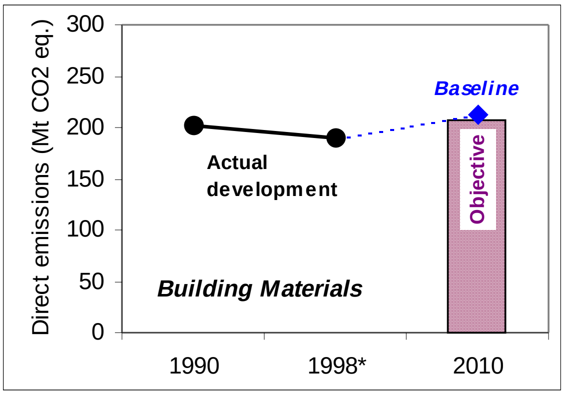
Chemicals	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	96	51	45	-53%	-12%	216	187	165	-24%	-12%
CO_2 (other)	11	14	14	25%	0%	11	14	14	25%	0%
CH_4	0.1	0.1	0.1	0%	0%	0.1	0.1	0.1	0%	0%
N_2O	108	48	21	-80%	-55%	108	48	21	-80%	-55%
HFC	27	7	0.4	-99%	-95%	27	7	0.4	-99%	-95%
Total	243	121	81	-66%	-33%	362	257	201	-44%	-22%



Energy related CO_2 emissions (96 Mt CO_2) and emissions of nitrous oxide in the adipic acid and nitric acid industry (108 Mt CO_2 eq.) were the most important sources of greenhouse gases in the chemical industry sector in 1990. Indirect emissions related to electricity consumption add an additional 119 Mt CO_2 to this emission level. In the baseline, direct emissions are projected to decrease by 50% as a consequence of the following developments: a reduction of energy related CO_2 emissions due to a shift to high value-added, low-energy chemicals production (pharmaceuticals); an emission reduction of nitrous oxide by the adipic acid industry which has already been realised in almost all European production sites; and a projected emission reduction of HFC-23 which is a byproduct of the production of HCFC-22 which in turn is currently being phased out as a consequence of the Montreal Protocol. The cost-effective objective implies a further attainable reduction of 40 Mt CO_2 eq. (to 66% of the 1990 emission level) with the most important contribution of nitrous oxide abatement in the nitric acid industry and of HFC-23 during HCFC-production.

Building materials industry

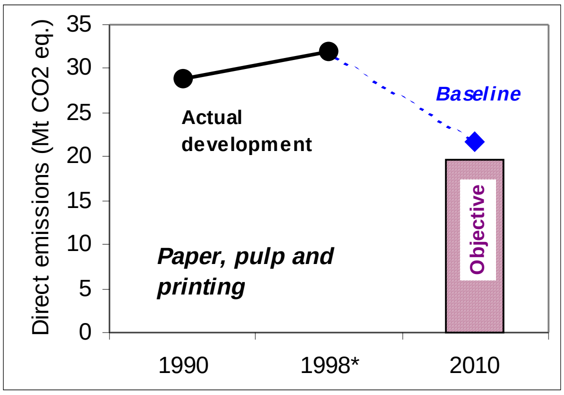
Building materials	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	95	92	89	-6%	-3%	131	121	114	-13%	-6%
CO_2 (other)	106	120	119	12%	-1%	106	120	119	12%	-1%
Total	201	212	208	3%	-2%	237	240	232	-2%	-3%



In 1990, CO_2 emissions in the building materials industry were equally divided between direct energy related emissions and process emissions. CO_2 process emissions are related to clinker making in the cement industry. Indirect emissions are relatively small compared to other sectors (18% in 1990). The baseline projects a small increase of 5% due to increased production of cement, glass and ceramics[17]. Specific energy consumption will decrease by between 2.5% and 8.5% (by 2010 compared to 1995) due to technological progress and a shift from the processing of primary to secondary glass. The cost-effective objective implies an attainable reduction of 4 Mt CO_2 compared to the baseline, which is still 7 Mt CO_2 or 3% above the 1990 emission level.

Paper, pulp and printing industry

Paper, pulp and printing	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	29	22	20	-32%	-9%	69	106	92	34%	-13%
Total	29	22	20	-32%	-9%	69	106	92	34%	-13%



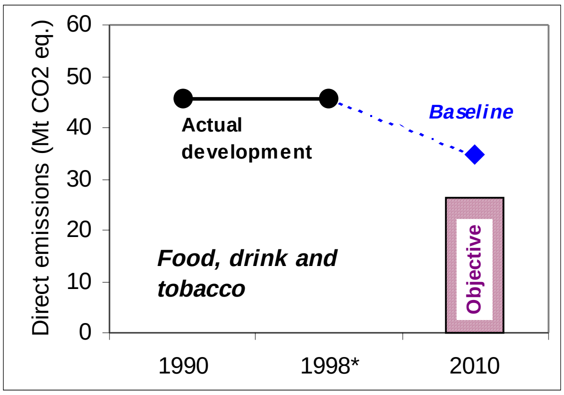
Direct energy related CO_2 emissions of the paper, pulp and printing industry were 29 Mt in 1990[18]. The indirect emissions related to electricity and steam consumption were estimated at an additional 40 Mt CO_2 in 1990. The 2010 baseline projects a decrease of direct emissions by 7 Mt of CO_2 but a considerable increase of indirect emissions compared to 1990 emission levels. The overall effect on total emissions is an increase of 53%. It is assumed that production of pulp will become further concentrated in the major producing countries (Finland and Sweden). In addition, paper recovery potential is expected to be further exploited. The share of

[17] Cembureau considers that the growth of cement production, and the corresponding CO_2 emissions, in the PRIMES baseline are overestimates. This needs to be looked into when the PRIMES baseline is updated.
[18] CEPI has indicated that their own estimates of paper and pulp industry CO_2 emissions are different from those used in this study. This study uses the emissions based on the energy balances of Eurostat.

secondary paper to total production, expressed in terms of a volume index number, is projected to reach 72% in 2010 (66% in 1995). Technological progress at the process level is projected to be rather slow in the baseline. Specific energy consumption reductions of 3 and 4% for basic and secondary paper processing in 2010 from 1995 levels are anticipated. In terms of value added, the overall energy intensity is projected to improve by almost 10% during the same period (1995 to 2010).

Food, drink and tobacco industry

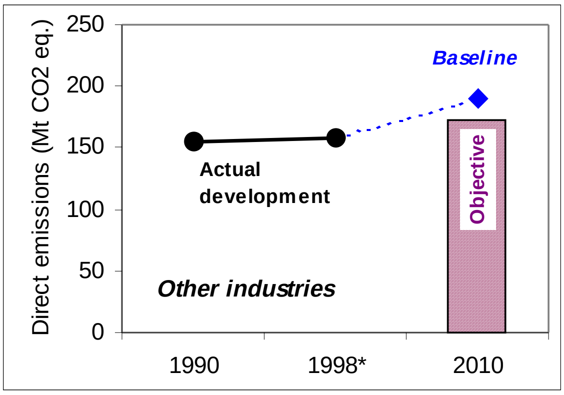
Food, drink and tobacco	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	46	31	26	-42%	-15%	89	103	91	2%	-12%
HFC	0	4	0	-	-100%	0	4	0	-	-100%
Total	46	35	26	-42%	-24%	89	107	91	2%	-15%



Direct emissions from the food, drink and tobacco industries are projected to decrease in the baseline by 24% from 46 Mt CO_2 eq. in 1990 to 35 Mt CO_2 eq. in 2010, despite an increase of HFC emissions related to refrigeration. However, indirect emissions are projected to increase by 29 Mt CO_2 which will be the most important component of the total emissions attributed to this sector. Total emissions are projected to increase by 20%. The cost-effective objective implies an attainable reduction of 16 Mt CO_2 relative to the baseline (-15%), which would result in a 2010 emission level of 2% above the 1990 level.

Other industries

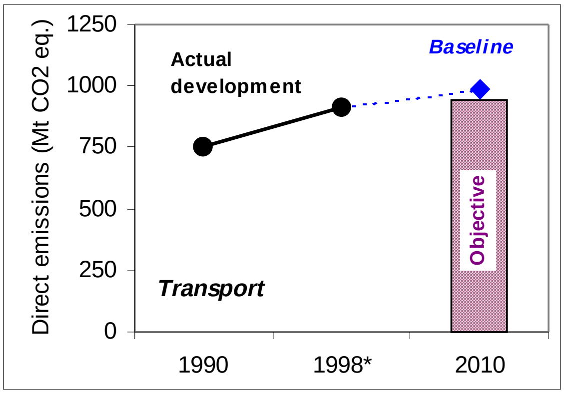
Other industries	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	108	107	103	-4%	-4%	260	248	226	-13%	-9%
CO_2 (other)	16	17	17	8%	0%	16	17	17	8%	0%
CH_4	0.1	0.1	0.1	0%	0%	0.1	0.1	0.1	0%	0%
N_2O	5	5	5	0%	0%	5	5	5	0%	0%
HFC	25	41	29	19%	-29%	25	41	29	19%	-29%
PFC	2	19	18	660%	-7%	2	19	18	660%	-7%
Total	155	189	172	11%	-9%	308	331	295	-4%	-11%



Greenhouse gas emissions from 'other industries' comprise energy related CO_2 emissions from the manufacturing of textiles and textile products, wood and wood products, rubber and plastic products, machinery and equipment as well as emissions of HFCs from insulation materials (foams) and PFCs in the semiconductor industry. In the baseline, the latter two non-CO_2 greenhouse gas emissions are projected to increase: HFCs as a consequence of the required replacement of CFCs under the Montreal Protocol and PFCs as a projected increase of the sector capacity (at 15%/year). The cost-effective objective implies an attainable reduction of 17 Mt CO_2 eq. compared to the baseline (-9%), which would result in a 11% increase compared to the 1990 emission level. Taking the reduction of indirect emissions into account, the cost-effective level of total emissions would be -4% below the 1990 level.

Transport sector

Transport	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	735	919	887	21%	-4%	760	953	916	21%	-4%
by transport mean										
road	624	741	724	16%	-2%	624	741	724	16%	-2%
train	9	2	2	-83%	-8%	34	36	31	-10%	-14%
aviation	82	150	135	65%	-10%	82	150	135	65%	-10%
inl. navigation	21	27	26	26%	-2%	21	27	26	26%	-2%
by transport activity (base year: 1995)										
passenger	545	609	589	8%	-3%	545	609	589	8%	-3%
freight	254	310	298	17%	-4%	254	310	298	17%	-4%
Non-CO_2 (road)	18	65	59	222%	-10%	18	65	59	222%	-10%
CH_4	5	3	3	-41%	0%	5	3	3	-41%	0%
N_2O (catalysts)	12	38	38	221%	0%	12	38	38	221%	0%
HFC (mobile airco)	1	25	18	1348%	-27%	1	25	18	1348%	-27%
Total	753	984	946	26%	-4%	778	1019	975	25%	-4%



Passenger cars and freight vehicles accounted for about 85% of the 1990 CO_2 emissions from the transport sector. Another main source of emissions was domestic and international aviation.[19] Minor sources of emission included rail, and inland and maritime navigation. Besides emissions originating from combustion of fuel, transportation also contributes to emissions of industrial fluorinated greenhouse gases associated with mobile air conditioning and nitrous oxide from the use of catalytic converters. In the baseline, emissions are projected to increase by 31% compared to 1990/1995 emission levels.

The sector study on transport considers options for reducing greenhouse gas emissions from the two main sources of transport related emissions: passenger cars and freight vehicles. Three types of options are identified: operational, strategic and demand related options. The latter two generally rely on influencing behaviour. Due to data unavailability and the influence of localised parameters on effectiveness estimates of costs and impacts across the EU could not be made.

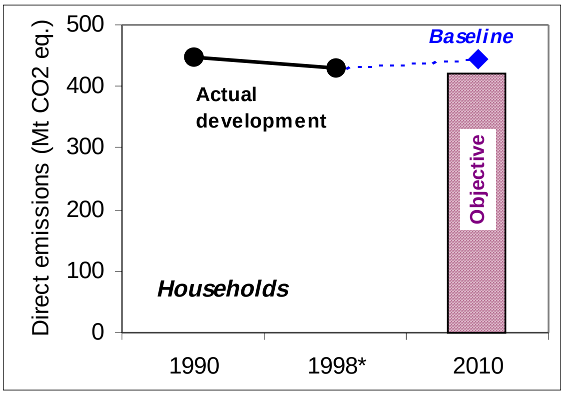
[19] Emissions from international aviation should not be taken into account in the reported emissions or in the emission reduction potential according to the IPCC methodology. However, due to the fact that data does not yet exist as to the split between domestic and international air transport emissions, this split has not been made.

The integrated analysis with the PRIMES model adds the following:

- Mobility demand is rather rigid, as it is related to the welfare of consumers. However, this fact does not constrain the achievement of significant emission reductions. For example, a 40% emission reduction is possible while reducing passenger-kilometres by only 6%.
- Improvement of energy intensity can reach up to 40% for both passenger and freight transport, over a period of 10 years without major technological breakthroughs or any major change in habits.
- There is a rather small potential for changes in the structure of transport activity because of issues regarding, amongst others, the reasons for travel and existing infrastructure. However, as mobility decreases, air travel which is to a large extent discretionary (a "luxury" good) is expected to be more affected.
- Potential dynamics of passenger transport are quite significant since efficiency improvements of an average vehicle can reach up to 45% in terms of consumption per vehicle-kilometre travelled. The results indicate that in collective transport modes better management (higher load factors, further use of information technology etc.) is a cost-effective option and can contribute significantly to the improvement of efficiency in passenger transport. However, limitations exist and further improvements require additional effort at the level of vehicle technologies.
- According to the model results there seems to be a large potential for improving management of freight transport while the technical potential for vehicle efficiency improvements seem difficult to approach even in the cases of strict emission reductions. Consequently, it is much easier and cost-effective to achieve an improvement of efficiency in terms of ton-kilometres travelled rather than reducing vehicle-kilometres travelled.
- Changes of energy demand and CO_2 emissions in the transport sector follow the same pattern due to rather limited potential for fuel substitution in the sector. The small horizon of the study, limits the potential for technological breakthroughs, regarding fuel cell or electric cars, that could lead to the use of less carbon intensive fuels (bio-fuels, natural gas, etc.).

Household sector

Households	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	447	444	420	-6%	-5%	792	746	683	-14%	-8%
HFC	0	1.7	0.6	-	-63%	0	1.7	0.6	-	-63%
Total	447	445	420	-6%	-6%	792	748	684	-14%	-9%



The households sector is an important source of greenhouse gas emissions, both directly through combustion of fossil fuels for heating purposes and indirectly, through electricity consumption. There is also a small contribution to the emission of fluorinated gases. In the baseline, direct emissions are assumed to remain stable despite some growth in housing stock. Electricity consumption and associated indirect emissions are assumed to grow.

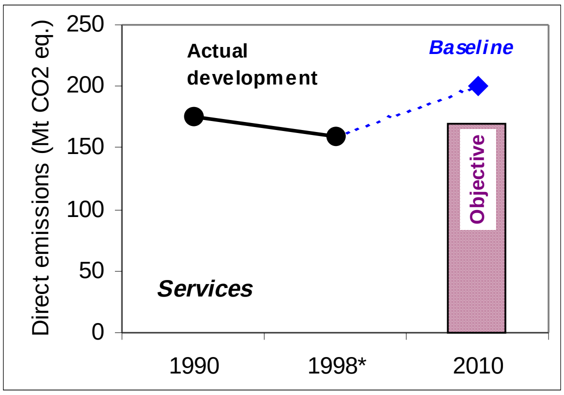
Emission reduction options that may be taken in households include improved insulation of existing dwellings, improved practices in new building construction, and improved efficiency of lighting and household equipment. Also important, but more expensive options, are the application of better insulating windows, condensing boilers, heat pumps and solar domestic hot water systems.

Important policy consequences are:

- Policies for improvement of the existing building stock have not yet received much attention on the European Union level, but could contribute substantially to cost-effective reduction of greenhouse gas emissions.
- When changing tenants or owners it would be important that the energy efficiency of the building would be known e.g. through an energy audit, so that the new tenant/owner could take action to improve the energy efficiency before moving in.
- Policies to improve the efficiency of electric appliances deserve continuation and reinforcement.

Services sector[20]

Services	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	176	194	164	-7%	-16%	448	495	423	-6%	-15%
HFC	0	5.7	5.7	-	0%	0	5.7	5.7	-	0%
Total	176	200	170	-3%	-15%	448	500	428	-4%	-14%



The services sector comprises the subsectors health (hospitals etc.), education, government (excluding defence), sports and entertainment, commercial offices, communications and transport, hotels and catering, retail, warehousing and craftsmanship. In the services sector, energy is mainly used for space heating, air conditioning and lighting, causing both direct and indirect carbon dioxide emissions. Furthermore, some contribution from HFC emissions is expected in the future. The building stock is expected to grow strongly and will be accompanied by a related increase in baseline greenhouse gas emissions (+14%).

Reduction options for the services sector include the improvement of energy management in buildings as well as retrofitting of buildings with insulation. More efficient lighting systems and office equipment are options with smaller reduction potentials. An important, but more expensive ($€_{99}$ 45/tCO_2) option is the application of better insulating windows. Some options for non-CO_2 emission reduction have comparable costs, but are much smaller in size.

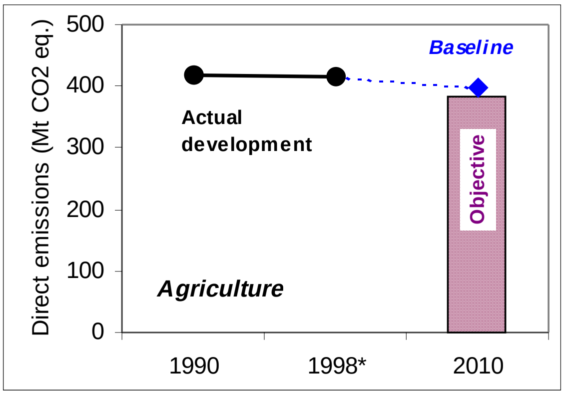
Important policy implications include:

- Policies for improvement of the building shell and equipment in buildings can greatly contribute to greenhouse gas emission reduction and is worth a greater effort on the European level. Such examples include the exchange of information on successful policy instruments, (further) labelling of equipment and materials (e.g. for lighting, glazing) and research and development (e.g. concerning integrated approaches to low-energy and zero-energy buildings for the various climate zones in the EU).
- Attention is required for operational practices, i.e. energy management in buildings.

[20] The 1990 and 1998 figures for energy related CO_2 emissions from services and agriculture differ slightly from the figures presented in the Eurostat Sirene database.

Agriculture[20]

Agriculture	Direct emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*	*Emissions in 1990*	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (energy related)	17	26	25	44%	-5%	17	26	25	44%	-5%
CH_4	194	178	170	-12%	-5%	194	178	170	-12%	-5%
N_2O	206	194	188	-9%	-3%	206	194	188	-9%	-3%
Total	417	398	382	-8%	-4%	417	398	382	-8%	-4%



The most important emissions from agricultural practices are methane from enteric fermentation in ruminants, nitrous oxide from soil processes and both gases from animal manure. A decrease in these emissions is expected in the baseline which relates to changes in this sector including the Common Agricultural Policy reforms. Emission reduction options in the agricultural sector minimise enteric methane emissions from ruminants by improving feed conversion efficiency, by increasing animal productivity and by improving rumen efficiency through the use of feed additives. Options to reduce emissions from manure include improved manure management systems and changing feed intake and digestibility. Various options were identified for reducing emissions from soil, but the potential, applicability and costs could not often be well identified, as a result of the emission reduction outcome not being the 'driving force' for implementing most of these options.

Emission reductions for methane and nitrous oxide are possible through:

- increased animal productivity for ruminants;
- improving feed conversion efficiency for ruminants;
- application of feed additives for ruminants;
- changing manure management practices (e.g. anaerobic manure digestion);
- lowering nitrous oxide emissions from soils through e.g. "precision farming" practices.

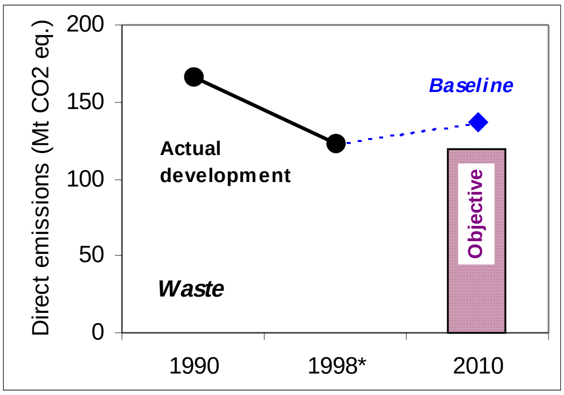
The overall reduction potential is estimated at 21 Mt or 4% of the 2010 baseline for methane and nitrous oxide, of which about two-third show net negative costs. Emission reduction options for agricultural CO_2 were not specifically analysed in the studies.

Important policy implications include:

- Evaluation of present and future changes in the Common Agricultural Policy regarding the effect on greenhouse gas emissions;
- Carrying out R&D to develop cost-effective systems to reduce methane emissions from cattle breeding.
- Encouraging better crop production methods so that N_2O emissions would be reduced.

Waste sector[21]

Waste	Direct emissions (Mt CO2 eq.)				
	Emissions in 1990	*Baseline emissions in 2010*	*Cost-effective objective 2010*	*Change from 1990*	*Change from 2010 baseline*
CO_2 (other)	8	8	8	0%	0%
CH_4	155	126	108	-30%	-14%
N_2O	4	4	4	0%	0%
Total	166	137	119	-28%	-13%



The main source of emissions from waste is methane from landfills. In landfill anaerobic methanogenic bacteria break down biodegradable carbon compounds and produce methane. In the baseline, emissions are about 20% lower in 2010 compared to the 1990 level as emissions from landfills are expected to decrease due to the recent adoption of the Landfill Directive. This directive requires that the amount of biodegradable waste sent to landfill is reduced, and that methane emissions are captured at new sites.

Emission reduction options mainly concern alternative ways of treating biodegradable waste such as by composting, bio-mechanical pre-treatment, incineration and recycling of paper and cardboard. Alternatively, landfill gas can be collected and burnt or oxidation of the landfill gas in the landfill gap can be improved, thus avoiding the methane escaping to the atmosphere.

The overall emission reduction potential compared to the baseline is estimated at 18 Mt of CO_2 equivalent.

[21] 1990 data on non-energy related CO_2 emissions as well as emission data for methane and nitrous oxide is taken from the UNFCCC database (July 1999) and are in accordance with the national communications of the Member States submitted at that time. Emission estimates for 1990 have since then been updated in the latest National Communication of the EU (May 2000, see footnote 7), which is not included in the analysis of this study. Updated methane emission estimates from waste in 1990 are 11 Mt CO_2 eq. lower than previously reported.

CONCLUSIONS

In this study the most cost-effective distribution of emission reductions among different sectors and gases was determined so as to meet the EU quantitative reduction objective for greenhouse gases under the Kyoto protocol. For the first time, the distribution was determined for all greenhouse gases that fall under the Kyoto protocol: both energy and process related CO_2, as well as non-CO_2 greenhouse gases. The main findings of this study are summarised below and fully presented in the summary tables in the main text and in detailed tables in Annex 1 and 2.

Two approaches were used: a top-down approach, which used an integrated energy-economy model, PRIMES, that simulates the EU energy system[22]; and a bottom-up approach, which made an engineering-economic analysis of individual emission reduction options using the GENESIS database[23]. The two approaches were combined in the meta-analysis, in which bottom-up information on non-CO_2 greenhouse gases and process emissions of CO_2 was incorporated in the top-down model on energy related CO_2 emissions.

In addition to this quantitative analysis, policies and measures were identified that could support the realisation of these emission reduction objectives for all sectors and gases. These are described in detail in the supporting main reports and the sector reports of the bottom-up analysis.

The main conclusions from this study are:

- From both the bottom-up and the top-down meta-analysis, it is apparent that emission reductions to achieve the European Union Kyoto target are achievable at low cost (the marginal cost is about $€_{99}$ 20-25/tCO_2 eq.). These results are based on an EU-wide allocation of least-cost objectives for different sectors.
- If each Member States were to meet its Kyoto target individually according to the Burden Sharing target, the EU-wide allocation of sectoral objectives would change only slightly from the previous case. However, the marginal cost of compliance for emission reduction of greenhouse gases would increase from $€_{99}$ 20 to $€_{99}$ 42 per tCO_2 equivalent for the EU as a whole, with values ranging from $€_{99}$1 to over $€_{99}$ 100 per tCO_2 equivalent for the various Member States.
- This study has clearly demonstrated that cost-effective implementation of the Kyoto Protocol calls for different sectors to make differing quantitative contributions to reduce greenhouse gas emissions. Giving every sector, or even every actor within a sector, the same reduction objective may be perceived as "fair". However, using a different definition of equity where the "effort" of each sector is the same rather than the emission reduction percentage, differentiated sectoral reduction objectives would be identified. This study has shown that such differentiated reduction objectives are, from an economic perspective, highly

[22] P. Capros, N. Kouvaritakis, L. Mantzos (2001): Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU, National Technical University of Athens, Athens, March 2001

[23] C. Hendriks, D. de Jager, K. Blok et al. (2001): Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU, Ecofys and AEA Technology, Utrecht, January 2001

desirable provided that the objectives are established in order to minimise costs to the society.

- By setting the objectives in a least cost manner, the Kyoto Protocol compliance cost for the EU is estimated to be $€_{99}$ 3.7 billion annually during the first budget period of the Kyoto Protocol (2008 to 2012), which is equivalent to about 0.06% of EU gross domestic product in 2010. Thus, reaching the Kyoto target need not be overly costly to the EU provided that a least-cost route is chosen. The effects of changes in land use (sinks), as well as flexible mechanisms of the Kyoto Protocol, have not been included in this estimate. If these were included, the compliance costs would most likely be lower.
- Even if the analysis carried out in this study is comprehensive, it still represents only a 'snapshot' of the EU situation in 2000. Thus, the sector specific allocation of emission reduction objectives would change if, for instance economic growth changed substantially, if some sectors underwent rapid growth changes or if technological breakthroughs facilitated cheaper emission reduction options. Thus, it must be recognised that the emission reduction objective allocations described in this study will alter in the years to come. It is, therefore, important to consider these allocations in a dynamic context. In particular, the optimal allocation is likely to be different in the second commitment period (i.e. after 2012).
- If the objectives set out in this report were used as a basis for the allocation of emission reduction targets in EU-wide or national emissions trading schemes, the dynamic efficiencies arising from emission trading would be appropriately combined with the cost-effective reduction potentials that exist in different sectors.
- In terms of emission reduction potential the energy sector is one of the most important. Fuel shift currently holds the greatest reduction potential up to the first commitment period of the Kyoto Protocol (2008-2012). It should be carefully considered whether what policies would ensure fuel switching. (Additional) carbon taxation would ensure a further shift to low-carbon fuels. The inclusion of the energy supply sector in emission trading schemes, both at the Member State and the EU level, is another option.
- From the bottom-up analysis it becomes clear that substantial reduction potential is available in the end-use manufacturing industry and the building sector.

RECOMMENDATIONS

The following recommendations are made:

1. Emission trading among all Member States in well defined sectors will result in significant cost reductions in reducing greenhouse gas emissions to 8% less than 1990/1995 emission levels. It is recommended that not only energy related CO_2 emissions are included but also, when measurable, other greenhouse gases. These gases are: process emissions of CO_2 in the cement, iron and steel industries and chemical industries, PFC emissions from aluminium production, N_2O emissions from adipic and nitric acid production, HFC emissions from chemical industry (by-product of HCFC22 production) and process emissions of the oil and natural gas industry. The reduction of compliance costs of an EU-wide trading could be as much as half compared to a situation where each Member State would comply with they Kyoto target individually.
2. As it is important to set up a trading regime so that it is not excessively complicated, it may prove impractical to include some of these sectors under the trading regime. Nevertheless, the results of this study will help in assigning realistic numbers of emission permits to those sectors that are given the prospect to trade greenhouse gas emissions.
3. As the energy markets in the EU are currently undergoing liberalisation this may render more difficult the implementation of some CO_2 emission reduction options, in particular in combined heat and power. Therefore, the European Commission and the Member States should ensure that the transition period is as short as possible and, if required, additional policies and measures are designed to reduce possible negative impacts on emission reduction of greenhouse gases.
4. Fuel switch in power generation, mainly from coal to natural gas, comprises a large part of the reduction potential for the energy supply sector. In some Member States this option has already, to some extent, been in the process of implementation since 1990. It is uncertain to what extent further implementation of this option will take place without additional policy interventions. Import of coal, life-time extension of existing power plants and remaining coal subsidies can hinder the shift away from coal. It is important to monitor market developments and take appropriate measures in case fuel shift develops slower than projected. Measures such as the inclusion of the energy supply sector in emission trading schemes, both at the Member State and the EU level, as well as introducing or extending carbon taxation, would further support the shift to low-carbon fuels.
5. Combined Heat and Power (CHP) can make an important emission reduction contribution. Although many applications of CHP are low in cost, current market conditions are not favourable to some CHP applications. Market barriers, such as transport tariff schemes which are unfavourable for autoproducers, should be removed.

6. Renewable energy sources have a high potential for emission reduction but are often expensive. In developing renewable energy policies, the importance of renewables in the longer term should be considered. Important benefits can be accrued from the learning effects of renewable energy policies and that drive the cost of renewable energy down for future use. Instruments with dynamic cost-effectiveness incentives, such as 'green' or renewable energy certificates, could become important and should be supported on a EU level. The implications of the co-existence of green certificates and CO_2 certificates should be examined.
7. Nitrous oxide emissions from industry can be reduced at very low costs. To a large extent, mainly in adipic acid production, this option has already been implemented. It is important to note that for emission reduction in nitric acid production, further technological development is still necessary. The European Commission could play a stimulating role in this development by supporting demonstration projects and designing European emission standards and/or defining best available technologies.
8. Options for emission reduction of nitrous oxide from catalytic converters in the transport sector are not taken into account in the analysis of this study as no implementing technologies are currently available. Given the international market for car-manufacturing, the Commission could support research and development of low-N_2O catalytic converters for road vehicles and design emission standards.
9. The ACEA/JAMA/KAMA agreement aims at a significant emission reduction of CO_2 emissions which covers about 75 Mt of CO_2 of the reduction potential of the 100 Mt of CO_2 that could be reduced in the transport sector itself. It is important to monitor the implementation of the ACEA agreement and to take appropriate measures should the implementation of the agreement develop slower than projected. The reduction potential in emissions of transport trucks could be realised by an agreement with truck manufactures, similar to the ACEA agreement.
10. Emissions of HFCs from mobile air-conditioning and refrigeration could be reduced by setting standards for low-leakage equipment and ensuring that the End-of-Life Vehicles directive succeeds in recovering of HFCs from scrap cars.
11. As the energy consumption of public, commercial and residential buildings in the EU is still relatively high, an EU-wide approach to improve the situation is recommended. The exchange of information on successful policy instruments, labelling of equipment and materials (e.g. for lighting, glazing) and research and development (e.g. concerning integrated approaches to low-energy and zero-energy buildings for the various climate zones in the EU) are possible measures that could be adopted. Retrofitting existing buildings, better management of energy use in office buildings carrying out energy audits of dwellings when they are handed over to new owners/tenants and building more energy efficient (both in terms of cooling and heating) new buildings are some options which offer significant reduction potentials.

12. Reduction opportunities of non-CO_2 greenhouse gases in the agricultural sector seem relatively small in the EU. However, while making agricultural practices more sustainable and greener, also climate related considerations should be included, in particular in manure management and the treatment of soils. Compesating farmers for lowering greenhouse gas emissions in farms, if the monitoring problems can be overcome, as part of the agricultural subsidies could be one new way of lowering agricultural emissions.
13. Research and development of new agricultural practices with minimal climate change and other environmental effects could be stimulated on an EU level.
14. For methane emissions from waste the implementation and effectiveness of the Landfill Directive is of major importance and should be closely monitored.
15. Technologies with possible high reduction potentials in the mid- to long-term should be supported by international R&D programmes. Examples include: fuel cells, heat pumps, renewables and CO_2 storage.

ANNEX 1 LEAST-COST ALLOCATION OF SECTORAL OBJECTIVES TO REDUCE GREENHOUSE GAS EMISSIONS: EU-WIDE RESULTS

Results of the meta-analysis for the EU in the full flexibility scenario, i.e. an European-wide allocation of least-cost objectives for different sectors.

The tables show the most cost-effective distribution of emission reductions among different sectors and gases to meet the EU overall quantitative reduction objective for greenhouse gases under the Kyoto protocol: on average -8% in the period 2008 to 2012 compared to 1990/1995 base year emissions.

The industry sector is also presented on a sub-sectoral level. Energy related CO_2 emissions from the transport and energy supply sector are also presented at a more detailed level. ACEA/JAMA/KAMA agreement is included in the baseline. Industrial boilers are allocated to industry.

Note: In this summary for policy maker's the nitrous oxide emission projections of the transport sector were taken from the transport sector report dated December 2000. Since then, these projections have been revised down and are reported in a version of the report dated March 2001. Due to this revision total EU emissions are about 4.6 Mt CO_2-eq. lower. Due to time restrictions it was impossible to incorporate these changes in this summary report for policy makers. If this revision were included in the analysis, the main implication would be that the objectives of other sectors would be slightly less demanding. 4.6 Mt of CO_2-eq. emissions are only about 1% of the total reduction requirement for the EU. Thus, the effect of including this change would be small when this 1% is distributed to all sectors.

The EU-wide results are given in the file **SR Annex 1.xls** on:
http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

In a separate table, the actual emissions for 1998 are given. For energy related CO_{2-} emissions these are based on Eurostat energy balances. For N_20 and CH_4 the source is the National Communications of EU Member States. For fluorinated gases, due to lack of sector specific data, 1998 emissions were assumed to be an average of 1995 estimates and 2010 projections (Ecofys).

EU 1998 emission data (indicative)

industrial boilers allocated to industrial sectors

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)			Difference
	Emissions in 1990 or 1995	*Emissions in 1998*	*% Change from 1990 or 1995*	*Difference 1998 to base year (Mt CO2 eq.)*
Energy supply				
CO2 (fuel related)	1131.5	1094.9	-3.2%	-36.6
CO2 (other)	0.0	0.0		0.0
CH4	12.4	14.0	12.8%	1.6
N2O	41.9	30.6	-26.9%	-11.3
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	4.0	4.0	0.0%	0.0
Sub-total	1189.8	1143.5	-3.9%	-46.3
Fossil fuel extraction, transport and distribution				
CO2 (fuel related)	0.0	0.0		0.0
CO2 (other)	0.0	0.0		0.0
CH4	94.6	60.0	-36.6%	-34.6
N2O	0.3	0.3		0.0
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	94.9	60.3	-36.5%	-34.6
Industry				
CO2 (fuel related)	561.4	497.2	-11.4%	-64.2
CO2 (other)	156.8	153.0	-2.4%	-3.8
CH4	0.4	0.4	0.0%	0.0
N2O	112.8	74.6	-33.9%	-38.2
HFC	51.1	51.6	1.1%	0.6
PFC	10.0	17.7	77.0%	7.7
SF6	1.5	2.2	49.2%	0.7
Sub-total	894.1	796.8	-10.9%	-97.3
Transport				
CO2 (fuel related)	734.8	872.1	18.7%	137.3
CO2 (other)	0.0	0.0		0.0
CH4	5.2	4.2	-20.6%	-1.1
N2O	11.8	24.2	105.4%	12.4
HFC	1.2	12.9	940.1%	11.7
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	753.1	913.4	21.3%	160.4
Households				
CO2 (fuel related)	447.5	429.5	-4.0%	-18.0
CO2 (other)	0.0	0.0		0.0
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	0.8		0.8
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	447.5	430.3	-3.8%	-17.1
Services				
CO2 (fuel related)	175.6	157.2	-10.5%	-18.4
CO2 (other)	0.0	0.0		0.0
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	2.9		2.9
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	175.6	160.1	-8.9%	-15.6
Agriculture				
CO2 (fuel related)	17.3	20.0	15.5%	2.7
CO2 (other)	0.0	0.0		0.0
CH4	193.8	179.0	-7.6%	-14.8
N2O	205.8	217.0	5.4%	11.2
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	416.9	416.0	-0.2%	-1.0
Waste				
CO2 (fuel related)	0.0	0.0		0.0
CO2 (other)	7.6	6.5	-13.9%	-1.1
CH4	155.1	110.2	-29.0%	-44.9
N2O	3.7	5.7	53.2%	2.0
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	166.4	122.4	-26.5%	-44.0
All sectors				
CO2 (fuel related)	3068.1	3070.8	0.1%	2.8
CO2 (other)	164.4	159.5	-3.0%	-4.9
CH4*)	461.7	367.8	-20.3%	-93.9
N2O	376.3	352.4	-6.4%	-23.9
HFC	52.3	68.3	30.5%	16.0
PFC	10.0	17.7	77.0%	7.7
SF6	5.5	6.2	13.0%	0.7
Total	4138.3	4042.8	-2.3%	-95.5

*)"The estimates for 1990 emissions are based on a different methodology and are 11

Industrial sectors

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)			Difference
	Emissions in 1990 or 1995	*Emissions in 1998*	*% Change from 1990 or 1995*	*Difference 1998 to base year (Mt CO2 eq.)*
Iron and steel				
CO2 (fuel related)	172.6	161.3	-6.6%	-11.3
CO2 (other)	23.4	22.4	-4.3%	-1.0
CH4	0.2	0.4	125.8%	0.2
N2O	0.0	0.0		0.0
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	196.2	184.0	-6.2%	-12.1
Non-ferrous metals				
CO2 (fuel related)	15.2	13.2	-13.1%	-2.0
CO2 (other)	0.0	0.0		0.0
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	0.0		0.0
PFC	7.7	7.1	-7.9%	-0.6
SF6	1.5	2.2	49.2%	0.7
Sub-total	24.4	22.5	-7.7%	-1.9
Chemicals				
CO2 (fuel related)	96.4	65.4	-32.1%	-31.0
CO2 (other)	11.4	11.2	-1.2%	-0.1
CH4	0.1	0.2	33.3%	0.0
N2O	108.2	71.2	-34.2%	-37.0
HFC	26.5	16.9	-36.5%	-9.7
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	242.6	164.9	-32.0%	-77.7
Building Materials				
CO2 (fuel related)	95.2	79.4	-16.5%	-15.7
CO2 (other)	105.8	110.5	4.4%	4.7
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	201.0	190.0	-5.5%	-11.0
Paper and Pulp				
CO2 (fuel related)	28.9	32.0	10.8%	3.1
CO2 (other)	0.0	0.0		0.0
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	0.0		0.0
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	28.9	32.0	10.8%	3.1
Food, drink and tobacco				
CO2 (fuel related)	45.5	43.7	-3.9%	-1.8
CO2 (other)	0.0	0.0		0.0
CH4	0.0	0.0		0.0
N2O	0.0	0.0		0.0
HFC	0.0	1.9		1.9
PFC	0.0	0.0		0.0
SF6	0.0	0.0		0.0
Sub-total	45.5	45.6	0.3%	0.1
Other industries				
CO2 (fuel related)	107.6	102.1	-5.1%	-5.5
CO2 (other)	16.2	8.9	-45.1%	-7.3
CH4	0.1	0.0	-96.7%	-0.1
N2O	4.7	3.4	-26.5%	-1.2
HFC	24.5	32.9	34.0%	8.3
PFC	2.3	10.7	356.9%	8.3
SF6	0.0	0.0		0.0
Sub-total	155.4	158.0	1.6%	2.5
Total industry				
CO2 (fuel related)	561.4	497.2	-11.4%	-64.2
CO2 (other)	156.8	153.1	-2.4%	-3.8
CH4	0.4	0.5	53.9%	0.2
N2O	112.8	74.6	-33.9%	-38.2
HFC	51.1	51.6	1.1%	0.6
PFC	10.0	17.7	77.0%	7.7
SF6	1.5	2.2	49.2%	0.7
Total industry	894.0	797.0	-10.9%	-97.0

ANNEX 2 LEAST-COST ALLOCATION OF SECTORAL OBJECTIVES TO REDUCE GREENHOUSE GAS EMISSIONS: RESULTS PER MEMBER STATE

Results of the meta-analysis for each Member State in accordance with the Burden Sharing Agreement.

The tables show the most cost-effective distribution of emission reductions among different sectors and gases to meet the Member State quantitative reduction targets for greenhouse gases under the Kyoto protocol (see table below).

Emission reduction targets of the EU Member States: reduction targets in terms of percentage for average annual emissions in the period 2008-2012 compared to the 1990/1995 base year emissions

Member States		Commitments in accordance with article 4 of the Kyoto Protocol
Austria	AU	-13%
Belgium	BE	-7.5%
Denmark	DK	-21%
Finland	FI	0%
France	FR	0%
Germany	GE	-21%
Greece	GR	25%
Ireland	IR	13%
Italy	IT	-6.5%
Luxembourg	LU	-28%
Netherlands	NL	-6%
Portugal	PO	27%
Spain	SP	15%
Sweden	SV	4%
United Kingdom	UK	-12.5%
European Union	EU15	-8%

The industry sector is also presented on a subsectoral level. Energy related CO_2 emissions of the transport and energy supply sector are also presented in a more detailed level.

The ACEA/JAMA/KAMA agreement is included in the baseline.

Industrial boilers are allocated to industry.

Note: In this policy maker's summary the nitrous oxide emission projections of the transport sector were taken from the transport sector report dated December 2000. Since then, these projections have been revised down and are reported in a version of the report dated March 2001. Due to this revision total EU emissions are about 4.6 Mt CO_2-eq. lower. Due to time restrictions it was impossible to incorporate these changes in this summary report for policy makers. If this revision were included in the analysis, the main implication would be that the objectives of other sectors would be slightly less demanding. 4.6 Mt of CO_2-eq. emissions are only about 1% of the total reduction requirement for the EU. Thus, the effect of including this change would be small when this 1% is distributed to all sectors.

The results for Member States are given in the file **SR Annex 2.xls** on:
http://europa.eu.int/comm/environment/enveco/climate_change/sectoral_objectives.htm

ANNEX 3 ALLOCATION OF EMISSIONS TO SECTORS

Allocation of emissions to sectors

In this study sectors are defined according to the Nomenclature des Activités de la Communauté Europeénne (NACE)[1]. While the definition of sectors was quite clear, it was sometimes difficult to allocate emissions to sectors. As its basis the PRIMES model uses Eurostat energy balance data, which differ from the National Communications to the UNFCCC made under the Intergovernmental Panel for Climate Change (IPCC) guidelines[2].

A major difference between the IPCC guidelines and the Eurostat definition arises from the allocation of autoproduction, i.e. electricity and steam generated on site by energy demand sectors (notably industry). Under the IPCC guidelines, CO_2 emissions from industrial autoproduction are allocated to the industry sector[3]. The energy balances of Eurostat, however, classify autoproduction as energy supply. In addition, PRIMES deviates from Eurostat definitions in that the PRIMES model treats CO_2 emissions from industrial boilers as arising from the energy supply sector whereas, under the Eurostat definition, they are allocated to the industry where the heat production occurs. The reason for this is that industrial boilers often compete with power generation[4] by other sources. Thus, because of the way autoproduction is allocated in the energy balances of Eurostat and because of the way PRIMES allocates industrial boilers, PRIMES assigns a higher share of CO_2 emissions to the energy supply sector. These two differences result in allocating over 200 Mt of CO_2 emissions from industry to the energy supply sector[5].

During the validation exercise of this study, it became evident that many industrial sectors regard their emissions based on the IPCC definitions. Thus, in order to make the results of this study comparable, the emissions from energy supply sectors are divided into (i) autoproduction (industrial and other generators), (ii) utilities, (iii) boilers in industry, refineries and district heating and (iv) fuel extraction and refineries. Refineries are shown separately because they are sometimes treated as “industry” and sometimes as “energy supply”. In this Policy Maker's Summary the results of the PRIMES analysis will be presented according to the Eurostat definitions (i.e. industrial boilers are allocated to the industry sector), unless stated otherwise. As it is not known how autoproduction is allocated between different

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[1] The exact definitions are given in the summary report on results of the bottom-up analysis (see footnote 4 in main text).

[2] Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual (Volume 3) available at http://www.ipcc-nggip.iges.or.jp/public/gl/invs6a.htm

[3] IPCC Guidelines (p. 1.3 under heading Energy) state: “In order to estimate the full emissions of the industry sector, emissions from autoproduction should be included with emissions from other fuel use within industry. At the same time the emissions from the autoproduction of electricity and heat should be excluded from the energy transformation source category to avoid double counting. ”

[4] The logic is that a firm has a choice of producing the necessary steam itself, produce it in combination with electricity generation or to purchase this from a power supplier. And the firm can sell part of the steam or electricity generated, depending on its own energy demand.

[5] Specifically, according to the National Communications of EU Member States, energy related industry sector emissions were 606 Mt of CO_2 in 1995. According to Eurostat they were 518 Mt and according to PRIMES 379 Mt. The emissions of power generation sector were therefore larger according to the energy balances used ad defined in Eurostat and PRIMES.

industrial sectors, as it has not been possible to allocate these emissions for each industrial sector.

Energy related direct and indirect CO_2 emissions

As explained in the previous section the breakdown of emissions is given per sector following the sectoral classification of PRIMES/Eurostat. The emissions allocated to each sector in this report are referred to as **direct emissions**, i.e. emissions from electricity and steam production and refineries (the energy supply sector) are not allocated to the end-use sectors (all sectors except the energy supply sector). The emissions of the energy supply sector can also be allocated to the end-use sectors, i.e. the allocation of the **indirect emissions**. The total emissions per end-use sector can then be defined as the sum of the direct and indirect emissions.

Indirect emissions (emissions from energy supply sector) can be reduced by using less energy (i.e. improving the production processes in the end-use sectors) or by improving the energy conversion efficiencies in the energy supply sector, (i.e. by using less fossil fuel to produce the same amount of electricity, steam and converted fuel). In the bottom-up approach, emission reductions obtained by improving the production process of end-use sectors is allocated to the end-use sector, regardless of whether the option reduces the direct and/or the indirect emissions of the sector. The total reduction potential can only, therefore, be expressed as a fraction of **the total emissions**.

This approach differs from the approach followed in PRIMES which allocates the total emission reduction from both improved use and improved generation of electricity and steam to the energy supply sector, regardless of whether the activity takes place on the industrial site or not.

ANNEX 4 METHODOLOGICAL SUMMARY: REPRESENTATION OF GREENHOUSE GAS EMISSION REDUCTION POTENTIALS

In this Annex first a methodological summary of combining the top-down and bottom-up approaches is given. Then some additional representations of the top-down and bottom-up analysis are presented.

Combining top-down and bottom-up approaches

In order to combine the top-down and bottom-up approaches it is vital that the marginal abatement cost curves are constructed in both cases. A marginal abatement cost curve tells how much it would cost to reduce one additional tonne of CO_2. In different sectors the marginal abatement cost curves are usually not the same. Figure A shows the marginal abatement cost curves of two sectors. For the sector called "Easy" it is relatively easy to reduce greenhouse gases. For the other sector, called "Lean", it is much more difficult to do so. The Kyoto constraint can be illustrated by a vertical line **x**. If both sectors would need to reduce **x** tonnes of CO_2, "Easy" sector would need to pay the area below the marginal cost curve (from zero to point $\mathbf{E_o}$) while "Lean" would have to pay much more (the area below the line between zero and $\mathbf{L_o}$).

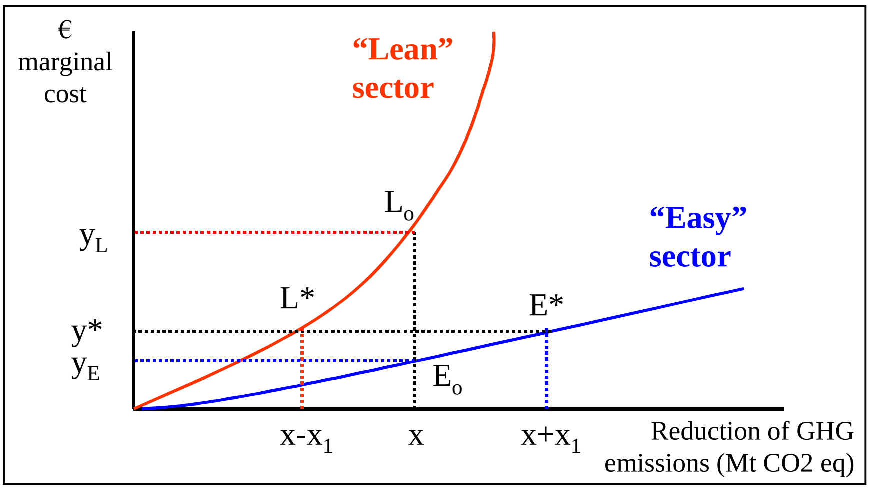

Figure A The case for differentiated reduction objectives with two sectors

Imagine that all companies in "Easy" sector would be owned by the sector "Lean". It would be clearly in both sectors interest to split the burden of the Kyoto target differently: "Easy" would reduce more emissions while "Lean" would do less. In the most cost-effective point "Easy" would reduce $\mathbf{x+x_1}$ tonnes while "Lean" would reduce $\mathbf{x-x_1}$ tonnes. Both would pay a marginal cost of **y*** per tonne of CO_2. Now "Lean" would need to pay the area under zero and **L*** while "Easy" would pay the area under zero and **E***. The total costs of the two sectors are reduced and, as a whole, the two sectors are better off with the differentiated allocation of the Kyoto objective. The government or a regulator can take the view of all sectors and suggest an allocation in which the sectors would be better off in aggregate.

In this study, the marginal cost curves of all sectors and all gases have been developed. For energy related CO_2 emissions the curves have been developed by the PRIMES model. For the non-energy related CO_2 emissions as well as all non-CO_2 greenhouse gases the bottom-up approach was used. Using the approach described in Figure A, the optimal allocation is obtained by finding the lowest marginal cost that ensures that the Kyoto target is reached in total. Clearly, the crucial issue is to have the marginal abatement cost curves estimated correctly. In particular, it is important that the curves are relatively accurate in the cost ranges identified in this study (i.e. below about €50/tCO_2). The lowest marginal cost was found to be €$_{99}$ 20/tCO_2 for all greenhouse gases.

Example of top-down approach: PRIMES marginal cost curve for energy related CO_2 emissions

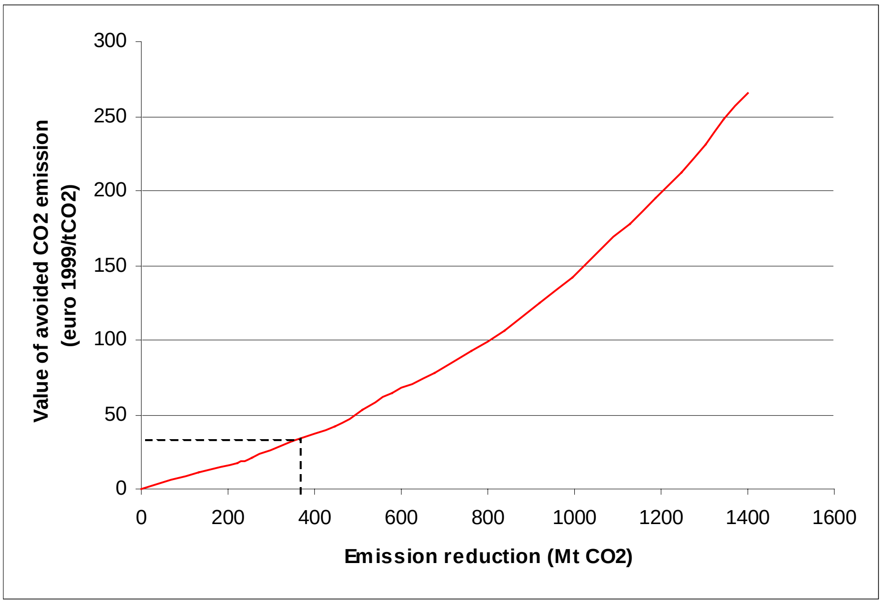

Figure B The value of avoided carbon dioxide as a function of the carbon dioxide emission reductions in the European Union in the year 2010 according to the simulations with the PRIMES model (energy related CO_2 emissions, including ACEA agreement, 1999 euros).

Figure B gives an indication of the sensitivity of the marginal abatement costs of carbon dioxide emission reduction as a function of total energy related CO_2 emissions. The results of the PRIMES analysis show a rather steep increase of the value attached to carbon dioxide mitigation at decreasing overall emissions. A reduction of carbon dioxide emissions of 8% (or 370 Mt CO_2)[1] is achieved at marginal abatement costs of €$_{99}$ 34 per tCO_2 eq. (ACEA agreement taken into account).

[1] 3193 Mt - 0.92x3068 Mt=370 Mt

Example of bottom-up approach: How GENESIS creates the marginal cost curve for all greenhouse gases

Figures C and D represent the methodology and results of the bottom-up approach in the GENESIS database. The total of emission reduction options identified equals almost 1953 Mt CO_2 equivalent. The total emission reduction refers to a reference level for which no emission reductions or policies are implemented (the frozen technology reference level) resulting in an attainable emission level of 3322 Mt CO_2 equivalent. (-20% of 1990/1995 emissions). Figure C is the cost curve with each option depicted as a step in the curve, whereas Figure D is an illustration of the overall approach.

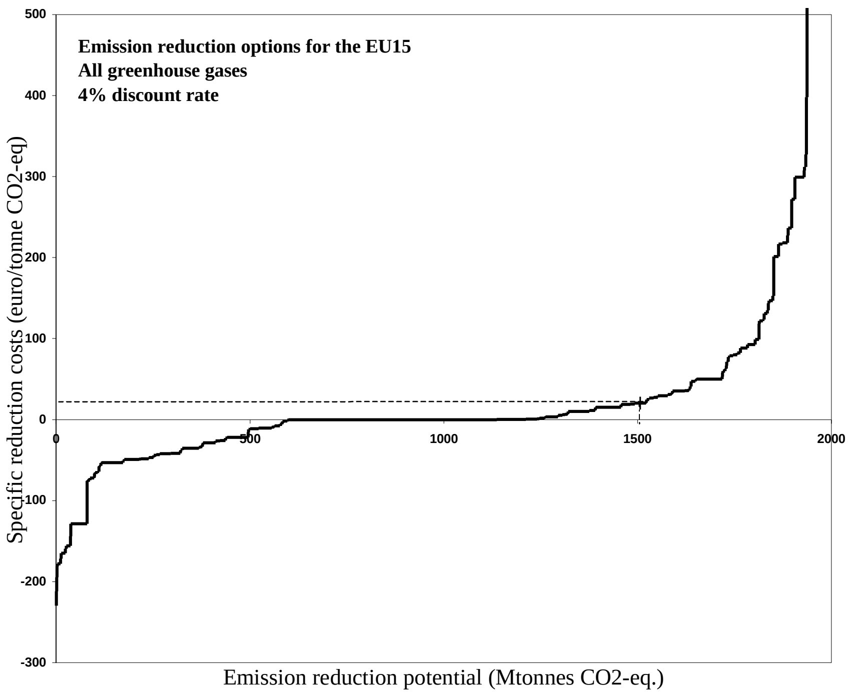

Figure C The value of avoided greenhouse gas emissions as a function of the greenhouse gas emission reductions in the European Union in the year 2010 according to the GENESIS bottom-up analysis. The emission reduction refers to a level at which no reduction options are implemented at all (the frozen technology reference level). The cost data are given in 1990 euros (1 $euro_{1999}$ = 1.3 $euro_{1990}$).

Many measures can be taken at net negative costs, i.e. the monetary benefits of an option are estimated to be larger than the costs. Most of these options are energy efficiency improvement options in the end-use sectors. The category of zero cost options mainly is made up of fuel switch in the electricity sector[2]. Options with negative or zero costs represent about 64% of the identified reduction potential.

The options that cost less than $€_{99}$ 25/tCO_2 eq. (the third cost bracket) comprise emission reduction of nitrous oxide in the chemical industry (nitric acid and adipic acid), renewable energy sources (some biomass applications, on-shore wind energy

[2] The costs of fuel switch in the electricity sector (e.g. the switch from coal to natural gas) is highly sensitive to local market situations and largely uncertain due to the ongoing liberalisation and privatisation developments in the energy sector. The net costs may be slightly positive or slightly negative. For that reason they are set to zero.

as well as small scale hydropower), energy efficiency improvements at vehicles (both passenger and freight transport) and insulation of existing dwellings and numerous energy efficiency improvement options in all energy demand sectors. This category represents about 14% of the identified reduction potential.

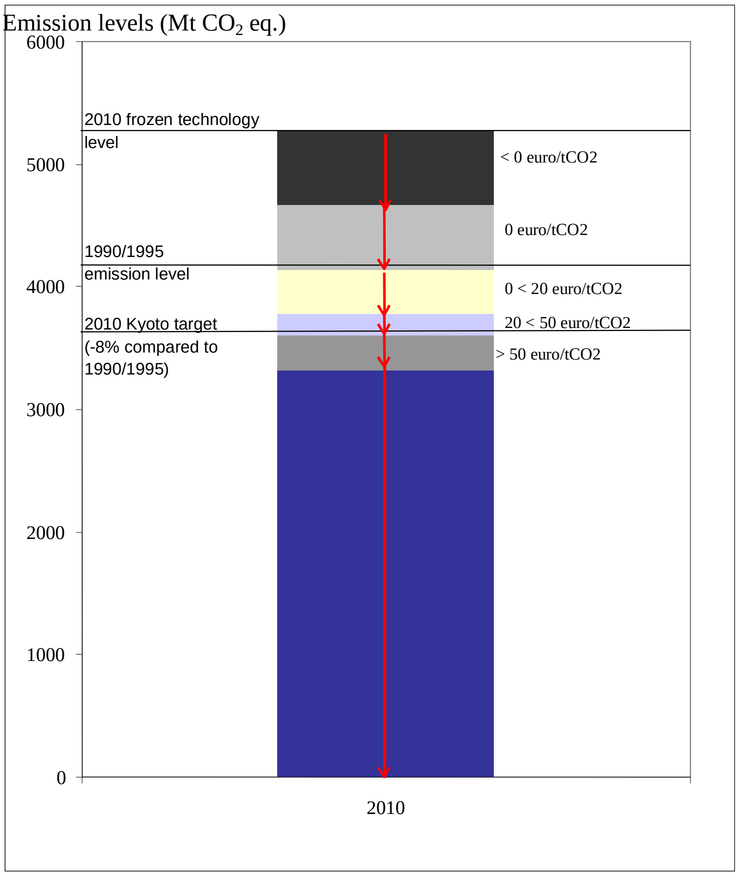

Figure D GENESIS approach: How emissions can be brought down by 2010 from the level at which no reduction options are implemented at all (the frozen technology reference level). The emission reductions in various cost categories are indicated by the arrows. For comparison, the 1990/1995 level and the 2010 target level are indicated. The cost brackets are given in 1990 euros (1 $euro_{1999}$ = 1.3 $euro_{1990}$).

The most important measures in the medium cost category (25 - 65 $euro_{1999}/tCO_2$ equivalent) comprise the insulation of service sector buildings, emission reduction of methane through waste incineration, the replacement of grey cast-iron natural gas distribution network, emission reduction of PFCs from chemical vapour deposition in the semiconductor industry and various measures for HFCs in all sectors (e.g. cooling, air conditioning, foams). This group represents about 7% of the reduction potential.

The remaining 15% is comprised of about 60 options in all sectors. The most important reduction option in this category is CO_2 removal and storage, with an assumed reduction potential of 50 Mt CO_2 in 2010. This figure may actually vary from 10 to 100 Mt CO_2, depending on the acceptance of this option and the success of demonstration projects for various emission sources and storage concepts. The storage capacity in the European Union is estimated at about 950 $GtCO_2$, which is equal to storage of all 1990 CO_2 emissions for more than 200 years.

ANNEX 5 LIST OF REPORTS

Reports prepared in the framework of the project 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change':

BOTTOM-UP METHODOLOGY GENESIS

Summary report

Chris Hendriks, David de Jager, Kornelis Blok et al.. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change: Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU', ECOFYS Energy and Environment / AEA Technology, Utrecht, The Netherlands, March 2001.

Sector reports (engineering/economic analysis study)

- S. Joosen & K. Blok. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change Economic Evaluation of Carbon Dioxide Emission Reduction in the **Household and Services** Sectors in the EU'. ECOFYS Energy and Environment, The Netherlands, January 2001.
- J. de Beer, D. Phylipsen, & J. Bates. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Carbon Dioxide and Nitrous Oxide Emission Reductions in **Industry** in the EU – Bottom-up Analysis'. ECOFYS Energy and Environment, The Netherlands & AEA Technology Environment, Culham, United Kingdom. January 2001.
- C. Hendriks, D. de Jager, J. de Beer, M. van Brummelen, K. Blok & M. Kerssemeeckers. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Emission Reduction of Greenhouse Gases in the **Energy Supply** sector in the EU'. ECOFYS Energy and Environment, The Netherlands. March 2001.
- J. Bates, C. Brand, P. Davison & N. Hill. 2000. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Emissions Reductions in the **Transport** Sector of the EU'. AEA Technology Environment, Culham, United Kingdom. March 2001 (update).
- J. Bates. 2000. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Emission Reductions of Nitrous Oxides and Methane in **Agriculture** in the EU'. AEA Technology Environment, Culham, United Kingdom. February 2001 (update).
- J. Bates & A. Haworth. 2000. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change Economic Evaluation of Emission Reductions of Methane in the **Waste** Sector in the EU'. AEA Technology Environment, Culham, United Kingdom. March 2001 (update).
- C. Hendriks & D. de Jager. 2001. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Methane Emission Reduction in the **Extraction, Transport and Distribution of Fossil Fuels** in the EU'. ECOFYS Energy and Environment, The Netherlands. January 2001.
- J. Harnisch & C. Hendriks. 2000. 'Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Emission Reductions of **HFCs, PFCs and SF6** in Europe'. ECOFYS Energy and Environment, The Netherlands. April, 2000.

Top-Down methodology PRIMES

P. Capros, N. Kouvaritakis & L. Mantzos. 2001. ‘Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU’, National Technical University of Athens, Athens, March 2001.

General/Overview reports

K. Blok, D.de Jager & C. Hendriks. 2001. ‘Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change – **Summary Report for Policy Makers**, ECOFYS Energy and Environment, AEA Technology, National Technical University of Athens, Utrecht, March 2001.

K. Blok, D. de Jager, C. Hendriks, N. Kouvaritakis & L. Mantzos. 2001. ‘Comparison of 'Top-down' and 'Bottom-up' Analysis of Emission Reduction Opportunities for CO_2 in the European Union’ (Memorandum), ECOFYS Energy and Environment / National Technical University of Athens, Utrecht, January 2001.