Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change

Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU

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Contribution to a Study for DG Environment, European Commission by Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens

Preface

This report is a contribution to the study "Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change" launched by the Environment DG of the European Commission in 1999. The analysis presented in this report is based on the energy system model PRIMES, developed and maintained at NTUA (see www.e3mlab.ntua.gr). However, the analysis has been complemented by the results of the analysis of non-CO2 greenhouse gases carried out by AEA Technology and Ecofys. Earlier versions of this report were presented in three workshops organised by DG Environment in November 1999 and March 2000, as well as subsequent comments received bilaterally. The lists of participants of the workshops are given in Appendix IV. Efforts have been made to include the comments of workshop participants and some additional reviewers. As sometimes it has not been able to resolve the divergences of opinion, such issues are flagged in footnotes.

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.

Executive summary

As part of the “Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change” study, launched by the Environment DG, the PRIMES model has been used to provide insight on the contribution of energy producers and users to reduce CO_2 emissions in the EU. The results obtained from PRIMES model show the reduction potential of each sector under a system-wide analysis.

The PRIMES model includes all energy related CO2 emissions and allocates them either to the energy production or consumption side. PRIMES model allocates emissions from electricity steam and district heat production to the supply side.[1] Thus, the emissions of the use of electricity, industrial heat or district heating are all allocated to the energy supply sector in the PRIMES model. Emissions in the energy user side include the combustion of fossil fuels. Thus, the use of natural gas to heat a home or gasoline to drive a car is allocated to households and transport sectors respectively.[2]

The PRIMES model baseline (i.e. “business-as-usual”) emission until 2010 were agreed upon in the “Shared Analysis” project, which was concluded under the auspices of the DG Transport and Energy in 1999. The Shared Analysis baseline included the policies and measures that were in place at the end of 1997. However, the effect of the environmental agreement with between European, Japanese and Korean car manufacturers (the “ACEA Agreement”) to reduce fuel consumption of cars to 140 grams CO2 per km has been included in the baseline.

The results obtained from PRIMES model have been combined to the results obtained from the bottom up analysis performed by ECOFYS and AEA Technology[3]. The purpose was to define the least-cost optimum to reduce greenhouse gas emissions in each sector in the EU. Table i summarises these results assuming that the EU Member States achieve the –8% reduction target jointly.

The role of non-CO2 greenhouse gases emissions in achieving the Kyoto target is significant. Under baseline conditions the emissions of non-CO2 gases are projected to change by -6.8% from 1990 levels. CO2 emissions, on the other hand increase at the same period by 4.1% (or 6.7% without the ACEA Agreement). The compliance to the Kyoto target in 2010 is achieved through a reduction of 271 Mt CO2 for CO2 emissions and 112 Mt CO2 equivalent for non-CO2 greenhouse gases.[4]

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[1] These include industrial boilers and industrial autoproducers of electricity and steam but the emissions from industrial boilers can be allocated to the industry where the activity takes place.

[2] The PRIMES model can analyse shifts due to changes in technology in energy demand side (e.g. if a diesel locomotive is replaced by electricity, the model allocates the emissions from transport to energy supply and the emissions from energy supply demand on the fuel mix that is used to generate electricity. In addition, the PRIMES model can show the emissions due to electricity and steam use in such a way that they are allocated to the energy demand sectors.

[3] 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

[4] The " ACEA Agreement” is according to PRIMES projected to reduce CO2 emissions by more than 80 Mt CO_2 in 2010. Consequently, the achievement of the Kyoto target for the EU becomes easier.

Table i: Allocation of effort by pollutant for achieving the Kyoto target under a regime with full flexibility (including the ACEA Agreement in the baseline)

	Baseline scenario			Emission reduction from 1990 levels		Compliance cost
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
CO2 emissions	3068.1	3193.3	4.1	-146.0	-4.8	20.3
demand side	1936.6	2032.6	5.0	-25.5	-1.3	
industry[1]	561.4	449.5	-19.9	-145.9	-26.0	
transport[2]	734.8	919.0	25.1	152.0	20.7	
domestic	640.4	664.1	3.7	-31.6	-4.9	
supply side	1131.5	1160.7	2.6	-120.4	-10.6	
Non-CO2 GHGs emissions	1070.2	996.9	-6.8	-185.1	-17.3	20.3
Total	4138	4190	1.3	-	-8.0	20.3

Source: PRIMES, ECOFYS, AEA Technologies

[1] *emissions from industrial boilers allocated in the demand side*

[2] *ACEA/JAMA/KAMA agreement is included*

Concerning CO2 emissions only, in the least-cost allocation of sectoral reduction objectives, the energy supply side is the key driver for emissions reduction (-150 Mt CO2 from the baseline in 2010 or -120 Mt CO2 from 1990 level)) followed by the domestic (households and tertiary) sector (-55 Mt CO2 from 2010 or -32 Mt from 1990). In the least-cost allocation, industrial sectors would reduce their emissions from 2010 by 34 Mt or by 146 Mt from 1990. It needs to be emphasised that between 1990 and 2010, the EU industry is projected to make significant energy efficiency improvements under baseline conditions, and that the industry will undergo significant structural changes. These lead to a reduction of CO2 emissions by more than 110 Mt CO2 in 2010.

In the EU energy system, the most important measures to achieve the Kyoto target are:

- Changes in the fuel mix in favour of less carbon intensive fuels, both in the energy supply and demand sides,
- Higher adoption of carbon free energy forms (e.g. wind energy, biomass/waste), especially in the energy supply side,
- Higher penetration of co-generation units for the production of electricity and steam to the detriment of industrial boilers,
- Structural changes in industry leading to less energy intensive processes,
- Continuation and reinforcement of energy conservation measures seeking better housekeeping in the energy demand side.

The power generation sector plays a crucial role because it has many low cost opportunities for emission reduction and because electrical technologies enable efficiency gains in the demand side. Transport remains a sector posing a particular policy challenge because of very high projected growth of CO2 emissions and high adjustment costs. The implementation of the ACEA Agreement reduces the marginal abatement cost for the EU energy system $€_{99}$ 31.6/tCO2 to $€_{99}$ 20.3/tCO2 and the total compliance costs are reduced by €2.9 billion.

In order to achieve the reductions of CO2 emissions in the EU energy system poses a major challenge. However, it should be clear that whatever policies or measures, including emission trading, are selected, the adjustment in the energy system needs to be based on the carbon content fuel used. Thus, whatever policies are chosen the end result will be that those fuels having higher carbon content will need to be less attractive than fuels with low or no carbon content. One EU wide policy to comply with the Kyoto target would be to charge the carbon content of fuels either directly or indirectly. According to the PRIMES calculations, with an increase of the price of the carbon content by €75 per tonne (which is about €20/tCO2) the EU would reach the Kyoto target, assuming that the emissions or non-CO2 gases would be reduced by other policies and measures.

There are two drawbacks in a charge based on the carbon content of the fuel. One relates to the political difficulties in gaining EU-wide acceptance. The second is that there is no guarantee that the tax will lead to –8% reduction: if the tax is "too low", the target will not be attained and if it is "too high", there would be an overshoot of the target. Because of these inherent difficulties, it is recommended that other EU-wide policies and measures are considered to reach the Kyoto target.

Both national and EU-wide cap-and-trade of greenhouse gas emissions offers a new opportunity to reach the Kyoto target in such a manner that those wishing to over-comply would get compensated for their ambitions. Such dynamic incentives are one important reason why emission trading should be seriously considered. The least-cost allocation of objectives, as presented in this study, offers a starting point for allocating the emission reduction targets for participating sectors. Such targets should be seen as the best estimates, based on current knowledge.

In addition to emission trading, some other policies and measures could also assist in reducing energy related CO2 emissions. Setting sector specific energy efficiency measures (in e.g. energy production or consumption) would reduce CO2 emissions. This study shows the effects of reduction in energy consumption in terms of CO2 emissions. Further, as de-carbonising of the energy system needs to occur in order to reduce CO2 emissions, this could be targeted by specifically supporting low (e.g. natural gas as well as CHP) or no (renewables) carbon energy sources. This support could be direct (i.e. subsidies) or indirect (i.e. setting minimum shares of energy production from low or no-carbon sources e.g. through a Green Certificate scheme).

Based on the least-cost allocation of emission reduction objectives, the compliance costs of the EU would be €3.7 billion per annum during the first commitment period (2008-2012) of the Kyoto Protocol. This represents 0.06% of the projected GDP of the EU in 2010. It should be noted that due to the current EU energy market liberalisation, electricity prices for both industrial users and households have declined substantially over the last years. Thus, a least cost achievement of the Kyoto target would not place an unbearable burden on the European industry and citizens.

This study has not looked at the effect of the "flexibility mechanisms" of the Kyoto Protocol. Thus, the reduction target for all greenhouse gases for the EU as a whole has been chosen to be –8% throughout this study.

There are still a lot of uncertainties surrounding the developments in non-energy related CO_2 emissions as well as the non-CO2 greenhouse gases (methane, nitrous oxides, HFCs, PFCs and SF6). The development of the non-energy related greenhouse gas emissions, which amounted to 1070 Mt CO_2 equivalent (or about 25% of all emissions in the EU) in 1990, play a crucial role. As this study has used the results of the reduction potential of these non-energy related greenhouse gases, the uncertainties contained in the analysis of those gases, affect the results of this study as well.

During the validation of this study by industrial experts, a lot of comments were given to the forecasts of sectoral production. As these forecasts influence the projections of CO2 emissions, it would be beneficial to undertake sensitivity analysis with the forecasts of how industrial sectors see their production develop up to 2010. Unfortunately, there was no time or resources to carry out such important, but time consuming, sensitivity analysis. Finally, it should be emphasised, that some policies and measures that have been approved after 1997 either in the EU (e.g. the Integrated Pollution Prevention and Control Directive) or the Member States (increased support to renewable energy) have not been included in this study. Thus, additional work is required to update the baseline. Such additional work could be complemented by the in-depth knowledge of industry specific sectoral forecasts of production.

1. Introduction

The PRIMES model[5] and its use within the Shared Analysis project[6] quantified a set of scenarios for the European energy demand and supply system. The purpose of this report is to build on this work and to present the results of an analysis showing how much different sectors would need to reduce their greenhouse gas emissions so that the European Union would reach its target of reducing greenhouse gas emissions by 2008-2012 by 8% from 1990 level. For analytical purposes the year of 2010 is representing these years.

This reports describes the main elements of the PRIMES model and discusses how valid the baseline of the Shared Analysis project is. It also shows the likely mechanism in each sector to adjust so that the EU would reach the Kyoto target. In addition, the likely importance of the environmental agreement between European, Japanese and Korean car manufacturers to present to the market more fuel efficient vehicles (agreement not included in the baseline for Shared Analysis project) is also examined. The baseline constructed in this report is used as the basis for a bottom-up analysis that is carried out on energy related CO_2 emissions by ECOFYS.

The projections for the demand and supply sectors were designed to be consistent with the rest of the energy system. The exact of definition of sectors is given in Appendix III. Scenarios that reduce emissions are assumed to simulate a response of the entire energy system to globally imposed emission constraints. In this sense, the scenarios are top-down oriented, since the model simulates the allocation to the sectors of the collective emission reduction effort. The model follows an explicit representation of technologies, engineering constraints and plants. It should be qualified as an engineering economic model.

For each energy demand sector, the model answers to the following question: what is the optimal least cost configuration of the sector so as to generate a certain level of value added, while satisfying constraints that represent technical, fuel availability and emission restrictions. It is assumed that a representative agent of the sector performs a stepwise set of decisions to configure production and energy use in the sector. He has to define physical production, recycling if applicable, possible structural changes in sub-sectors and production processes; he has to choose the technology for each energy use, manage the capital replacement procedure and select the fuel. This is considered to be a simultaneous decision taking into account fuel and energy form prices as given from other sub-models of PRIMES. The sector addresses then to these other sub-models demand for derived and primary energy forms.

The energy demand sectors are to a considerable extent decomposed into several sub-sectors. Industry is subdivided into nine main sectors and several sub-sectors. Residential demand is broken down into five typical households. The tertiary sector is split into five sub-sectors. Finally transportation identifies categories of means and transport mode.

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[5] PRIMES is a partial equilibrium model for the European Union energy system developed and maintained at the National Technical University of Athens, E3M-Laboratory led by Prof. Capros. The most recent version of the model used in this study covers all EU Member States, based on data from EUROSTAT, has a five-year periodicity and uses 1995 as the base year. PRIMES is a result of collaborative research under a series of projects supported by the programme Joule of Directorate-General Research of the European Commission. See Appendix I for a short description of PRIMES.

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

For the electricity and steam generation system, the model answers to the following question: what is the optimal least cost operation and configuration (including new investment) of the system that produces electricity and steam, separately and/or jointly, so as to meet the demand, while satisfying technical, fuel availability and emission restriction constraints.

The following sections use the results of the PRIMES model coming from a large series of scenarios and sensitivity analysis runs to analyse how the energy system reacts to different emission limitation objectives for 2010. The purpose is to assess the different sectors adjustment capability as a first step to setting appropriate sectoral objectives in the EU.

The sections present this analysis per sub-sector both for the demand side (industry, residential, etc.) and the supply side (renewables, cogeneration, etc.). It is worth noting at the outset that the results are obtained by running the entire PRIMES model and not from the utilisation of sectoral models. Given the high uncertainties regarding the evolution of total greenhouse gas emissions and in order to obtain a better understanding of the sectoral potential and reaction to emission constraints, besides the sectoral adjustments in the context of the Kyoto target two additional scenarios are examined, namely the two times Kyoto (i.e. –16% in 2010 from 1990 levels) and four times Kyoto (i.e. –32% in 2010 from 1990 levels).[7] All scenarios describe the reduction of CO2 emissions without taking into account other greenhouse gases emissions. In other words, it is assumed in these sections that the overall reduction of CO2 would be 8% from 1990 levels by 2010. In the last section of this study, this assumption is relaxed.

In the last section of the report, the results obtained from the PRIMES model are combined with the analysis of non-CO2 greenhouse gases (carried out by Ecofys and AEA Technology). In this analysis the potential contribution of the different Member States and sectors in achieving the Kyoto targets are assessed. For this purpose a "meta-model" was constructed. This model combines the marginal abatement cost curves of CO2 and non-CO2 greenhouse gas emissions. Using the "meta-model" three scenarios to reach the –8% reduction target were examined: (i) the flexibility scenario (assuming all Member States achieve the EU-wide reduction target of –8% jointly) including the "ACEA Agreement", (ii) the flexibility scenario excluding the "ACEA Agreement" and (iii) the Burden Sharing scenario (assuming that each Member State achieves its Burden Sharing Target alone) including the "ACEA Agreement".[8]

During the validation process of the study, industry experts complained that they were unable to relate the CO2 emission data and projections of PRIMES to their own estimates or to EUROSTAT numbers. The reason for the discrepancy is that PRIMES allocates CO2 emissions of industrial boilers to energy supply, while EUROSTAT (and industries) allocate these emissions to the industrial sector concerned. In order to make the numbers compatible, two sets of tables have been prepared: one set of tables shows the results based on PRIMES classification of industrial boilers (to energy supply sector) and the other set based on EUROSTAT classification (to industry). Total emission are naturally not affected, only the sectoral allocation. Finally, all tables also show the emissions from energy supply sector would be reallocated to industry, households and services based on

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[7] The discussion of the two additional scenarios provides detailed insights of sectoral adjustments required if the reduction target would be more demanding than the one set in the Kyoto Protocol. Therefore, these sections with additional information can be left unread if the focus of the reader is the first commitment period (2008-2012) of the Kyoto Protocol.

[8] The case "excluding the ACEA Agreement " was not analysed because this was not thought to add much further insight and because this was not considered policy relevant.

their energy consumption. These “indirect” emissions should be helpful when the effects of changes in energy demand are analysed.

Greenhouse gas emissions of industry sector in 1990 and in 2010, as well the cost effective objectives are given in Appendix V. Thus, to conserve space, tables on CO_2 or other greenhouse gases are not shown in the text, except in the summary tables in Chapter 7 “Conclusions”.

2. Interaction between demand and power generation

The PRIMES model covers the energy sector as a system. When imposing a global emission constraint, a final demand sector might prefer undertaking electricity savings to allow for lower carbon emissions than reducing emissions from combustion taking place directly in the sector. The model computes a least-cost allocation of the collective effort to the sectors. Conclusions about the emission reduction possibilities of a sector are drawn as a result of system-wide analysis, through the model. This is not comparable to engineering approaches that usually consider the sectors disconnected from each other.

The basic source of data for energy consumption by sector and fuel is EUROSTAT (detailed energy balance sheets). By using additional information (surveys of cogeneration operation and capacities and surveys on boilers), the balance sheets have been modified in order to represent explicitly the production of steam. According to PRIMES definitions, steam includes industrial steam and distributed heat (at small or large scale). It should be noted that in the balance sheets, EUROSTAT reports steam production in the transformation input/output only if the producer sells that steam. If the steam, irrespectively of the way it is produced (e.g. a boiler or a CHP plant), is used for self-consumption only, EUROSTAT accounts only for the fuels used to produce that steam and includes these fuels at the level of final energy consumption. The PRIMES database departs from EUROSTAT practice by introducing that steam (for self-consumption) in the final energy consumption tables of the balance sheets and inserting the fuels used to produce it in the table of transformation input and output. This is necessary for the model to calibrate to a base year that properly accounts for the existing cogeneration activities (even if they are used for self-generation of steam) and to fully exploit the potential contribution of cogeneration to electricity and steam production.

The PRIMES model includes only direct carbon emissions in the final demand sectors. Emissions from steam and electricity production are included in the supply sectors, which generate steam and electricity. It is possible to allocate these supply side emissions to those sectors that use energy. Seen from the point of view of energy consumption, the emissions arising from the use of electricity, steam and district heating are “indirect” emissions.

Emission reduction constraints have been applied as global constraints in solving the PRIMES model in order to obtain an allocation of energy and emissions reduction, as the model itself would suggest. Given the technical features and design of PRIMES the imposition of global emissions constraint is equivalent to the inclusion of a variable, which reflects all the economic costs imposed by the global constraint.

The mechanism through which the carbon constraint is attained involves the attribution of an appropriate economic value to the reduction of emissions of carbon. Equivalently, the ability to emit carbon obtains a scarcity value and is allocated an implicit price. Correspondingly economic agents are faced with changes in the relative prices, reflecting the carbon emissions that each commodity or activity involves. This, of course, leads to adjustments in the behaviour of producers and consumers of energy that tend to shift away from activities that involve emissions.

In other words, in the scenarios examined, the EU energy system has been treated as one economic unit without any a priori allocation of emissions reductions to any sector or country. Thus, in principle, the model could allocate all required reductions in emissions to a single sector or a single country, if this were economically more efficient, irrespectively of any political or social considerations. The results obtained from the analysis showed that the power and steam generation system is the most responsive to the introduction of small to medium emission reduction objectives while the potential improvement from the demand side is activated principally when higher emission reduction targets are set.

The contribution of a final demand sector to collective emission reduction can vary when varying the level of the collective emission reduction effort. At a lower emission reduction objective, the systems-wide analysis might indicate more cost-effective measures in the power and steam generation sector. On the other hand, when the collective emission reduction effort is higher, cost-effective measures in power and steam tend to become exhausted, so some sectors, depending on their structure, are obliged to do more emission abatement in a direct way.[9]

It should be noted that due to the approach described above (allocation of fuels used in industrial boilers as well as of corresponding CO2 emissions on the supply side, allocation of produced steam as demanded fuel on the demand side) the structure of energy requirements and, correspondingly, direct CO2 emissions in industrial sectors are altered compared to EUROSTAT data. Appendix II discusses these differences in detail. The impact measured following this approach is more significant in sectors such as chemicals, paper and pulp and food drink and tobacco industries, which involve high utilisation of steam in their production processes. In that sense, the analysis, partly underestimates the potential contribution of industrial sectors in reducing CO2 emissions examining only the changes that occur at the level of direct energy uses, while changes regarding production of steam are allocated to the supply side.

It is also important to note that the reporting requirements of National Communications under the UN Framework Convention on Climate Change – as specified by the Intergovernmental Panel of Climate Change (IPCC) – are different from the coverage in this report. The main differences are: (a) under Primes, industrial generation of power and steam (referred to as “autoproduction”) is allocated under power generation sector (according to EUROSTAT definition) while under IPCC guidelines such power generation is under “industry”), and (b) international aviation emissions are included in the Primes (and EUROSTAT) numbers while they are reported as a memo item under UNFCCC. In terms of CO_2 emissions the differences between sectors are important, as the emissions from “autoproduction” were 109 Mt of CO_2 in 1998. This represents about 12% of conventional thermal power emissions of the EU. International aviation contributed 74 Mt of CO_2 emissions in the EU Member States.

[9] Direct emissions include those emissions that arise from the combustion of fossil fuel in the sector (e.g. heating a furnace with gas). Indirect emissions refer to those emissions that arise in the energy supply sector due to the use of energy (e.g. the emissions of a coal-fired power plant due to the use of electricity when using an electric arc.

3. Reduction of CO2 from industry

In this section the results of the attainment if an EU-wide –8% reduction target are shown for each main energy consuming industrial sector. Each section has a short discussion of how valid the Shared Analysis baseline is followed by a description of the main features of the baseline. Then the results of how the sector would react when the energy systems as a whole would reach the –8% target are given. The boxes "additional information" give further insights of how sensitive the sector is if the Kyoto target was more demanding, i.e. if the target was "two times Kyoto" or -16% from 1990 or "four times Kyoto" or –32% from 1990. Section 3.7 concludes what the least-cost emission reduction potential industrial sectors would be according to the PRIMES model.

3.1. Iron and steel sector

The production of the iron and steel sector (as modelled in PRIMES) is divided into two sub-sectors, the traditional "integrated steelworks" sub-sector (using mainly coke and iron ore as raw materials) and the "electric arc furnace" (EAF) sub-sector, which uses scrap as its basic raw material. In the model projections for steel production is related to the evolution of sectoral value added. The model allows for the possibility of reflecting situations in which higher value added may be obtained with relatively lower production in physical units, for example by improving product quality.

3.1.1. Is the current PRIMES baseline still valid in relation to short run trends?

According to the latest data available from the International Iron and Steel Institute (IISI), steel production in the EU increased from 153 Mt in 1995 to 155 Mt in 1999 (160 Mt in 1998). The PRIMES projection for 2000 production is 158 Mt of steel, which seems in broad agreement with the latest data available.

The share of EAF production in the EU increased from 32.5% in 1995 (about 27% in 1990) to 38.2% in 1998. The corresponding figure in the PRIMES baseline for the year 2000 is 38%.

Integrated steelworks using blast-furnace plants are very energy-intensive, in fact about 3 times more than EAF, and therefore even small shifts from the one process to the other can lead to significant changes of the overall energy intensity of the sector. Between 1990 and 1997 the overall specific energy consumption of the iron and steel sector (mainly because of the effect of shifting from integrated steelworks to EAF) improved by more than 10% (or 1.5% per year). The projected specific energy consumption improvement in PRIMES from 1995 to 2000 is about 1% per year, while for the same period technological progress at the process level has been limited. However, the lack of disaggregated data as regards energy consumption by process does not allow for a comparison with technical progress as observed in the near past.

On the basis of the above comparisons it can be argued that PRIMES results for the short run are consistent with recent trends in iron and steel sector.

3.1.2. What is the basic mechanism reflected in the PRIMES baseline scenario towards 2010?

The key assumption regarding the PRIMES projection to 2010 for iron and steel is that in the context of the EU single market integrated steelworks will become concentrated in some major basic steel producing countries and companies. A certain basic processing capacity will remain active in those major poles in the EU, while smaller factories will specialise and further shift towards EAF. More specifically the following are included in the baseline scenario:

- Sectoral value added is assumed to increase by 6.5% from 1995 to 2010. Because of product quality improvement, production of steel in 2010 is projected to increase by only 4% from its 1995 level (1% from 2000) reaching 159.5 Mt of steel.
- According to IISI medium-term projections, steel demand in 2005 will increase from 2000 levels by about 2 Mt (or 1.5%) in the EU. Historical trends have shown that growth rates of steel demand in the EU are similar to those of steel production. If historical trends continue in the near future then the production of steel for 2010 is underestimated in the PRIMES baseline scenario.
- According to baseline projections about 47% of steel production in 2010 will be derived from EAF. Requirements for scrap steel as raw material are projected to reach 100 Mt in 2010. In 1997, about 87 Mt of scrap steel was consumed by iron and steel industries (from 73 Mt in 1990, i.e. an increase of about 14 Mt or 8% in 7 years). In that sense, the additional scrap requirements for 2010 (+13 Mt from 1997) seem feasible.
- Overall specific energy consumption in iron and steel is projected to improve by 7.2% between 2000 and 2010 again due mainly to restructuring. Limited technology improvement is projected at the specific process level. As a result of product quality improvement a more significant progress is projected for sectoral energy intensity in terms of value added (+12% in 2000-2010).

3.1.3. Sector adjustment under Kyoto according to PRIMES

The projected evolution of the iron and steel sector under baseline conditions leads to a substantial decrease (by almost 25%[10]) in sectoral CO_2 emissions in 2010 compared to 1990 levels. Under a global emission restriction, the PRIMES model estimates a least-cost allocation of the emission reduction effort to the various demand and supply sectors of EU Member State. As a result, the imposition of the Kyoto emission reduction constraint leads to a further reduction of CO_2 emissions also in the iron and steel sector.

In order to reach the Kyoto target, the sector is predicted to undergo the following changes:

- The iron and steel sector shifts more aggressively into EAF, the share of which increases to 52% of steel production in 2010 (47% in baseline). Besides efficiency gains this shift is also driven by the relative ease with which the electricity generation system reduces emissions via the improvement of carbon intensity.
- Overall steel production is also affected decreasing to 154 Mt of steel in 2010 (compared to 159.5 Mt under baseline conditions). This reduction does not affect the sectoral value added, i.e. product quality is further improved compared to baseline.
- Scrap requirements in 2010 reach 105 Mt (a small change from baseline where they stood at 100 Mt of scrap).[11]

[10] Emissions for electricity production are included in the electricity sector

[11] A reviewer of this report has suggested that there might not be enough scrap metal to satisfied this demand. This issue cannot be resolved as part of this study, though.

- Specific energy consumption in 2010 improves by 5% on top of baseline. The improvement is due to the structural shift towards EAF and not to technological progress in specific processes or equipment. The corresponding energy intensity improvement reaches 8% on top of baseline.
- CO_2 emissions in iron and steel decrease by more than 15% from baseline in 2010 (or 36% from 1990 levels).

The projected evolution of the iron and steel sector under the imposition of the Kyoto emission reduction target for the EU energy system seems to be reasonable. However, there are two issues that need to be clarified. First, the increased share of EAF may lead to the need of imports of specific products (e.g. steel for heavy construction uses). Second, the production cost of steel is projected to increase by 10% from baseline levels. If iron and steel industries in other Annex B Parties[12] would not face the Kyoto constraint, the competitiveness of EU iron and steel industry would be affected negatively. However, if the other Parties would face a relatively higher constraint (i.e. if the target for the competitors would be tougher), the EU iron and steel producers would gain in competitiveness.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

For higher levels of emission reduction targets, there are no additional potential gains from shifting into EAF. To abate more it is necessary to adopt more efficient technologies, especially in integrated steelworks, that could lead to significant improvements in terms of specific energy consumption. However, given the long lead times of energy related equipment in the sector, the existing overcapacity and the fact that in recent years the sector has undergone a considerable investment program for renovation and restructuring, the adoption of new technologies in the horizon to 2010 will require the premature replacement of existing equipment. This involves high costs and explains the inertia of the sector, regarding technology improvement, in the context of the baseline and the emission reduction scenarios.

More specifically, the analysis of cases involving high emission reduction effort can be summarised as follows:

- The imposition of a global emission reduction target of –20% from 1990 for the EU energy system makes the adoption of direct smelting and direct reduction technologies (allowing for a decrease of the use of coke in blast furnaces and reducing the need for ore preparation) cost effective. Energy intensity of integrated steelworks improves by 8% from baseline while the efficiency of blast furnace processing in integrated steelworks improves by more than 10%. However, unit production costs increase by almost 18% from baseline levels. Potential improvement of blast furnace processing due to this technology can reach up to 35%.
- A global emission reduction target of at least –30% from 1990 levels for the EU energy system would be required before adopting hot connection techniques and mainly near-net-shape casting that replace continuous slab casting and hot rolling. In this case efficiency improvement in casting and rolling operations reaches

[12] These are mainly OECD countries.

15% and 20% as compared to baseline for integrated steelworks and EAF respectively. In addition, blast furnace processing efficiency further improves up to 30% from baseline levels. As a result the cumulative energy intensity improvement in integrated steelworks exceeds 20%, while that of EAF reaches 13%. The unit production costs of steel increases, however, by 22%.

- Scrap pre-heating and other techniques that contribute in making the electric arc processes more efficient become cost effective only for very high emission reduction targets (at least -35% from 1990 CO_2 emissions for the EU energy system).

In total, potential efficiency improvement in integrated steelworks can reach up to 35% while that for EAF can reach up to 20%. However, in the medium term horizon of 2010, this will lead to substantial increases in production costs (more than 30% from baseline levels) seriously affecting the competitiveness of the EU iron and steel sector.

Table 1: Changes in the iron and steel sector under different emission reduction regimes

	1995		2010		
	Energy demand	Production from Electric arc	Energy demand	Production from Electric arc	Energy intensity
	Mtoe	%	Mtoe	%	% change from 1995
Austria	1.8	9	1.8	18	-5.3
Belgium	4.2	8	4.4	15	-5.1
Denmark	0.1	100	0.1	100	-4.0
Finland	1.3	34	2.1	19	24.4
France	6.9	25	6.1	42	-12.1
Germany	14.5	34	11.9	54	-22.6
Greece	0.1	100	0.1	100	-1.9
Ireland	0.1	98	0.1	99	-9.2
Italy	7.6	52	6.2	69	-17.9
Netherlands	2.3	4	2.3	10	-4.2
Portugal	0.3	37	0.3	54	-11.7
Spain	3.5	49	3.1	68	-16.4
Sweden	1.9	18	2.0	27	-4.7
United Kingdom	7.9	22	8.0	37	-11.4
TOTAL EU	52.6	32	48.5	47	-13.2

	Kyoto		Two times Kyoto		Four times Kyoto	
	Production from Electric arc	Energy intensity	Production from Electric arc	Energy intensity	Production from Electric arc	Energy intensity
	%	% change from 2010 baseline	%	% change from 2010 baseline	%	% change from 2010 baseline
Austria	26	-8.4	27	-12.2	39	-34.0
Belgium	22	-9.9	24	-14.2	33	-36.8
Denmark	100	-3.2	100	-5.3	100	-15.8
Finland	25	-8.4	28	-13.8	33	-32.4
France	51	-9.9	56	-15.9	77	-43.4
Germany	57	-7.0	59	-10.5	72	-37.3
Greece	100	-4.2	100	-6.7	100	-20.1
Ireland	99	-3.8	99	-9.4	100	-20.0
Italy	70	-5.5	72	-9.8	83	-35.4
Netherlands	15	-9.2	15	-13.4	23	-36.4
Portugal	65	-11.6	65	-14.6	79	-37.5
Spain	71	-5.7	74	-11.0	84	-33.4
Sweden	39	-7.9	43	-11.5	63	-32.5
United Kingdom	46	-10.9	47	-14.8	57	-37.1
TOTAL EU	52	-8.3	54	-12.5	66	-36.8

Source: PRIMES

3.2. Aluminium and other non-ferrous metals production

In the PRIMES model primary and secondary aluminium are represented as two distinct sectors. Primary aluminium production involves treating bauxite and then decomposing dissolved alumina into a crude molten metal through electrolysis. Electricity consumption in electrolysis represents over 80% of energy use in the sector. Thermal processing in the sector uses all kinds of fuel and electricity. Secondary aluminium production processes scrapped aluminium products to refine and thermally convert into primary aluminium. This process requires only about 15 % of the energy consumed in primary aluminium production. Production of zinc, lead, copper and other non-ferrous alloys is also represented in PRIMES.

Projected production is related to the evolution of the value added of non-ferrous metals industries.

3.2.1. Is the current PRIMES baseline still valid in relation to short run trends?

According to the latest information available from the International Primary Aluminium Institute (IPAI) and the European Aluminium Association (EAA), primary aluminium production in the EU increased by 3.2% between 1995 and 1997 and reached 2230 Mt per year (2160 Mt in 1995). The baseline scenario constructed using the PRIMES model projects a fall in total primary aluminium production in 2000 to a level of 1850 Mt (-14.5% from 1995 levels).[13] Secondary aluminium production, as projected in PRIMES, increases by 25% from 1995 to 2000. The corresponding increase for the period 1995-1997 on the basis of the latest data available is of about 5-6%. Overall production of aluminium increases by 4% from 1995 to 1997 while the corresponding projection for the 1995-2000 period is about 3%.

PRIMES projections as regards the increase of production for other non-ferrous metals in the 1995-2000 period ranges between 6.5% for lead to 9.5% for copper.

Given the significant difference in terms of energy intensity between primary aluminium production and other non-ferrous metals production, any shift from one process to the other leads to significant changes of the overall energy requirements of the sector. According to EUROSTAT energy balance sheets data demand in non-ferrous metals industries increased by 8% between 1995 and 1997. The projected increase between 1995 and 2000 in PRIMES is only 1.5% (-8% as regards aluminium production, +8.5% for other non-ferrous metals).

It seems from the above that the increase of primary aluminium production, and to a lesser extent of total aluminium production, has been underestimated in PRIMES. As a result energy requirements in non-ferrous metals production are not projected to increase at growth rates as high as the ones observed in the latest statistics. Thus, the CO2 emissions arising from aluminium production are likely to be higher than what is predicted by PRIMES using the Shared Analysis baseline.

3.2.2. Basic assumptions reflected in the PRIMES baseline scenario towards 2010?

The non-ferrous metals industry is also a high capital and energy intensive industry. The EU single market will affect concentration and specialisation in the industry. The key assumption as regards the PRIMES projection to 2010 for non-ferrous metals production is that few factories will produce using basic processing. In the same period, production of copper and zinc is expected to exhibit accelerated growth while production of lead increases at smaller rates. More specifically, the baseline projection involves the following:

- Sectoral value added from non-ferrous metals production is assumed to increase by 18% from 1995 to 2010. Physical production of non-ferrous metals (expressed as an index because of the different products included in the sector) in 2010 is projected to increase by 17% from its 1995 level.
- Primary aluminium production is projected to drop to 1400Mt in 2010 (-35% from 1995 levels) while secondary aluminium production increases by more than 60% from 1995 levels to reach 2860 Mt. The latter would represent 67% of total aluminium production in the EU, against 45% in 1995. Such a change

[13] According to the European Aluminium Association the production of primary aluminium was 2457 Mt in 1999. Thus, it is clear that the baseline scenario is underestimating the growth of primary aluminium production and this needs to be addressed when the PRIMES baseline is updated.

implicitly assumes higher imports of primary aluminium into the EU, since it cannot be solely attributed to higher recycling of aluminium.

- Copper production increases in 2010 by 24% from 1995 levels, followed by zinc (+18%) while a moderate increase is projected for lead and other non-ferrous alloys (around +15%).

The restructuring of the sector, reducing basic processing, explains the spectacular drop in overall energy intensity (both in terms of physical production and sectoral value added) in the baseline (-14 and -15% respectively in the 1995-2010 period). Technological progress at specific industrial processes is shown to be very limited in the baseline projection with the exception of copper production where an improvement of a maximum of 5% is obtained.

3.2.3. Sector adjustment under the Kyoto commitment

Carbon emissions in the non-ferrous metals sector under baseline conditions increase by almost 8% in 2010 from 1990 levels. This represents a small fraction (0.4%) of total emissions in the EU energy system.

Bearing in mind that electricity is the main fuel used in non-ferrous metals production (accounting for 56% of energy requirements in 1995) and that emissions from electricity production are included in the electricity sector, it is obvious that the sector has a rather limited potential in terms of directly reducing emissions while energy savings of electricity can lead to a significant indirect decrease of CO_2 emissions. Any savings of electricity would of course imply indirect gains in terms of carbon emission reduction.

When the energy system as a whole meets the Kyoto emission reduction commitment, and according to the PRIMES results, the non-ferrous sector undergoes the following changes:

- Overall physical production decreases by 2% from baseline levels in 2010. This reduction affects less the sectoral value added, as it is possible at some extend to shift in favour of higher value added products.
- Structural changes, that would allow for further reducing basic processing, are very limited. One of the reasons is that such a restructuring is projected to take place already under baseline conditions. Secondary aluminium production remains stable at baseline levels and primary aluminium production further decreases by only 4% from baseline in 2010. Achieving higher, than baseline, recycling rates of aluminium would be difficult, since both institutional and technological factors limit the potential for recycling.
- Energy intensity in 2010 improves by 3.5% compared with baseline, but the same improvement in terms of specific energy consumption of basic materials is limited to only 1.5%. The overall emission constraint related to Kyoto commitment is small to trigger further technology progress at the level of specific processes or basic equipment.
- CO_2 emissions in non-ferrous metals production decrease by almost 6% from baseline in 2010 (+1.5% from 1990 levels) indicating that the sector has limited potential as regards direct emissions reduction. The sector also contributes to the collective emission reduction effort by saving electricity; yet this saving is small in magnitude.

Meeting the Kyoto commitments and the adjustments in the non-ferrous sector imply rather small changes on production costs which would increase only by 1.5% from baseline.

Table 2: Changes in non-ferrous metal industries under different emission reduction regimes

	Baseline				Kyoto	Two times Kyoto	Four times Kyoto
	Value added	Energy demand (in Mtoe)		Energy intensity	Energy intensity		
	% change in 1995-2010	1995	2010	% change in 1995-2010	% change from baseline in 2010		
Austria	17.9	0.06	0.07	-0.7	-2.1	-3.6	-8.3
Belgium	38.1	0.36	0.48	-2.1	-2.8	-4.8	-12.5
Denmark	14.2	0.02	0.02	-2.5	-3.6	-6.0	-16.5
Finland	60.8	0.18	0.20	-29.1	-2.1	-3.6	-8.6
France	4.8	1.41	1.30	-11.9	-2.1	-3.6	-8.0
Germany	28.5	2.36	2.12	-29.9	-2.3	-3.8	-19.6
Greece	23.5	0.64	0.72	-8.8	-4.0	-6.1	-16.4
Ireland	59.8	0.27	0.44	-0.2	-2.6	-4.2	-15.6
Italy	14.5	0.82	0.81	-13.4	-2.1	-3.6	-8.6
Netherlands	33.6	0.49	0.51	-22.3	-3.4	-5.0	-10.0
Portugal	32.8	0.03	0.03	-6.6	-3.7	-5.9	-13.2
Spain	14.6	0.93	0.91	-14.5	-4.5	-7.6	-8.1
Sweden	3.3	0.28	0.25	-14.5	-0.2	-0.8	-2.0
United Kingdom	33.6	1.05	1.17	-16.5	-5.5	-8.1	-14.5
TOTAL EU	18.2	8.89	9.04	-14.0	-3.1	-4.9	-12.8

Source: PRIMES

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

As in the case of the iron and steel sector, the non-ferrous metals industry is characterised by long lead times of energy related equipment and the fact that in the last years the sector has undergone a considerable investment program for renovation and restructuring. In that sense, the adoption of new technologies in the horizon to 2010 will require to some extent premature replacement of existing equipment that will in turn involve high costs. Because of the above the sector reacts through the adoption of more efficient technologies only when more stringent emission reduction targets are set.

More specifically the results of the analysis with PRIMES show the following:

- The imposition of a global emission reduction target as high as –35% from 1990 levels for the EU energy system implies for the sector that it is globally cost-effective to adopt advanced melting and holding furnaces (reducing energy needs through heat recuperators and regenerators), as well as the use of oxygen-assisted combustion in aluminium production. The combination of the above technologies leads to an improvement of energy intensity for aluminium production by 10% from baseline. In addition, furnaces, kilns and electrolysis plants for other non-ferrous metals need to undertake improvements that are globally cost-effective under high emission reduction targets, which lead to an overall sectoral intensity improvement of 8.5% compared to baseline. The adoption of these improved technologies in non-ferrous metals industries leads to an increase of average production costs by 5%.
- Advanced electrolysis technologies based on improved Hall-Heroult cell efficiency become cost-effective at even higher emission reduction targets. In this case the efficiency of electrolysis plants in

aluminium production can improve by up to 20% from baseline levels. This improvement combined with the further penetration of the above-mentioned technologies leads to an overall energy intensity gain of 12% from baseline. The increase in terms of average production cost is 7%.[14]

The top-down analysis indicates that to a short-term horizon such as 2010, the non-ferrous industry has limited possibilities to improve efficiency and substantially contribute to a reduction of carbon emissions. In cases when the energy system is faced with tougher emission restrictions and hence is obliged to deal with higher costs the non-ferrous metals industry is forced to adopt efficient processing technologies, at the expense of premature replacement of capital and higher average production costs.

In such a short-term horizon and given the pressures in a very globalised market, such as that for non-ferrous metals, it seems more cost-effective to improve recycling on the demand-side and directly link renewables to supplying the few major primary aluminium factories of Europe. Further analysis on these two issues is necessary.

3.3. Cement and other non-metallic minerals

The sector of building materials includes the production of cement, glass, ceramics and other non-metallic minerals. Cement is produced in special kilns that reduce raw material through fossil fuels that keep up the high temperature required for the process. The PRIMES model considers only energy fuels as being usable in cement kilns. There is however experiences (e.g. in France) in which waste materials of various kinds are burnt in the kilns. This option has not been considered in the analysis.

In general, pyro-processing assuring a chemical reaction constitutes the basic processing for building materials. Melting silica sand produces glass. Bricks and ceramics is just clay until fired. All sub-sectors are very energy-intensive and are separately modelled in PRIMES.

Due to the significant diversity in sectoral products, the physical production is expressed by means of an indicator (index number). It is related to the evolution of the value added of non-metallic minerals industries with variable sub-sector proportions.

3.3.1. Is the current PRIMES baseline still valid in relation to short run trends?

The PRIMES projection for 1995-2000 shows an increase in cement production by 7%. According to the latest data available from the Global Cement Information system, production in the EU remained stable between 1995 and 1997. However, more recent information available from CEMNET indicates an increase in production in 1999 by 4% (from 1995) for three major cement producers in the EU (Germany, Italy and Spain) that account for more than 50% of EU production. It is expected that the current growth prospects for the EU will also involve higher demand for cement.

The PRIMES baseline projects an increase of production of glass by almost 10% in the period 1995-2000. Recycled glass processing increases by 17.5%, while the results show an increase of 2.5% for primary glass production. As a result, the share of recycled glass in total glass production increases to 52% in 2000 from 48.5% in 1995. Production of ceramics and other non-metallic minerals is projected to increase by 10% between 1995

[14] Not including any costs from stranded investment.

and 2000. No recent data were found to check these trends concerning glass and ceramics.

The overall specific energy consumption of the sector of building materials improves under baseline assumptions by 1.5% in the period 1995-2000. The corresponding energy requirements are projected to increase by 7.5% in the same period. According to EUROSTAT recent energy balances, the demand by the sector decreased by 1.8% between 1995 and 1997 mainly as a result of stagnation of material production.

Because of the lack of detailed production data and the wide range of products included in the sector it can not be argued whether PRIMES projections for the short run are in line with recent information.

3.3.2. Basic assumptions reflected in the PRIMES baseline scenario to 2010

A key assumption of the baseline scenario is that within the EU single market the concentration in few large factories will mainly take place in the Southern Member States (Greece, Italy, Spain and Portugal). However, significant levels of domestic production will persist in all Member States because it is more cost effective to have the high-bulk/low-value materials produced domestically rather than transported over long distances. The expansion of the sector in the South is driven partly by high growth in internal demand and by exports. It is also assumed that higher recycled glass processing will take place, but at different degrees across EU Member States reflecting different local markets and possibilities. For example the glass market is very specific in Member States such as Portugal and Spain that produce high quality glass products.

More details about the baseline scenario are given below:

- The sectoral value added of non-metallic minerals production is assumed to increase by 29% in 2010 from 1995 levels. Physical production of non-metallic minerals (expressed in terms of an index number) is projected to increase by 23% in 2010 compared to 1995.
- Cement production is projected to increase by 13.5% between 1995 and 2010 (from 173 Mt to 196 Mt of cement).[15] However production patterns vary considerably: in the South the rise is 32.5% while in other EU Member States there is a drop (-4%) on average. Technological progress in cement production is rather modest in the baseline projection (-3.5% in terms of specific energy consumption in 2010 from 1995).
- The production of glass is projected to increase by 32% in 1995-2010. The share of recycled glass in total glass production is projected to reach 59% in 2010 (48.5% in 1995). Here also technological progress is modest: specific energy consumption is lower in 2010 by 6% and 5% for primary and recycled glass processing. But this progress combined with the structural shift in favour of recycled glass leads to an overall improvement of energy intensity in the glass sector of 8.5% in 2010 compared to 1995, in the baseline scenario.
- The production of ceramics and other non-metallic minerals increases by 23 and 30% respectively. The improvement of specific energy consumption in the

[15] It should be noted that CEMBUREAU projects that cement production will reach 1990 levels (185 Mt of cement) by 2010 consistent with a long-term decline in average annual cement production in the EU (CEMBUREAU's note: "*Potential CO_2 Emission Savings in the Cement Industry of EU (15) from 1990 to 2010*"). The projection retained for this study incorporates a secular decline in most of northern Europe but assumes a more buoyant market in the South hence resulting in slight overall growth.

production of ceramics is of the order of 8% (in 2010 from 1995) and only 2.5% in other non-metallic minerals.

For the overall buildings material sector, the baseline projection shows relatively high energy intensity gains: final energy needs of the sector expressed as a ratio to the sector's value added, improves by 8.5% in the period 1995 to 2010. This is a combined result of specific processing technological progress, some material recycling and the restructuring of the sector in favour of higher value added varieties of the products.

3.3.3. Adjustment of the sector under the Kyoto target

The emissions of carbon from direct energy combustion[16] in the sector of building materials decrease in the baseline by almost 7.5% in 2010 from 1990. For various reasons this reduction mostly takes place in the period 1990 to 1995. The baseline scenario shows a steady increase in emissions (11.5% in 2010) from 1995.

Under the Kyoto obligations for the EU, the top-down analysis indicates the following changes for the building materials sector:

- The index of physical production decreases roughly by 2% in 2010 compared to baseline. The reduction in terms of the sector's value added is smaller, because of shifts towards higher value added products.
- Cement production bears the strongest pressure and decreases by 3.5% in 2010 compared to baseline. The improvement (relative to baseline) in specific energy consumption of cement production is rather modest: 1.5% in 2010.
- The production of glass is less affected, decreasing by only 1% compared to baseline. This drop is higher in primary glass processing (-3% from baseline), while secondary processing is unaffected. The share of recycled glass is marginally higher than in the baseline (roughly at a level of 60%). The analysis assumes that the low-cost potential of further increase of glass recycling (on top of what is already incorporated in thye baseline scenario) is rather limited because of technical limitations, the diversity of glass products and the lack of scrap material (practically only bottles are recycled). However, depending on the structure of the glass industry, some countries may experience higher recycling rates (e.g. 80% in the Netherlands). The Kyoto emission reduction target is not enough to trigger significant improvements in specific energy consumption of glass processing. The improvement is rather modest: 1.5% on top of baseline in primary glass production, +2% in secondary glass processing.
- The production of ceramics and other non-metallic minerals decreases by less than 2% from baseline levels. Again, technological progress is found to be modest (roughly 1.5% on top of the baseline scenario).

Under the Kyoto commitment, the energy intensity (ratio of energy needs over value added) of the sector improves in total by 3.5%, also reflecting structural changes in favour of higher value added production. Carbon emissions from energy combustion in the sector decrease by 5 percentage points in 2010 compared to baseline (-12% from 1990). Production costs in the sector increase on average by 4%.

[16] Carbon emissions from non-combustion are not considered in this analysis.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

The manufacturing of some non-metallic minerals (especially cement and basic processing of glass) is highly capital intensive and needs long lead-times for factory reconstruction.

Because energy costs are a high proportion of total production costs and a competitive market environment, the European cement industry is very efficient in energy terms and yet improving in the baseline scenario. The potential for glass recycling in the horizon to 2010 is exploited to a considerable extent in the baseline scenario. The energy use in the production of many non-metallic minerals is mainly related to kiln technology, for which technological progress prospects are evolving slowly. For these reasons, before undergoing deep emission reduction in the sector, the system should be highly constrained in terms of carbon emissions (in other words it must be faced relatively high costs). In these cases the sector undergoes premature replacement of capital equipment enabling considerable improvements in average specific energy consumption. The top-down analysis quantified several cases. Two are illustrated below:

- The imposition of an emission reduction target of –25% from 1990 levels at the level of the whole EU energy system leads to an improvement of specific energy consumption in building materials of more than 8% from baseline. This is the combined effect of the introduction of advanced kiln technologies and advanced electrical technologies (for mixing, grinding and milling) in cement industries (specific energy consumption decreases by 6% from baseline), the use of advanced burners in oxy-fuel process glass furnaces (specific energy consumption decreases by 8% from baseline) and the replacement of tunnel kilns with roller kilns in ceramics and other non-metallic minerals production (leading to a decrease of specific energy consumption by 6 and 8% respectively). The adoption of these technologies leads to an increase of average production cost of 7.5%.

A global emission reduction target of –35% (from 1990) triggers, among others, the introduction of dual batch/cullet pre-heaters in glass processing, leading to lower energy requirements of up to 30%. Combined with the further penetration of other efficient technologies, specific energy consumption of glass processing is reduced by roughly 20% from baseline. The unit production costs of non-metallic minerals increase by about 12% compared to baseline.

According to the top-down systems analysis, the potential efficiency improvement in non-metallic minerals production can reach up to 25% (ranging from 15% in cement production to 30% in glass production). However, in the medium term horizon of 2010, this will lead to substantial increase of production costs (more than 20% from baseline levels) seriously affecting the competitiveness of the sector.

Table 3: Changes in building materials sector under different emission reduction regimes

	Baseline				Kyoto	Two times Kyoto	Four times Kyoto
	Value added	Energy demand (in Mtoe)		Energy intensity	Energy intensity		
	% change in 1995-2010	1995	2010	% change in 1995-2010	% change from baseline in 2010		
Austria	25.0	0.71	0.87	-1.4	-3.4	-6.1	-15.6
Belgium	23.7	1.26	1.53	-2.0	-4.0	-6.7	-17.8
Denmark	20.5	0.52	0.54	-13.7	-3.6	-6.8	-17.0
Finland	12.7	0.66	0.66	-10.1	-4.1	-7.0	-20.5
France	8.6	4.10	4.11	-7.7	-3.3	-5.9	-16.5
Germany	12.7	7.87	8.07	-9.0	-3.6	-6.4	-16.5
Greece	85.8	1.37	2.31	-9.0	-3.2	-5.1	-11.6
Ireland	25.6	0.11	0.15	4.4	-3.1	-5.6	-13.6
Italy	31.5	6.79	8.21	-8.1	-3.1	-5.7	-15.0
Netherlands	40.0	0.80	1.11	-0.7	-3.8	-7.1	-19.3
Portugal	93.5	1.03	1.76	-11.6	-2.9	-4.5	-13.8
Spain	77.4	3.96	5.25	-25.3	-2.8	-5.2	-15.9
Sweden	5.1	0.48	0.47	-6.0	-4.8	-7.6	-15.2
United Kingdom	16.7	2.75	3.11	-3.0	-3.9	-6.6	-16.5
TOTAL EU	28.8	32.42	38.17	-8.6	-3.3	-5.9	-15.8

Source: PRIMES

3.4. Chemical sector

The chemical sector is characterised by a large variety of products (over a thousand) and a large number of energy related processing technologies. PRIMES being a rather aggregate energy system model cannot represent the different products and the relevant production processes in an analytical manner. The model groups the products into four producing sectors, namely fertilisers, petrochemicals, inorganic chemicals and low energy chemical products (including pharmaceuticals, cosmetics and others). In energy use terms, the first three sectors are energy intensive. Petrochemicals mostly use energy products (fossil fuels) as raw material and produce low carbon emissions per unit of production. Production processes are also represented in an aggregate manner, while reflecting the general requirements of the different chemical industries (use of electrolysis for inorganic substances production, heat and pressure in energy intensive chemical industry, competition between electricity and thermal processing etc.).

Due to the significant diversity of sectoral products, the physical production is expressed by means of an indicator (an index number). It is related to the evolution of the value added of chemical industries through a statistical function, which allows for dissociating value added growth from the increase in production of basic chemicals.

3.4.1. Short run trends

The European sector of chemicals has been a very dynamic sector in the decade 1990 to 2000. The growth of production and value added took place mainly in the low-energy chemical products, while energy-intensive chemicals were growing at a significantly lower rate.

The baseline scenario projects a growth of more than 10% from 1995 to 2000 for the sector. The share of low-energy chemical products is projected to increase continuously, reflecting the on-going structural changes (56% in 2000).

This shift leads to a significant improvement of overall energy intensity in chemical industries, which drops by 8% in 2000 from 1995, as energy requirements in low-energy chemicals are only about 6% of the energy requirements of energy intensive chemical products. Energy efficiency gains at the level of basic processes are projected to be rather modest, ranging between 1% and 4% (for fertilisers and petrochemicals for example).

According to EUROSTAT energy balances, energy requirements in chemical industries (excluding fuel input as raw material in the petrochemical sector) decreased by 2.3% in the period 1995 to 1997. The PRIMES projection for the short run indicates an increase of energy demand in chemicals by 2.5% between 1995 and 2000 primarily because the scenario assumes a recovery of growth after 1997.

3.4.2. Basic assumptions in the PRIMES baseline scenario towards 2010

The key assumption in the PRIMES baseline projection to 2010 as regards chemicals production is that the demand driven shift towards low-energy chemical products (pharmaceuticals, cosmetics etc.) will be further accelerated. In addition, in the context of the EU single market, production of energy intensive chemical products will become concentrated in some major producing countries and companies. More details are given in the following:

- The sectoral value added of the chemical sector is assumed to increase by almost 44% from 1995 to 2010. The sector is characterised by the shift towards low-energy chemicals production, the share of which reaches 60% in 2010 (53% in 1995).
- At the level of basic processing, the baseline scenario projects relatively modest technology progress in terms of specific energy consumption (energy per volume of material). In the production of fertilisers and low-energy chemicals the specific energy consumption drops by 2% in 1995-2010. A relatively bigger improvement is projected for petrochemicals (7.5%) and inorganic chemicals (4%).

The shift towards low-energy chemicals is the key factor that explains the considerable improvement of the overall energy intensity of the sector. The ratio of energy demand per value added improves by 20% in 2010 from 1995.

3.4.3. Adjustment of the sector under the Kyoto target

The above changes in the structure of the chemicals industry, among other factors, explain the considerable drop of carbon emissions in the sector. A drop of CO_2 emissions of roughly 20% is already observed for the period 1990 to 1997. The baseline scenario projects a stability of direct emissions from 2000 to 2010. Energy demand will increase by roughly 1% per year during this period, but this is mostly covered by electricity and steam the emissions of which are accounted for in the power and steam generation sector.

The global emission restriction to meet Kyoto commitments also drives adjustments in the chemicals sector. The sector undergoes the following changes:

- Sectoral production decreases by 0.5% in 2010 compared to baseline. Fertilisers and inorganic chemicals decrease more than petrochemicals and low-energy chemicals. Because of the significant economic restructuring of the sector in favour of low-energy products which characterises the baseline, there is little room for further restructuring.
- The higher penetration of heat pumps in heat processing in the chemical sector leads to an improvement of efficiency of energy use by about 15% compared to the baseline. Heat pumps allow for savings of electricity in the use of heat and cooling and indirectly (through the power sector) contribute to emission

reductions. The share of heat pumps increases to 12% from 3% in the baseline for 2010.[17]

- The specific energy consumption ratios improve roughly by 5% on top of baseline levels. The improvement is equally distributed across the different sub-sectors and is mainly due to the adoption of heat pumps and other electro-technologies. In addition, the introduction of pinch analytical techniques, which optimise heat recovery in thermal processes and allow for energy savings, leads to an improvement of thermal processing equipment efficiency by 5%.
- The sector reduces its CO_2 emissions by 15% on top of baseline reductions in 2010 (-30% from 1990 levels). This result is due to the combined effect of technology progress and fuel shift towards electricity and steam, the emissions of which are included in the power sector.

The implications on average production costs in the chemical sector are small: 2% higher than baseline.

Table 4: Changes in the chemical sector under different emission reduction regimes

	Baseline				Kyoto	Two times Kyoto	Four times Kyoto
	Value added	Energy demand (in Mtoe)		Energy intensity	Energy intensity		
	% change in 1995-2010	1995	2010	% change in 1995-2010	% change from baseline in 2010		
Austria	35.2	0.55	0.61	-18.7	-2.2	-4.6	-12.9
Belgium	39.3	2.53	3.15	-10.7	-5.0	-8.2	-22.8
Denmark	22.0	0.27	0.28	-16.5	-5.0	-7.5	-16.0
Finland	37.2	0.59	0.69	-13.9	-4.5	-6.8	-17.6
France	40.0	4.60	5.29	-17.8	-2.3	-3.6	-7.4
Germany	52.8	12.64	13.65	-29.3	-7.0	-10.1	-24.3
Greece	37.5	0.20	0.40	46.6	-2.8	-5.5	-12.9
Ireland	146.4	0.24	0.57	-4.9	-3.7	-6.7	-17.7
Italy	23.6	5.46	6.02	-10.9	-3.8	-6.0	-15.3
Netherlands	50.6	4.40	5.81	-12.3	-6.4	-10.2	-22.2
Portugal	44.1	0.46	0.58	-13.7	-5.1	-7.5	-17.9
Spain	39.3	4.00	4.87	-12.6	-5.1	-8.4	-18.7
Sweden	35.6	1.01	1.09	-20.2	-1.6	-2.5	-6.8
United Kingdom	43.4	4.41	5.35	-15.5	-5.3	-8.0	-19.4
TOTAL EU	43.6	41.37	48.34	-18.6	-5.2	-8.0	-18.9

Source: PRIMES

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

There is a big range of technology possibilities that may be applied to improve energy efficiency and save energy, in particular electricity. As a result the sector is more responsive than other industrial sectors to the imposition of higher emission restrictions at a global scale.

A collective emission reduction effort corresponding to two-times the Kyoto commitments could trigger significant further progress in the chemical sector as regards energy efficiency and savings. The sectoral specific energy consumption can improve by more than 10% on top of baseline

[17] According to a consultant of the Commission (Mr. Kemna –VHK) heat pumps are not seen as a cost-effective solution in the horizon of 2010. However, PRIMES model results indicate that heat pumps (and not electrical heating equipment (i.e. simple resistance heaters) could be a cost-effective options in the context of adjusting to the Kyoto targets.

improvements. This is due to the combined effect of the following: further penetration of heat pumps which have large implications in terms of efficiency gains (up to 75%); larger use of pinch analytical techniques (10% efficiency gains); penetration of improved electrical technologies mainly in reaction and separation processes (efficiency improves by 10% on top of baseline). These changes lead in an indirect way to considerable reduction of carbon emissions, via the adjustments effected in the power and steam generation system. The cost implications (average production cost) are rather small: 4.5%. The potential efficiency improvement in chemicals production can reach up to 25%. The corresponding change of production costs is in average 10% higher than baseline.

3.5. Paper and pulp production

The manufacturing of paper requires that a fibre source (e.g. wood) is chipped, digested, bleached and then formed as slurry (pulping) from which paper is produced. Large amounts of steam (for thermal processing) and electricity (for mechanical processing) are necessary to debark and chip the wood, digest the wood, bleach the pulp and dry the paper product. Use of waste paper, instead of wood, reduces energy requirements avoiding the initial processing, which is energy-intensive.

3.5.1. Is the current PRIMES baseline still valid in relation to short run trends?

According to the latest data available from the Confederation of European Paper Industries (CEPI) and the European Topic Centre on Waste (ETCW) paper production in the EU increased by about 8% between 1995 and 1997. According to PRIMES projections under baseline assumptions, paper production involving pulp production will increase by 11% in 2000 from 1995, which seems in accordance to latest data available. Secondary paper processing (i.e. not involving pulping) in the EU increased by 11% in the 1995-1997 period. The corresponding figure in the PRIMES baseline for the period 1995-2000 is 15%.

The shift towards secondary paper processing characterised by specific energy consumption which is about half of that for basic paper processing (including pulping) results in an improvement of overall specific energy consumption[18] (-2% in 2000 from 1995 levels) while for the same period technological progress at the process level has been rather limited.

According to EUROSTAT energy balance sheet data[19], energy demand in the paper and pulp industry increased by 4.5% in 1995-1997. According to PRIMES projections energy demand in paper and pulp production will increase by 9.5% between 1995 and 2000 under baseline assumptions.

[18] CEPI recommends that energy requirements be considered according to the pulping process considered and the required final product characteristics, since the pulp and paper sector is not homogeneous as regards energy consumption.

[19] CEPI highlights that the principle of allocating on-site emissions resulting from steam and electricity production to the energy sector is not consistent with the IPCC guidelines, which provide a common framework for the assessment of GHG emissions and facilitates comparison between studies. In particular, the emissions of industrial CHP are allocated differently in EUROSTAT energy balances and in the National Communications. Further, it should be noted that the paper and pulp numbers also include the emissions from printing industry.

On the basis of the above comparisons it can be argued that PRIMES results for the short run are consistent with recent trends in the paper and pulp sector.

3.5.2. Basic assumptions driving the PRIMES baseline scenario towards 2010

The key assumption driving the PRIMES projection to 2010 as regards paper and pulp production is that production of pulp will become further concentrated in the major producing countries (Finland and Sweden). In addition, paper recovery potential will be further exploited to the horizon of 2010.

The sectoral value added of the paper and pulp sector is assumed to increase by almost 40% from 1995 to 2010. In terms of physical production, the increase reaches 35% reflecting product quality improvement in the sector. Secondary processing of paper increases by 45% in the same period, while the growth of basic pulp processing increases by only 15%. The share of secondary paper to total production, expressed in terms of a volume index number, reaches 72% in 2010 (66% in 1995).

Technological progress at the process level is projected to be rather slow in the baseline. Specific energy consumption drops in 2010 by 3 and 4% for basic and secondary paper processing from 1995 levels. In terms of value added the overall energy intensity improves by almost 10% during the same period 1995 to 2010.

3.5.3. How does the sector adjust to meet the Kyoto target in the PRIMES analysis?

In the baseline scenario, CO_2 emissions in paper and pulp production increase by 5.5% in 2010 from 1990. The sector largely (85%) depends on the use of steam and electricity the emissions of which are included in the power and steam generation sector.[20] The main response of the sector to collective emission restrictions is to do savings of steam and electricity.

Under the Kyoto compliance scenario the sector undergoes the following changes:

- Sectoral production decreases by 1% from baseline levels in 2010. The decrease is rather uniform for both primary and secondary paper processing reflecting the fact that paper recycling develops strongly in the baseline scenario which in turn limits further deployment under the imposition of emission reduction targets.

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[20] CEPI notes that in this study it is unclear how energy from biomass, that results in CO2 neutral emissions is considered, taking into account that bio-energy represents about half of 50% of on-site energy consumption for the pulp and paper industry.

As already described in chapter 2, PRIMES decomposes final demand requirements as provided by EUROSTAT between those that address direct energy uses and those that refer to production of steam in industrial sectors. This approach allows for a full exploitation of cogeneration possibilities in PRIMES. In that sense it could be argued that part of the emission reduction achieved in the supply side is driven from the behaviour of industrial producers. Furthermore, the EUROSTAT database includes a category for final consumption in industry, which incorporates fuel consumption that is not allocated in a specific sector. In general, biomass-waste consumption is allocated to this category and is not included in specific industrial sectors. In the context of the Shared Analysis study following extensive discussions with experts and specialised institutes on to the appropriate allocation of consumption of biomass-waste it was agreed that in most cases this represents consumption of the paper and pulp sector for steam production. This approach has also been retained in this study. For example in the case of Finland consumption of 2.7 Mtoe of biomass-waste in this category is recorded. This quantity is black liquor and is solely used in paper and pulp industries for steam generation.

- The overall specific energy consumption improves by 2.5% on top of baseline. The energy intensity in terms of value added improves by 3.5%.
- The sector mainly saves electricity and steam (more than 3% in average). Direct CO_2 emissions are reduced by 4.5% from baseline levels (+1% from 1990).

These changes have small implications on average production cost, which is higher by 1% than baseline.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

As explained above the potential of the sector to reduce direct carbon emissions is limited. However, technological improvement driven by high global emission reduction efforts leads to indirect emission gains because of savings of electricity and steam.

Examples of such technology changes are accelerated adoption of impulse drying technologies, advanced pulping techniques involving better management of steam input, as well as the use of sensors in paper refining. These become cost-effective when the energy system faces an emission target twice as deep as the Kyoto commitments. In such a case the overall specific energy consumption can improve by 10%. The improvement of energy efficiency at the scale of specific processes can reach 17% (e.g. in drying) and even 25% (in pulping and refining processes). The corresponding rise of average production costs is again small: 3% higher than baseline.

Table 5: Changes in the paper and pulp industries under different emission reduction regimes

	1995		2010			Kyoto	Two times Kyoto	Four times Kyoto
	Energy demand	Secondary paper processing	Energy demand	Secondary paper processing	Energy intensity	Energy intensity		
	Mtoe	%	Mtoe	%	% change from 1995	% change from baseline in 2010		
Austria	1.0	66	1.4	73	-9.0	-2.9	-4.8	-10.7
Belgium	0.4	71	0.6	78	-8.4	-3.0	-5.2	-12.4
Denmark	0.2	93	0.3	95	-9.4	-3.6	-6.2	-15.3
Finland	5.2	50	7.8	53	-18.6	-3.3	-5.5	-11.4
France	3.5	75	3.8	80	-9.3	-2.2	-4.0	-10.4
Germany	3.8	84	4.6	87	-14.0	-4.2	-6.9	-15.8
Greece	0.2	94	0.2	96	-4.3	-5.0	-9.0	-21.6
Ireland	0.1	100	0.1	100	-2.4	-3.7	-6.6	-16.3
Italy	3.0	90	3.7	93	-5.1	-3.3	-5.8	-14.6
Netherlands	0.6	94	0.7	95	-3.5	-3.2	-5.8	-14.0
Portugal	0.8	35	1.1	43	-6.8	-3.0	-4.9	-11.7
Spain	1.9	70	2.6	76	-7.1	-3.4	-6.4	-15.8
Sweden	5.0	45	5.4	57	-11.4	-2.0	-3.3	-7.2
United Kingdom	2.5	87	3.6	90	-5.8	-3.6	-6.3	-15.2
TOTAL EU	28.4	66	35.9	71	-9.1	-3.1	-5.3	-12.4

Source: PRIMES

3.6. Other industrial sectors

The PRIMES model separately represents the following sectors:

- Equipment goods (for transport, for households, machinery, etc.),
- Food, beverages and tobacco,
- Textiles and

- Other goods (e.g. wood products, rubber, construction, etc.).

These sectors are characterised by low energy-intensity, involving few specific product processing energy uses. Such cases are coating and foundries in the equipment goods industry. Most energy uses depend on crosscutting technologies (motor drives, compressors, heating and cooling, etc.). There is noticeable demand for steam in food processing, and low enthalpy heat uses (e.g. for drying and separation) in some sectors.

3.6.1. Is the current PRIMES baseline still valid in relation to short run trends?

The following table summarises the evolution of energy demand in these other industrial sectors as observed through recent statistics:

	Energy Demand growth		Energy Intensity
	1995-1997 (EUROSTAT data)	1995-2000 (PRIMES results)	1995-2000 (PRIMES results)
Engineering	+2.0%	+12.5%	-0.5%
Food, drink, tobacco	+1.0%	+10.5%	-0.3%
Textiles	-0.5%	+2.0%	-0.6%
Other industries	+8.0%	+7.0%	-0.2%
Total	+3.3%	+9.0%	

The statistics for 1995-1997 show low growth of energy demand as a result of a general slowdown of economic growth. The PRIMES baseline scenario assumes economic recovery and high growth at the end of the 90s (corroborated by recently available macroeconomic indicators).

3.6.2. Basic assumptions in the PRIMES baseline scenario towards 2010

The key assumptions and findings as regards the evolution of other industrial sectors in the horizon to 2010 are illustrated in the following table:

Changes in 1995-2010 under baseline assumptions	Value added	Specific Energy Consumption of key Processes	Energy intensity
Engineering	+50%	-3%	-8%
Food, drink, tobacco	+36%	-2.5%	-5%
Textiles	+13%	-3.5%	-3.5%
Other industries	+20%	-2%	-4.5%

Technological progress embodied in new capital is assumed to leave energy efficiency relatively unaffected in the horizon to 2010. The improvement of energy use as compared to value added (energy intensity) is significantly higher, reflecting product quality improvement in the sectors, reaching up to 8% in the engineering sector.

3.6.3. How does the sector adjust to meet the Kyoto target in the PRIMES analysis?

In the baseline scenario, CO_2 emissions in other industrial sectors are projected to increase by 11.5% in 2010 compared to 1990. The imposition of the Kyoto emission reduction constraint leads to a relatively small reduction of direct CO_2 emissions in this sector. The sector undergoes the following changes:

- Production activity decreases slightly by about 0.5% in 2010 compared to baseline. The decrease is rather uniform in all the sub-sectors.
- The improvement in terms of specific energy consumption ranges between 2.5% (for food, drink and tobacco and other industries) and 3% (for the engineering and textiles sectors) additional to baseline improvements. The corresponding energy intensity improvement ranges between 3 and 4%.
- The sector is not energy intensive and energy costs represent a small fraction of total production costs. In that sense the sector shows strong inertia and adjusts slowly. Carbon emissions are reduced by 4.5% from baseline and remain well above the level in 1990 (+7%).

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

The industrial sectors under discussion are mostly dependent on crosscutting technologies as far as energy consumption is concerned. When the system faces emission restrictions, more efficient crosscutting technologies are adopted and penetrate in the markets. Sectors in which the energy costs are small compared to total production cost do not have enough incentive to accelerate capital replacement and benefit from the ensuing advanced crosscutting technologies.

The sector reacts more when influenced by rather high collective emission reduction efforts and consequently faces rather high costs for energy use. In such a case, the improvement of sectoral specific energy consumption can reach 10% in food, drink and tobacco and 15% in the manufacturing of equipment, compared to baseline.

Heat pumps play a considerable role and penetrate up to 25% in the corresponding energy uses, leading energy efficiency gains and indirect emission reductions. In the equipments good industries, significant possibilities are identified in the domain of metal processing. Adoption of advanced coating equipment and foundries may result in an efficiency improvement in the corresponding energy uses of the order of 25%.

The potential of efficiency improvement ranges between 15 and 20% while the corresponding impact in terms of production costs is rather small: only 1% in average higher than in the baseline.

Table 6: Changes in the other industrial sectors under different emission reduction regimes

	Baseline				Kyoto	Two times Kyoto	Four times Kyoto
	Value added	Energy demand (in Mtoe)		Energy intensity	Energy intensity		
	% change in 1995-2010	1995	2010	% change in 1995-2010	% change from baseline in 2010		
Austria	37.0	1.12	1.43	-6.4	-3.4	-5.7	-13.1
Belgium	56.4	2.83	3.62	-18.1	-3.2	-5.9	-15.9
Denmark	43.4	1.63	2.00	-14.5	-3.3	-6.1	-15.1
Finland	59.0	1.29	1.70	-17.1	-3.5	-6.4	-16.1
France	42.8	15.33	18.50	-15.5	-2.6	-4.7	-13.4
Germany	37.0	17.28	20.16	-14.8	-3.9	-7.5	-17.0
Greece	3.4	1.41	1.49	2.0	-3.4	-6.9	-18.2
Ireland	140.3	0.91	1.51	-30.6	-4.2	-7.5	-16.5
Italy	27.0	11.22	13.68	-4.1	-3.7	-6.3	-14.5
Netherlands	59.9	4.83	6.95	-10.0	-2.7	-5.2	-15.3
Portugal	50.7	1.39	1.84	-12.2	-2.7	-4.6	-14.8
Spain	53.4	5.43	7.69	-7.8	-3.2	-5.7	-14.5
Sweden	48.8	2.90	3.58	-17.0	-3.1	-5.3	-13.1
United Kingdom	39.6	13.77	17.71	-7.8	-3.3	-6.3	-15.9
TOTAL EU	40.6	81.34	101.86	-10.9	-3.3	-6.1	-15.2

Source: PRIMES

3.7. Conclusions

The PRIMES model results indicate that industrial sectors are quite responsive to the introduction of emission reduction targets in the EU energy system. Industrial sectors adjust by improving energy efficiency at the level of direct energy uses, shifting towards less carbon intensive fuels (natural gas, electricity and steam) with electro-technologies playing a key role, altering the structure of production processes towards less energy intensive ones and, finally, producing steam using cogeneration units instead of industrial boilers.[21]

At the level of direct energy uses emission reduction from 1990 levels under the Kyoto target constraint reach up to 18.5% whereas the corresponding emission reduction from baseline levels in 2010 reaches 8.4% (see Table 7). In other words, CO2 emissions in EU industry (at the level of direct energy uses) are projected to exhibit a significant decrease even under baseline conditions. This is the combined effect of technology improvement (as discussed in previous chapters) and changes in the fuel mix in favour of electricity and steam.

When emissions of industrial boilers are accounted for in the industrial sectors, the emission reduction achieved becomes even higher (-30% from 1990 levels, -12.4% from baseline levels in 2010). However, this result is to a large extent due to the shift of producers from the use of boilers to the use of CHP units in terms of covering their energy needs for steam. While emissions from industrial boilers decrease by more than 65% from 1990 levels (close to –34% from baseline in 2010), CO2 emissions from cogeneration units owned by industrial producers exhibit an increase of 47.5% from 1990 levels (-28% from baseline in 2010).

[21] It should be reminded here that in PRIMES in order to have a better representation of the competition domain for electricity and steam production, fuel input in industrial boilers is allocated to the power and steam generation system.

Table 7: CO2 emissions from industrial sectors

	Emissions in 1990	Emissions in 2010 under baseline conditions	Emissions in 2010 under Kyoto target conditions	% Change from 1990	% Change from 2010 baseline
	Direct emissions (Mt CO2 eq.)				
Iron and steel	174.8	132.2	112.4	-35.7%	-15.0%
Non-ferrous metals	16.2	12.5	11.8	-27.1%	-5.1%
Chemicals	26.2	21.3	18.4	-29.6%	-13.4%
Building materials	98.2	91.0	87.0	-11.4%	-4.4%
Paper and pulp	10.6	11.2	10.8	1.6%	-3.6%
Other industries	98.4	109.7	105.6	7.3%	-3.8%
Total Industry	424.4	377.9	346.1	-18.5%	-8.4%
	Direct emissions incl. industrial boilers (Mt CO2 eq.)				
Iron and steel	172.6	133.9	115.3	-33.2%	-13.9%
Non-ferrous metals	15.2	12.5	11.8	-22.3%	-5.0%
Chemicals	96.4	51.3	37.0	-61.6%	-27.8%
Building materials	95.2	92.0	88.2	-7.3%	-4.1%
Paper and pulp	28.9	21.3	17.3	-40.0%	-18.5%
Other industries	153.1	137.9	123.4	-19.4%	-10.5%
Total Industry	561.4	448.7	393.0	-30.0%	-12.4%
of which from industrial boilers	*137.0*	*70.9*	*47.0*	*-65.7%*	*-33.7%*
	Indirect emissions other than industrial boilers (Mt CO2 eq.)				
Iron and steel	56.6	41.9	34.7	-38.6%	-17.1%
Non-ferrous metals	41.3	19.9	15.7	-61.9%	-21.1%
Chemicals	119.4	136.1	112.9	-5.4%	-17.0%
Building materials	35.8	28.9	22.1	-38.2%	-23.4%
Paper and pulp	40.2	84.5	66.0	64.0%	-21.9%
Other industries	196.1	214.5	173.0	-11.8%	-19.3%
Total Industry	489.4	525.8	424.5	-13.3%	-19.3%
of which from industrial generators of electricity and steam	*123.7*	*253.7*	*182.6*	*47.6%*	*-28.0%*
	Total emissions (Mt CO2 eq.)				
Iron and steel	229.2	175.8	150.0	-34.6%	-14.7%
Non-ferrous metals	56.5	32.4	27.6	-51.2%	-15.0%
Chemicals	215.8	187.4	150.0	-30.5%	-20.0%
Building materials	130.9	120.8	110.3	-15.8%	-8.7%
Paper and pulp	69.1	105.7	83.3	20.5%	-21.2%
Other industries	349.3	352.4	296.4	-15.1%	-15.9%
Total Industry	1050.8	974.5	817.6	-22.2%	-16.1%

Source: PRIMES

The shift towards the use of electricity and steam is also clearly illustrated when indirect emissions (i.e. emissions corresponding to the production of electricity and steam demanded by industrial sectors) are examined. At the level of total emissions in industry the share of indirect emissions increases from 46.5% in 1990 to 52% in 2010 (54% under baseline conditions) despite the fact that the electricity and steam generation system, as discussed in Chapter 6, is the most responsive to the introduction of emission reduction constraints.

4. Reduction of CO2 from Private and Public Services, Households and Agriculture

The structure of energy demand in private and public services as well as households is quite similar because the bulk of energy consumption takes place in buildings (like office blocks, hospitals, schools, dwellings etc) and for the same reasons, namely heating, cooling, cooking, lighting and the use of appliances. There are important statistical problems regarding the split of energy consumption in these sectors. The energy balances usually determine energy consumption in the domestic sector as a difference between total supply and the demand in industry and transport. Data to split between services, households, etc. are even more problematic.

In recent years, EUROSTAT and the national statistical services made a substantial effort to improve on this issue and determined such a split on the basis of several cross-sectional surveys about energy consumption carried out in Member States. The surveys for households have taken place twice, and are more reliable. The survey on the tertiary sector has not finished yet. PRIMES has used these surveys as much as possible, together with national data and other information (e.g. MURE, IKARUS, ODYSSEE data bases). Nevertheless the statistical basis, especially regarding the split in sub-sectors, remains poor. Consequently, many of the detailed numbers presented below both for the past and future energy uses should be seen as indicative of actual trends rather than as precise data and forecasts.

The technologies determining energy efficiency in services and households are effectively the same. However, differences in terms of energy related equipment size, especially for heating and cooling purposes, results in significant differences as regards consumers' behaviour. The average size of this equipment for a government building or an office block is likely to be significantly larger than that for a dwelling. Consequently, technologies that facilitate economies of scale in energy use are much more likely to be adopted by the services sector than by households. In addition, decisions to invest in energy efficiency are taken by firms in the tertiary sector and by individual people (or house builders) in the households sectors. Their perception of capital costs and opportunity costs of capital naturally differ, in a way that investment in efficiency is easier to be adopted by firms than by individuals.

4.1. Tertiary sector (Private and public services, Agriculture)

4.1.1. Is the current PRIMES baseline still valid in relation to short run trends?

The current baseline scenario for the years 1995 to 2000 is compared to the revised energy balance sheets of EUROSTAT, latest data available for 1997. Table 8 shows this comparison.

Table 8: Evolution of energy demand (Mtoe) in tertiary in the short-run

	EUROSTAT statistics			PRIMES results		
	1995	1997	% change	1995	2000	% change
Total	124.1	127.0	2.4	124.3	140.3	12.9
Solids	1.7	1.1	-38.7	1.5	0.8	-45.8
Liquids	36.9	36.6	-0.8	37.5	40.2	7.4
Gas	34.8	35.5	2.1	34.9	39.6	13.4
Dictributed heat	6.2	6.6	6.5	5.7	6.8	18.1
Electricity	43.3	45.9	6.1	43.2	51.4	19.0
Renewables	1.2	1.3	10.3	1.5	1.5	1.4
% in total final demand	13.8	13.6		14.0	14.7	

Source: PRIMES

Differences for the base year are explained by the fact that the data used for PRIMES calibration are older compared to the currently available of EUROSTAT. However, the differences are rather small and are not considered to influence the projection.

As regards both total demand of the tertiary sector and the trends in specific fuel use, the PRIMES projections seem to be roughly in line with recent trends, given also that economic growth is expected to be much higher in the late 90s than in the 95-97 period. Also 1997 has been a particularly warm year, whereas the PRIMES projection assumed a continuation of average weather conditions (identical to 1995).

4.1.2. Basic assumptions in the baseline scenario

The service sector as a whole is expected to see its share of GDP increasing in the period to 2010. Thus, it will be the fastest growing sector in most EU countries while agriculture grows at rates below GDP growth.

The development of the tertiary sector will be increasingly boosted by rising standards of living as no saturation effects are expected in the overall use of services. On the consumption side in the period to 2010, as saturation is increasingly approached for most products even in the EU Member States that are presently less wealthy, households will spend an ever rising proportion of their incomes on services. For example, it has been observed that services related to leisure and telecommunications increase very rapidly with income (their income elasticity is close to 2). Similarly, the use of services as intermediate goods will be boosted as services and knowledge based industries is the segment of the EU economy expected to grow rapidly. Increased competition in industrial goods markets from low cost developing countries will result in EU Member States continuing their specialisation towards the service sector. This is already observed in the trade patterns of the EU whose exports have an increasing content of higher value services, like engineering and financial services.

The baseline scenario shows the following trends:

- Value added in the tertiary sector is assumed to increase by almost 50% between 1995 and 2010 compared to a GDP growth of 44% in the same period. Value added in market services increases by more than 60%, followed by non-market services and trade at about 35%, while growth in the agricultural sector is assumed at 18.5%.
- Energy needs in the tertiary sector (expressed as an indicator incorporating improvement of comfort standards and building infrastructure) are projected to increase by 40% in 2010 from 1995 levels (compared to the 50% growth of value added) reflecting buildings thermal integrity improvements, higher productivity and saturation effects in comfort standards which in turn lead to a gradual decoupling of sectoral growth and energy demand growth (this takes place mainly beyond 2010).

- Technological progress is more pronounced in electrical equipment which exhibit an average efficiency improvement of 13.5% in 2010 compared to 1995. Efficiency improvement of air-conditioning equipment reaches 10%, of space heating equipment 7.5% while that of other heating uses equipment is close to 6%.

Table 9: Evolution of the tertiary sector in 2000-2010

	2000	2010	% change
Value added (000 Meuro'90)	4142	5348	29.1
Energy intensity			
toe per unit of value added	33.9	29.7	-12.2
toe per capita	0.373	0.415	11.4
Energy demand (Mtoe)			
Total	140.3	159.0	13.3
% of electrical equipment	12.5	14.5	
by fuel			
Solids	0.8	0.3	-63.4
Liquids	40.2	39.5	-1.8
Gas	39.6	42.1	6.6
Distributed heat	6.8	10.0	47.5
Electricity	51.4	65.8	28.0
Renewables	1.5	1.3	-12.8
% in total final demand	14.7	16.7	

Source: PRIMES

Table 9 summarises the evolution of the tertiary sector in the baseline for the period 2000-2010.

The rapid penetration of new types of electric appliances in the sector (such as computers, telecommunication equipment etc.) is projected to continue in the horizon to 2010 leading to an increased share of consumption for electrical equipment in the sector. The above trend combined to a projected shift in heat uses towards the use of electricity and the further penetration of air conditioning, explain the high growth of demand for electricity. The share of electricity in the fuel mix of the tertiary sector reaches 41.5% in 2010 (36.6% in 2000).

The long-term trends of energy technology development in the office buildings are closely related to the deployment of decentralised power and steam generation systems. Small-scale cogeneration, either gas-based conventional or fuel cells, is likely to become cost-effective at the scale of a group of service buildings. Small-scale district heating and cooling systems based on efficient heat pumps have also become available for providing heating and cooling. Such developments are also cost-effective in buildings related to the tourism sector, such as hotels. As a result, under baseline conditions demand for distributed heat is also projected to exhibit a substantial growth in 2000-2010 reaching 6.5% of total energy demand in the tertiary sector as a whole from 4.8% in 2000.

The bulk of the shift towards electricity and distributed heat occurs to the detriment of liquid fuels the share of which drops in 2010 by 3.5 percentage units (to 25% from 29% in 2000). Natural gas is less affected losing however 1.5 percentage points in terms of market share (from 28% in 2000 down to 26.5% in 2010).

The combined effect of the above mechanisms leads to a rise in energy demand in the tertiary sector by 13.3% in the period 1995 to 2010, which is less than half of the corresponding growth of sectoral value added. Energy intensity, expressed in terms of value added, improves by 12.2% in the 2000-2010 period.

4.1.3. How does the sector adjust to meet the Kyoto target in the PRIMES analysis?

Following the significant growth of energy demand in the tertiary sector, as projected in the PRIMES baseline CO_2 emissions are also projected to increase. They rise by 14.5% from 1990 to 2010. The carbon intensity, given the shift in favour of electricity and distributed heat (for which emissions are included in the supply side) shows a spectacular improvement in the period 1995 to 2010.

The systems analysis of the Kyoto commitments shows that the tertiary sector may undertake emission reduction in priority because it seems to be one of the most responsive sectors to emission restrictions. There are two factors that may explain this finding: first in the tertiary sector energy is a luxury good, certainly related to comfort so relatively high responsiveness should be expected if energy prices start rising significantly (because of emission charges, for example); second, the energy equipment and the buildings are of a sufficient size to profit from economies of scale thus facilitating the acceptability of measures that may have longer pay-back times than acceptable by individual consumers. The prospects about the development of energy service companies also strengthen the above arguments.

Under the collective effort to meet the Kyoto commitments, the analysis with PRIMES forecasts that the tertiary sector will undergo the following changes:

- The improvement of the thermal integrity of buildings, the reconsideration of comfort standards and the more rational use of energy lead to a decrease of total energy needs up to 5% from baseline. About half of this change is due to improvements in thermal integrity. Since the stock of buildings has a very slow turnover, the improvement that is taking place mainly in new constructions will show up in the longer term.

- Efficiency improvement in electrical equipment can reach up to 40% on top of baseline gains. The introduction of high efficiency standards for lighting in tertiary sector buildings is one example of this type of improvement.

- Heating and cooling equipment in the tertiary sector can also obtain significant efficiency gains (15% better than in baseline). Further adoption of electric heating equipment (including heat pumps) is the key driver for this achievement. It is expected that 30% of energy needs in space heating can be converted to electric heating equipment under a Kyoto emission restriction.

- Technology progress in other heating uses (water heating etc.) and air conditioning equipment is less significant (6 and 5% on top of baseline in 2010).

The share of electricity in total demand in the tertiary sector therefore increases and reaches 46.5% (from 41.5% in the baseline) displacing liquid fuels and natural gas in the direct energy uses. The overall energy intensity of the tertiary sector improves by 14% in addition to the significant progress observed in the baseline.

As a result of the above changes, CO_2 emissions in the tertiary sector decrease by more than 24% in 2010 compared to baseline levels (-13% from 1990 levels). The energy related costs for the service sectors increase by 12%, which however imply a very small increase in total production costs for the sector.

Table 10: Efficiency gains in tertiary under different emission reduction regimes

	Baseline	Kyoto	Two times Kyoto	Four times Kyoto
	% improvement from 1995 levels			
Space heating	7.5	21.2	32.7	55.1
Other heating uses	5.9	12.1	16.7	24.5
Air conditioning	9.3	14.9	19.3	46.5
Electrical equipment	13.4	57.3	64.9	147.0

Source: PRIMES

How the sector adjusts to allow for higher emission abatement?

(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

Despite the significant progress observed in the context of the Kyoto emission reduction target, the additional potential remains quite significant even to a horizon as short as 2010. The sector can contribute to a bigger emission reduction effort by further improving the overall energy intensity and by adopting advanced technologies, mostly electric, in the end-uses.

To reach an emission reduction target two times bigger than the Kyoto commitment, it is cost-effective to reduce the energy needs in the tertiary sector by more than 20% per unit. Half of this reduction is estimated to be the result of improved thermal integrity, and half the effect of advanced electric technologies and rational use of energy. The potential for building thermal integrity improvement to reduce energy requirements in the horizon to 2010 is estimated at 10%. The corresponding figure for rational use of energy is 6.5%.

There is a large scope for further technological progress in electrical equipment used in the tertiary sector. Accelerated penetration of lighting equipment that complies with high efficiency standards is one example. Overall efficiency gains in electrical equipment can exceed 150% from baseline levels. The driver is electric heat pumps and at higher cost levels fuel cells. For the case of an emission reduction target two times deeper than Kyoto efficiency gains can go up to 45% higher than baseline.

The shift towards the use of electricity in space heating/cooling (mainly through heat pumps) has a double effect, leading to additional direct efficiency gains and lower emissions on the supply side.

The potential of technological progress in other heating uses (water heating etc.) is less significant and can go up to 20%. More efficient air-conditioning equipment needs high cost levels to penetrate in the market. However the potential improvement in air conditioning equipment can reach up to 50%.

The total economic potential in the tertiary sector for reducing emissions is high, corresponding to a cut of more than half of baseline emissions. High costs of energy services are implied in this case. However the implications on total production cost of the sector are small.

Table 11: Evolution of the tertiary sector under different emission reduction regimes by EU Member State

	Baseline			Kyoto		
	Energy demand	of which electricity	Energy intensity	Energy demand	of which electricity	Energy intensity
	Mtoe		toe per capita	Mtoe		toe per capita
Austria	4.1	1.6	0.49	3.7	1.5	0.44
Belgium	6.4	1.3	0.61	5.7	1.1	0.54
Denmark	3.0	1.2	0.55	2.6	1.1	0.48
Finland	2.5	1.2	0.46	2.2	1.1	0.41
France	26.1	12.6	0.43	22.9	13.5	0.37
Germany	32.6	11.4	0.39	27.1	10.8	0.33
Greece	3.7	2.1	0.33	3.2	1.8	0.29
Ireland	2.6	0.6	0.69	2.3	0.6	0.61
Italy	12.2	7.0	0.21	10.7	6.6	0.19
Netherlands	15.2	3.3	0.91	13.7	2.9	0.82
Portugal	2.5	1.3	0.24	2.2	1.1	0.22
Spain	11.4	5.9	0.28	9.9	5.7	0.25
Sweden	6.0	2.8	0.65	5.4	2.6	0.59
United Kingdom	30.8	13.6	0.51	25.4	12.9	0.42
TOTAL EU	159.0	65.8	0.42	136.9	63.4	0.36
	Two times Kyoto			Four times Kyoto		
	Energy demand	of which electricity	Energy intensity	Energy demand	of which electricity	Energy intensity
	Mtoe		toe per capita	Mtoe		toe per capita
Austria	3.5	1.5	0.42	2.9	1.2	0.35
Belgium	5.3	1.1	0.51	4.2	0.8	0.40
Denmark	2.5	1.0	0.45	2.1	0.9	0.39
Finland	2.1	1.1	0.39	1.8	0.9	0.34
France	20.6	13.4	0.34	15.8	12.0	0.26
Germany	24.7	10.5	0.30	19.6	9.2	0.24
Greece	2.8	1.5	0.26	2.3	1.1	0.20
Ireland	2.1	0.5	0.57	1.7	0.4	0.46
Italy	9.5	6.0	0.16	7.4	5.0	0.13
Netherlands	12.8	2.7	0.77	10.6	2.1	0.64
Portugal	2.1	1.1	0.20	1.6	0.9	0.16
Spain	8.7	5.2	0.22	6.8	4.6	0.17
Sweden	5.2	2.6	0.57	4.7	2.4	0.51
United Kingdom	22.6	12.3	0.38	16.7	9.8	0.28
TOTAL EU	124.4	60.5	0.32	98.2	51.4	0.26

Source: PRIMES

4.2. Households

4.2.1. Is the current PRIMES baseline still valid in relation to short run trends?

Table 12 summarizes the comparison between PRIMES baseline and latest EUROSTAT statistics as regards energy demand growth in households.

Table 12: Evolution of energy demand (Mtoe) in households in the short-run

	EUROSTAT statistics			PRIMES results		
	1995	1997	% change	1995	2000	% change
Total	240.6	252.2	4.8	239.8	256.3	6.9
Solids	8.1	7.6	-5.5	8.2	4.9	-40.5
Liquids	63.3	64.4	1.7	62.2	68.1	9.4
Gas	88.7	93.6	5.6	88.5	96.5	9.0
Distributed heat	9.8	9.6	-1.5	9.9	10.8	8.5
Electricity	50.0	52.1	4.1	50.0	56.1	12.1
Renewables	20.7	24.8	19.7	21.0	20.1	-4.4
% in total final demand	26.8	27.1		27.1	26.9	

Source: PRIMES

There are small differences as regards 1995 data, which are not considered to have any impact on the PRIMES projection. The trends both in terms of total demand and fuel mix changes are similar. There are however uncertainties, which are mostly due to the poor statistical basis about the split of demand for energy in the domestic sector. Regarding the fuels, it is clear in both the statistics and the short-term projection, that electricity and gas are an increasing preference for households. The PRIMES projection seems to fail in the forecasts about consumption of oil products and solid fuels. The renewables are also uncertain because they mostly concern traditional use of wood for which statistics are also poor.

4.2.2. Basic assumptions reflected in the PRIMES baseline scenario towards 2010

The major driving forces of energy use in the household sector include the number of households, their degree of wealth, the average size of each dwelling, the number of individuals belonging to the average household and climatic and cultural conditions.

The level of household income is quite important for energy consumption but given the maturity of economic well being in the EU, the effects are small except for some of the less economically mature countries, like Portugal, Greece Ireland and Spain. Growth of income in these cases result in more comfort and higher energy needs because of larger size dwellings higher penetration of appliances and in some case (like Greece) air conditioning. The projection is very different for other Member States in which the energy use in households seems to be highly saturated.

The basic trends in the current baseline scenario can be summarised as follows:

- Population growth is low in the EU for the period 2000-2010 (+1.7%). However, household size (inhabitants per household) is projected to decrease in the same period (-3.5%) reflecting demographical changes in the EU (aging of population) as well as changes in lifestyle.

- Income per household is assumed to increase by 19% between 2000 and 2010. However, the fact that most of the energy needs in houses are rather saturated in many Member States of the European Union, in particular for heating energy uses, combined with efficiency gains through better equipment and buildings lead to a significant improvement in energy intensity. This ratio, expressed as energy consumed per unit of income, improves by 16.7% in the period 2000 to 2010, while energy requirements per capita increase by just 2.5% in the same period. A significant decoupling between economic growth and energy demand in households takes place in the baseline scenario.

- The adoption of more efficient technologies in the domain of electric appliances and lighting is an important mechanism that limits the growth of electricity demand, already present in the baseline. The specific energy consumption of refrigerators improves on average by 28% in 2010 (compared to 1995). This rate is as high as 39% for washing machines, 18% for dryers, 18% for TV sets and 5% for small electric appliances. The average efficiency of lighting also improves in the baseline. There are two factors leading to the significant technological progress in electric appliances: the assumption that their penetration in households will be further accelerated in the horizon to 2010 (so they embody progress) and the fact that replacement of equipment occurs at short intervals (about 5 years on average) accelerating the purchase of more efficient equipment.[22]

- Efficiency gains in space heating equipment is, in 2010, 3.5% higher than in 1995, mainly as a consequence of shifting towards electric heating equipment (including heat pumps) that gain an additional market share of 4%. Efficiency gains are also obtained in the domains of water heating (+17.5% in 2010 from 1995 levels), air-conditioning equipment (2%), and cooking equipment (4%).

The evolution of households' energy demand over the period 2000-2010 in the baseline is illustrated in Table 13. The emergence of new uses of electricity and the higher penetration of electric appliances overcompensate the efficiency gains of equipment leading to high demand for electricity. Electricity use, being more efficient, and better-insulated houses explain the rather spectacular improvement in average energy intensity of the households sector. Distributed heat and gas gain in market share terms in the domain of heating.

Table 13: Evolution of energy demand in households in 2000-2010

	2000	2010	% change
Income per households (Euro'90)	24974	29694	18.9
Energy intensity			
toe per unit of income	69.2	57.7	-16.7
toe per capita	0.681	0.698	2.5
Energy demand (Mtoe)			
Total	256.3	267.4	4.3
% of electrical equipment	9.6	10.0	
by fuel			
Solids	4.9	1.4	-70.4
Liquids	68.1	67.4	-0.9
Gas	96.5	100.6	4.3
Distributed heat	10.8	13.0	20.6
Electricity	56.1	64.3	14.6
Renewables	20.1	20.7	2.9
% in total final demand	26.9	28.0	

Source: PRIMES

4.2.3. How does the sector adjust to meet the Kyoto target in the PRIMES analysis?

The changes in the fuel mix, in favour of electricity, gas and distributed heat, explain the continuous drop of carbon intensity of the households sector. The direct sectoral emissions of CO_2 are projected to remain rather stable in 2010 relative to the level of 1990, in the baseline scenario.

Under the collective effort to reach the Kyoto commitments, the households sector improves in terms of energy efficiency, but the adjustment possibilities are rather small compared to other sectors and in particular the tertiary sector. The households have significantly lower potential compared to the tertiary sector, because of lower economies of scale, the inability to handle high capital costs at the scale of an individual and the baseline trends that already show a significant improvement.

The additional changes that occur in the sector under Kyoto are the following:

[22] It has been commented by Mr. Kemna (VHK) that the replacement rate of equipment is rather unrealistic as most large energy consuming appliances have a product life of 12-15 years. However, recent trends show a higher rate of replacement of appliances because of increased comfort standards of new equipment technologies.

- The energy intensity (i.e. consumption per unit of income) in households is projected to improve further by 5.5% in 2010 from baseline. A similar improvement is projected for energy consumption per capita. About one third of this improvement is due to improved thermal insulation of new constructions (no significant improvements are observed for existing buildings because of high costs).[23] Better housekeeping, including variation of standards of comfort and more rational use of energy, contributes another third.
- Accelerated adoption of more efficient technologies is rather limited in the case of households (compared to the tertiary sector). Progress is observed in the domain of lighting and water heating equipment for which an improvement of 9% on top of baseline is projected. Keeping in mind that the efficiency improvement of electric appliances for home use was impressive already in the baseline (25% in 2010 from 1995), the additional improvement in the context of Kyoto restrictions is rather small.
- As regards the fuel mix, a substitution of liquid fuels by electricity is projected to accelerate in the case of the Kyoto emission reduction scenario. The market share of electricity increases to 25.3% (+1.3 percentage points from baseline). The shares of other energy forms remain rather stable.

As a combined effect of the above changes overall energy demand in households increases by only 5% in 2010 from 1995 (-5.5% from baseline in 2010), while CO_2 emissions decrease by 11% from 1990 (-10% from baseline in 2010). The Kyoto emission reduction target for the EU energy system, results in an increase of energy related expenditure of households by 4% (or about 150 € per household) compared to the baseline scenario.

Table 14: Efficiency gains in households under different emission reduction regimes

	Baseline	Kyoto	Two times Kyoto	Four times Kyoto
	% improvement from 1995 levels			
Space heating	3.5	5.0	6.8	22.9
Water heating	16.8	27.5	35.9	45.4
Other heating uses	4.0	5.3	6.0	8.3
Air conditioning	1.8	3.1	5.4	39.8
Electrical equipment (average)	24.5	26.2	27.7	41.5

Source: PRIMES

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

Behavioural changes related to energy use in the sector of households are an important driver of their adjustment to ambitious emission restrictions. Of course forecasting such changes is highly uncertain. Regarding energy related equipment the expected additional efficiency gains are rather modest, because in some domains the baseline scenario has involved high progress. There exist, however, significant additional possibilities in some domains, as for example for lighting and water heating.

The potential reduction of energy requirements as a result of improving

[23] Note that the option of improving thermal integrity in existing building constructions is available in PRIMES model, however it is not found to be a cost effective one.

buildings thermal integrity can reach up to 8.5% in a short-term perspective like the horizon to 2010. Due to the high costs involved in improving thermal integrity for existing houses, the technical potential is exploitable only at high emission restrictions, and only beyond a certain threshold regarding marginal abatement costs.

The potential for technology progress in electric appliances is limited due to the high level of adoption of advanced technologies already incorporated in the baseline. It is assumed that for the short horizon to 2010 no technological breakthrough is possible in the domain of electric appliances. The total additional efficiency gains are estimated as high as 15% on top of baseline.

In heating and cooling energy uses, the efficiency gains in space heating and water heating can be higher by 26% compared to baseline, 6% in cooking and up to 55% in air conditioning. However, these efficiency gains correspond to high marginal costs and become cost-effective in the context of considerably severe emission restrictions.

Theoretically, half the baseline CO_2 emissions in households can be reduced (46% from 1990) in which case the households will face an increase of energy related costs by roughly 20% compared to baseline (about 600 € per household per year).

Table 15: Evolution of the households sector under different emission reduction regimes by EU Member State

	Baseline			Kyoto		
	Energy demand	of which electricity	Energy intensity	Energy demand	of which electricity	Energy intensity
	Mtoe		toe per capita	Mtoe		toe per capita
Austria	7.2	1.4	0.86	6.9	1.4	0.83
Belgium	9.7	2.4	0.93	9.2	2.5	0.87
Denmark	5.0	1.0	0.92	4.7	1.0	0.86
Finland	6.8	1.9	1.29	6.5	1.9	1.23
France	44.3	11.7	0.72	42.4	12.4	0.69
Germany	68.2	12.4	0.82	63.7	12.1	0.77
Greece	5.2	1.8	0.47	4.9	1.7	0.44
Ireland	2.6	0.9	0.70	2.4	0.9	0.64
Italy	34.9	6.8	0.61	33.4	6.5	0.58
Netherlands	13.0	2.1	0.78	12.1	2.1	0.73
Portugal	4.0	1.5	0.38	3.8	1.5	0.37
Spain	12.6	5.5	0.31	12.1	5.5	0.30
Sweden	8.6	3.8	0.94	8.4	3.7	0.91
United Kingdom	45.3	10.8	0.75	42.0	10.6	0.70
TOTAL EU	267.4	64.3	0.70	252.4	63.8	0.66
	Two times Kyoto			Four times Kyoto		
	Energy demand	of which electricity	Energy intensity	Energy demand	of which electricity	Energy intensity
	Mtoe		toe per capita	Mtoe		toe per capita
Austria	6.7	1.4	0.80	5.8	1.4	0.69
Belgium	8.8	2.6	0.84	7.0	2.3	0.67
Denmark	4.4	0.9	0.81	3.6	0.6	0.65
Finland	6.2	1.9	1.18	5.1	1.4	0.97
France	41.0	12.5	0.67	34.4	11.8	0.56
Germany	60.4	11.8	0.73	48.8	10.5	0.59
Greece	4.7	1.6	0.42	4.1	1.2	0.37
Ireland	2.3	0.8	0.60	1.8	0.7	0.48
Italy	32.3	6.3	0.56	27.5	5.6	0.48
Netherlands	11.5	2.0	0.69	9.4	1.8	0.56
Portugal	3.7	1.4	0.36	3.4	1.2	0.33
Spain	11.7	5.3	0.29	10.1	4.7	0.25
Sweden	8.2	3.7	0.89	7.3	3.5	0.79
United Kingdom	39.4	10.4	0.66	32.3	9.4	0.54
TOTAL EU	241.3	62.7	0.63	200.5	56.2	0.52

Source: PRIMES

5. Transport sector

5.1. Overview and recent trends

The transportation sector is one of the most important sectors from the point of view of both energy consumption and environmental implications. Transportation accounted for more than 30% of the EU total final energy demand in 1995. It has been consistently the fastest growing final energy demand sector in the EU growing by 3.2% pa between 1985 and 1995, compared to 1% pa growth in total energy use. From an environmental point of view, transported accounted for 26.5% of CO_2 emissions in the European Union in 1995. The near complete dependence of the sector on oil products generates two sorts of concern:

- given the overall insensitivity of the sector to taxes and price changes and the absence of easily available substitutes, at least in the medium term, there is concern over meeting overall greenhouse gases targets by European countries, and
- since a significant amount of transportation takes place within city centres, a number of urban pollution issues arise, some of which have public health implications.

In order to capture better the different driving forces of transportation energy demand, the sector has been divided into:

a) passenger transportation, or the activity involving primarily the movement of people expressed in passenger-kilometres, and

b) freight transport, or the activity involving primarily the movement of goods expressed in ton-kilometres.

Passenger transportation represented about 70% of total transport energy consumption in 1995. Cars and motorcycles consume close to 75% of passenger transport consumption followed by aviation[24] (17%). In terms of mobility in passenger transport, cars and motorcycles accounted for more than 80% in the EU while public road transport accounted for only 9%. On average, each citizen of the EU travelled about 12300 km per year (in 1995). Road transport based on trucks dominated freight transport in the EU (29% of total energy for transportation, 70% of tonne-kilometres transported in the EU). Train transport follow in importance in terms of freight activity (18%), while inland navigation represented 12% of freight activity. Consumption by trains and inland navigation[25] generally represents a small fraction of total energy demand in the sector.

Travel needs in passenger transport can be satisfied by a number of different travel means (transport modes) such as private car, bus, airplanes, trains etc. Consumer undertake travel on the basis of a number of different reasons:

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[24] Within the PRIMES model, aviation includes both national and international flights from the EU, without distinguishing between the two (data on the split between domestic and international aviation is not currently available). Consequently total CO2 emissions from aviation are accounted for at the level of each Member State. However, according to the Guidelines for National Greenhouse Gas Inventories of the Intergovernmental Panel on Climate Change (IPCC), emissions based upon fuel sold to aircraft engaged in international transport should not be included in national totals, but reported separately.

[25] Consumption of international maritime bunkers is excluded from the analysis because according to EUROSTAT conventions it is not accounted for in national CO2 emissions.

- the bulk of travel is a necessity (an “inferior” good), including movement between home and work, for shopping purposes and others,
- there are many kinds of more or less "discretionary" travel, such as air travel, including leisure and social travelling (a “luxury” good).

The, historically observed, link between economic activity and the amount of travel can be highly affected by the purpose of travel and the degree of discretion available for transport modes. For example, the continued movement towards a single market in the EU is expected to lead to an increase in air travel for business purposes.

In the near past (1990-1995), the average distance travelled per capita increased by 5.4% in the EU, slightly above the increase in per capita income (see Table 16), while energy efficiency of passenger transport worsened by 1%.

Table 16: Recent trends in passenger travel

	Personal Income		Energy Efficiency		Distance Travelled	
	EUR90 per capita	Index 1995, 1990=100	toe/Mpkm	Index 1995, 1990=100	km per capita	Index 1995, 1990=100
AU	9839	103	41.9	104	12906	111
BE	9949	105	50.1	101	10819	110
DK	11494	113	47.1	101	13930	104
FI	9847	94	44.8	107	12546	99
FR	10330	104	37.6	107	13394	107
GE	9318	105	51.6	101	11176	100
GR	4022	105	37.9	104	10791	107
IR	6736	112	37.1	89	12947	103
IT	9731	104	33.6	88	12988	107
NL	9318	108	50.9	85	11242	102
PO	3946	108	39.4	100	8933	137
SP	6863	106	29.3	97	13476	110
SV	9510	93	49.2	100	13765	100
UK	8477	103	46.3	95	12103	102
EU14	**8902**	**104**	**41.6**	**99**	**12287**	**105**

Source: PRIMES

This deterioration of energy efficiency occurred because of the following changes:

- The market share of air transport in terms of passenger mobility increased from 3.7% in 1990 to 4.2% in 1995. Average passenger transport is almost four times more efficient than air transport.
- Average car efficiency remained rather stagnant in the five-year period due to increasing size of cars, horsepower and comfort standards (such as air-conditioning) overcompensating for the significant technological improvement that occurred in car technologies in recent years.

As can be seen in Table 16, it is the more wealthy countries that tend to have, on average, larger cars and the consequent higher energy intensity in terms of energy needed per passenger kilometre.

Freight transportation refers to the movement of goods and is closely linked to overall economic activity. However issues related to the landmass, the geographic location in terms of EU trade flows, and the dependence of the economy on industry play an important role as regards the need for freight transportation (see Table 17).

Table 17: Recent trends in freight transportation, 1995

	Gross Domestic Product		Energy Efficiency		tkm per unit of GDP	
	000 MEUR90	Index 1995, 1990=100	toe/Mtkm	Index 1995, 1990=100	tkm per 000EUR90	Index 1995, 1990=100
AU	135	109	109	86	126	99
BE	162	106	55	108	336	112
DK	113	111	80	107	135	96
FI	102	96	38	104	317	108
FR	993	105	69	97	216	103
GE	1418	109	38	108	298	126
GR	71	108	132	100	233	110
IR	48	132	65	107	186	93
IT	910	106	50	109	274	100
NL	248	111	105	98	136	98
PO	58	108	79	101	306	106
SP	414	107	46	98	560	111
SV	185	102	30	89	313	104
UK	816	106	65	116	269	100
EU14	**5672**	**107**	**53**	**106**	**280**	**108**

Source: PRIMES

Energy efficiency of freight transport in the EU improved by 6% in the 1990-1995 period. The electrification of railroads and the improvement of load factors as regards freight transportation are the key factors that led to this improvement. Efficiency of trucks improved by just 1% in 1990-1995, while the corresponding improvement in train transport and inland navigation was around 5%.

5.2. Sector evolution in the baseline projection

The baseline scenario extrapolates past trends showing high growth in mobility and freight transport. However, because of technological progress and structural changes in transport modes, energy demand grows at lower rates.

The rates of growth follow those of GDP and income. In 2010, passenger mobility is 27.5% higher than in 1995 (reaching 15200 km per capita). Structural shifts in transport modes are explained by the natural trend in favour speed.

Table 18: Passenger travel, activity and energy efficiency, EU

	Activity in passenger transports						Energy efficiency by mode				
	passenger-kilometres travelled (billion)			% Market Shares			toe/Mpkm			% Annual growth rates	
	1990	1995	2010	1990	1995	2010	1990	1995	2010	90/95	95/10
Passenger transport	**4247**	**4567**	**5823**	**100.0**	**100.0**	**100.0**	**41.1**	**41.6**	**41.3**	**0.2**	**-0.1**
Road transport	3797	4067	4939	89.4	89.1	84.8	36.4	36.6	36.0	0.1	-0.1
buses	410	406	439	9.6	8.9	7.5	21.7	22.3	21.7	0.6	-0.2
motorcycles	89	87	108	2.1	1.9	1.9	26.5	25.5	25.0	-0.8	-0.1
private cars	3299	3575	4392	77.7	78.3	75.4	38.5	38.4	37.7	0.0	-0.1
Train transport	265	281	442	6.2	6.2	7.6	19.3	19.3	14.7	0.0	-1.8
Aviation	160	194	411	3.8	4.3	7.1	172.2	166.6	125.2	-0.7	-1.9
Inland navigation	24	25	31	0.6	0.5	0.5	153.7	150.2	147.9	-0.5	-0.1

Source: PRIMES

Table 18 summarises the EU trends to 2010 as regards passenger transport in the Shared Analysis baseline:

- while the annual growth rate of mobility increases slightly between 1995 and 2010 compared to the 1990-1995 period, there is a significant shift towards the use of trains and aviation which increase at growth rates two and three times faster than that of mobility as a whole,
- despite growth in car efficiency of 0.1% pa, as recent trends indicate bigger sizes of cars and additional comfort standards continue to develop and counterbalance technological improvements,
- train transportation undergoes more significant progress in the baseline, reaching an average efficiency of 24% in 2010 compared to 1995, reflecting new technologies for electric trains,
- specific energy consumption of the average aircraft decreases by 25% mostly through technological change (engines, aerodynamics and new materials) but also because of larger aircraft and better management (higher load factors, further use of information technology etc). However, aviation remains the most energy intensive transport mean (about 3 times the average for passenger transport).

It is important to note that in the Shared Analysis baseline the possible impact of the voluntary agreement reached in July 1998 between the European Commission and the European, Japanese and Korean car manufacturers, was not included. Details of this agreement and its likely impact are presented in the context of next section.

Freight transport is projected to grow by 23% over the 1995-2010 period (see Table 19). Trucks lose market share (-4.4%) favouring trains (+3.8%) and navigation (+0.6%). Efficiency of freight transport improves by 0.5% pa between1995 and 2010.

Table 19: Freight transport, activity and energy efficiency, EU

	Activity in freight transports						Energy efficiency by mode				
	ton-kilometres travelled (billion)			% Market Shares			toe/Mtkm			% Annual growth rates	
	1990	**1995**	**2010**	**1990**	**1995**	**2010**	**1990**	**1995**	**2010**	**90/95**	**95/10**
Freight transport	**1372**	**1591**	**2102**	**100.0**	**100.0**	**100.0**	**56.6**	**53.2**	**49.4**	**-1.2**	**-0.5**
Road transport	934	1101	1362	68.1	69.2	64.8	78.0	72.3	71.2	-1.5	-0.1
Train transport	241	282	452	17.5	17.7	21.5	7.2	7.2	5.7	-0.1	-1.5
Inland navigation	197	208	288	14.4	13.1	13.7	15.3	14.4	14.6	-1.1	0.1

Source: PRIMES

The improvement in overall truck efficiency is not projected to be significant between 1995 and 2010. For trains, the factors that have already been discussed in the context of passenger transportation are also relevant for freight. However, the efficiency improvement in rail freight transportation is projected to be somewhat more limited than that in passenger rail. It is important to note that the combination of changes in freight mode and of the differential improvements in efficiencies among modes leads to a significant reduction in the overall freight efficiency.

Energy demand in transportation increases by 1.5% pa between 1995 and 2010. This rate is substantially below historical trends and is based on two factors:

- the approach of saturation levels as regards personal travel and urban stress, and
- the combination of technological advances and modal shifts, as in the case of freight transport.

Table 20: Energy demand in transport, EU

	Mtoe			% Annual growth rates		% Shares		
	1990	**1995**	**2010**	**90/95**	**95/10**	**1990**	**1995**	**2010**
Liquid fuels	248.3	269.7	335.1	1.7	1.5	98.3	98.0	97.3
liquified petroleum gas	2.7	2.8	2.8	1.0	0.0	1.1	1.0	0.8
gasoline	121.7	120.4	146.0	-0.2	1.3	49.0	44.6	43.6
kerosene	27.5	32.4	51.5	3.3	3.1	11.1	12.0	15.4
diesel oil and other liquids	96.3	114.1	134.8	3.4	1.1	38.8	42.3	40.2
Natural gas	0.2	0.4	0.4	13.1	0.0	0.1	0.1	0.1
New fuels	0.0	0.2	0.3		0.6	0.0	0.1	0.1
methanol	0.0	0.1	0.1		0.6			
ethanol	0.0	0.1	0.1		1.3			
liquified hydrogen	0.0	0.1	0.1		-0.2			
Electricity	4.0	4.8	8.6	3.5	4.0	1.6	1.7	2.5
Total	**252.5**	**275.1**	**344.3**	**1.7**	**1.5**			
Share in total final energy demand (%)	29.7	31.1	32.7	0.9	0.3			
CO_2 Emissions (Mtn CO_2)	735	800	994	1.7	1.5			
Share in total CO_2 emissions (%)	23.9	26.4	30.2	2.0	0.9			

Source: PRIMES

Liquid fuels continue dominating the fuel mix of transport activity (see Table 20).

Given the limited timeframe of the projection, the introduction of novel transportation fuels (bio-fuels, natural gas, etc.) is very limited. According to baseline assumptions, no significant technological breakthrough is projected to occur in the, rather limited, horizon to 2010 in the transportation sector. Consequently, fuel cells and electric cars do not penetrate in the transport sector.

The importance of the transportation sector increases over the period to 2010 in terms of both energy demand and overall EU emissions. The sector is projected to account for nearly a third of final demand by 2010 and for 30% of total EU CO_2 emissions.

5.2.1. The effect of including the ACEA agreement in the baseline

There has been an increasing emphasis on the part of EU policy makers towards trying to influence the efficiency of the use of transportation fuels through non-market instruments. This involves policy measures that relate to the makers of cars, of whom there is a relatively small number, rather than trying to affect the behaviour of each EU driver. An important precedent for such a policy emphasis is the Corporate Average Fleet Efficiency (CAFE) standards adopted by the US following the first oil crisis.

In 1998, European car manufacturers (ACEA)[26] made voluntary commitment to reduce the average CO_2 emission figure for all new cars to 140 g/km by 2008. This compares with a current level of emissions of about 186g/km. An intermediate target was set for 2003 up to 170g/km. The industry has also undertaken to make available to the market cars that emit 120 g/km by 2000 and to undertake further improvements beyond 2008 (an initial target for the average of new cars was set at 120g/km for 2012). Similar agreements have been made with the Japanese (JAMA) and Korean (KAMA) manufacturers with a target date of 2009. The effects of this so-called ACEA Agreement was not included in the Shared Analysis baseline or the emission reduction scenarios presented in previous chapters of this study. However, the impact of the ACEA

[26] As all North American car manufacturers have production facilities in the EU, the ACEA Agreement covers also cars manufactured in the US destined to the EU markets.

Agreement is examined here and the results are carried through the detailed results in Appendix V.

The analysis assumed that vehicle emissions are reduced to 170 g/km in 2003, 140 g/km in 2008, 120 g/km in 2012 and to 100g/km by 2020. Reductions have been assumed to take place linearly in the intervening years and involve no costs for the consumer or the manufacturer. The results of the implementation of the ACEA Agreement are quite significant both for emissions and for the demand for oil products within the EU. In the absence of emission restrictions, by 2010, the impact of the agreement is to reduce oil demand by 28 Mtoe (or more than half a million barrels per day) in the EU, which is equivalent to more than 4% of EU oil demand. The impact of the agreement on emissions is more limited than on oil demand but very significant nevertheless. By 2010, CO_2 emissions in the EU would decline by 2.5% when compared to the baseline.

5.2.2. Impact of most recent update (November 2000)

Following feedback on the results of the Shared Analysis baseline and analysis of recent data and trends in the transport sector an update of the scenario was performed in November 2000 for Directorate-General Transport and Energy. In this scenario the activity assumption driving the transportation sector has been increased somewhat over the outlook period. It was deemed that the Baseline scenario had been underestimating demand growth in the transport sector (for example by projecting demand of 299 Mtoe for 2000 in the EU a figure which according to the latest EUROSTAT energy balances had already been attained by 1998). In view of these developments, transport activity growth has been revised upwards for both passenger and freight transport. Furthermore the Updated scenario incorporated the ACEA Agreement, as well as the recent increase of international fuel prices. Finally, accelerated growth in aviation was also taken into account.

Under the updated scenario assumptions final energy demand in transport increases by more than 3% in 2010 from baseline levels. This increase is due to the revised assumptions as regards the evolution of transport activity. The revised transport activity growth more than counterbalances the effect of the incorporation of the ACEA Agreement. However, at the level of private cars consumption, which is the target of the agreement, energy requirements decrease compared to the Baseline scenario (-14.5% in 2010), despite the higher activity growth. CO2 emissions from the transport sector are also projected to increase by almost 4% in 2010 from baseline levels. Thus, it seems that further policies and measures should be targeted in particular towards aviation and road freight transport as the growth in the CO2 emissions of these two sectors seems very rapid indeed.

5.3. Sector Adjustment for Different Emission Reduction Targets

The transportation sector is currently very important for energy and emissions in the EU, accounting for about 30% of total CO_2 emissions. It is important to recall that energy demand in the sector seems to be rather insensitive to a number of policy instruments used in the past including very high taxation on fuels used for private transportation. Emission constraints influence consumers in many ways:

- they may reduce their mobility,
- change their driving habits,
- use more public transport, and
- purchase smaller and more efficient cars.

Similarly freight transport companies may better optimise the use of transport modes and choice of technology.

The cost of fuels in total transport costs represents a substantial component for some of the transport modes. However, in view of current prices for transportation fuels, which often consist of nearly 80% taxation, further use of market instruments to reduce energy consumption would require exceptionally high increases in taxation.[27] This is an important feature of transport economics and heavily influences the results obtained.

As can be seen in Table 21 the implications for the transport sector are increasingly important, as higher emission reduction targets are set.[28] It must be reminded here that the ACEA Agreement is not incorporated in the emission reduction scenarios.

Table 21: Impacts of emission reduction targets to transport sector, EU

	Baseline scenario			CO_2 Emission reduction target for the EU energy system		
	1990	2010	% change	small	medium	high
				% difference from baseline in 2010		
Travel per person (km per capita)	11662	15201	30%	-2%	-4%	-6%
Freight per unit of GDP (tkm/000 EURO90)	259	257	-1%	-5%	-9%	-12%
Energy intensity (toe/MEURO90)						
passenger transports $_{income\ related}$	56	52	-8%	-10%	-20%	-40%
passenger transports $_{GDP\ related}$	15	13	-13%		-30%	
Average efficiency of vehicle in passenger transports						
toe per Mpkm travelled	41	41	0%	-9%	-20%	-40%
toe per Mvkm travelled	85	85	1%	-7%	-15%	-45%
Average efficiency of vehicle in goods transports						
toe per Mtkm travelled	57	49	-13%	-8%	-20%	-35%
toe per Mvkm travelled	483	473	-2%	-1%	-10%	-20%
Energy demand in transports (Mtoe)	252	344	36%	-10%	-25%	-40%
CO_2 emissions in transports (Mtn CO_2)	735	994	35%	-10%	-25%	-40%

Source: PRIMES

The following conclusions can be drawn from the analysis:

- Mobility 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 mobility by only 6%.
- Activity in freight transport is more responsive to emissions reductions probably because of the better perception of costs by firms.
- 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 the reason of travel, existing infrastructure and others. 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 as efficiency improvement of an average vehicle can reach up to 45% in terms of consumption per

[27] Current levels of excise duties on gasoline within the EU vary from €319/1000lt in Greece to €670/1000lt in the UK.

[28] Small refers to a target of around –8% from 1990 levels, medium refers to a target of around –30% and high refers to a target of around –45% (i.e. exploiting sectoral potential)

vehicle-kilometre travelled. The corresponding improvement in terms of passenger-kilometres travelled can reach up to 40%. 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 compared to vehicle-kilometres travelled.
- Changes in terms of energy demand and CO2 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.).

Table 22: Vehicles improvement in passenger transport, EU

	Baseline scenario			CO_2 Emission reduction target for the EU energy system		
				small	medium	high
	1990	2010	% change	% difference from baseline in 2010		
Average efficiency of vehicle in terms of passenger-kilometres driven (toe per Mpkm travelled)						
public road transport	22	22	0%	-5%	-20%	-30%
private cars	39	38	-2%	-2%	-8%	-30%
train transport	19	15	-24%	-20%	-30%	-35%
aviation	172	125	-27%	-25%	-40%	-50%
Average efficiency of vehicle in terms of vehicle-kilometres driven (toe per Mvkm travelled)						
public road transport	385	364	-6%	-2%	-15%	-25%
private cars	65	62	-5%	-1%	-5%	-30%
train transport	2333	1649	-29%	-15%	-30%	-30%
aviation	13942	10205	-27%	-15%	-23%	-28%

Source: PRIMES

Table 22 summarises the potential improvement of vehicles for the different transport modes in passenger transport and for different levels of emission reduction targets.

The aviation industry can be very responsive to emission restrictions. Efficiency improvement in terms of vehicle-kilometres travelled ranges from 15% for small emission reductions up to 28% for stricter ones. These improvements are additional to a 27% improvement observed in the baseline. It must be mentioned that aircraft efficiency has improved by 50% over the past 25 years and this, according to some estimates, can be repeated in the period to 2020.[29] This means that while technical progress in the baseline is significant, it is cost-effective to accelerate it further in the context of emissions reduction. The corresponding figures for efficiency improvement in terms of passenger-kilometres travelled range from 20% to 50%, illustrating that for the specific transport mode there is a large scope for actions on better management (higher load factors, hubs, aircraft sizes adequate to trip length, etc).

[29] According to US Department of Energy: Technology Opportunities to reduce GHGs, October 1997

The findings are similar for train transport. Further technology improvement is possible on top of the significant improvement already registered in the baseline. However, there seems to be some saturation as regards the potential of high efficiency gains in the horizon to 2010. The structure of costs of train transport shows less dependence on energy costs than in other transport modes. Technology improvements are driven from competition with other modes and the introduction of new services rather than from cost changes due to energy and emissions. Because of that, efficiency improvement in terms of vehicle-kilometres travelled remains rather stable at around 30% over the range of emission reductions tested.

Improvement of public road transport is cost-effective and can reach up to 25% in terms of vehicle technology and 30% in terms of activity.

Energy efficiency improvements for cars are of course possible. The analysis shows that high economic incentives related to the cost of using energy are needed to obtain significant changes. Without the active participation of automobile manufacturers, who can re-optimise the design of the cars at rather low additional costs, it is unlikely to expect consumers to change their habits in car use except under conditions of very considerable additional fuel charges. The potential, if effectively exploited through adequate policy measures, is significant even in the horizon of almost one cycle of car park renewal. Without technological change, originating from vehicle suppliers, the behaviour of consumers can lead to up to 30% of energy efficiency improvement, measured either in mobility terms or in vehicle terms. The scope and effectiveness of measures in the context of urban mobility with cars should be stressed. In this domain, there are considerable benefits, besides CO2 related, to be derived from using less the cars and driving smaller and more efficient cars. These benefits (arising from the reduction of urban stress, local pollution, congestion, etc.) justify in their own right measures and incentives in favour of increasing the occupancy rates of cars in cities, combining transport modes, etc. These can have considerable effects on the average energy efficiency of mobility with cars, significantly reducing CO2 emissions.

Important technological change in cars in a short-term horizon (such as 2010) seems unlikely, except if automobile manufacturers as a whole introduce re-optimised car types in the market (as shown to be the case in the ACEA Agreement). The structure of costs of the use of cars and the highly subjective discount rates prevailing in this domain imply that consumers need very high incentives (or taxes on fuels) to prematurely replace their cars. Therefore, the life cycle of changes is aligned to the normal life cycle of the average car (see Pattas, 1997).

No technological breakthrough is expected before 2010, both as regards fuel cells and electric cars. However, the very high, energy efficiency of fuel cells by 2020 (assumed to be close to 3lt/100km), may lead to some penetration in the transportation market beyond 2010 but their initial application is more likely to occur in trains rather than trucks, and in trucks rather than cars. The first commercial prototypes are expected to be available in the Californian market before 2005. Similarly, the electric car, and a related breakthrough in batteries, represents a major potential uncertainty.

The major difference between transport modes, that is mainly responsible for their different behaviour as described above, is related to the size of vehicles and their relation to economies of scale. In addition, technologies that facilitate economies of scale in energy use are much more likely to be adopted by firms (as in the case of aviation, railroads and public road transport) than by individuals (owners of private cars). The perception of capital costs and opportunity costs of capital naturally differ, in a way that investment in efficiency is easier to be adopted by firms.

__Table 23: Vehicles improvement in freight transport, EU__

	Baseline scenario			CO_2 Emission reduction target for the EU energy system		
				small	medium	high
	1990	2010	% change	% difference from baseline in 2010		
Average efficiency of vehicle in terms of ton-kilometres driven (toe per Mpkm travelled)						
trucks	78	71	-9%	-5%	-20%	-35%
train transport	7	6	-20%	-25%	-35%	-45%
Average efficiency of vehicle in terms of vehicle-kilometres driven (toe per Mvkm travelled)						
trucks	456	445	-2%	-1%	-10%	-15%
train transport	2366	1815	-23%	-20%	-25%	-28%

Source: PRIMES

As can be seen in Table 23 the potential improvement in vehicle efficiency for trucks in is not sufficiently exploited even for high emission reductions cases. Efficiency improvements for trucks reach up to 15%. However, better management (for example, the use of bigger trucks with higher load capabilities) provides an important domain for making road transportation of goods more efficient. Efficiency improvement per ton-kilometre travelled can reach up to 35%. The results for freight train transport are rather similar to those described in passenger transport.

6. CO2 Reduction from Electricity and Steam Generation

The PRIMES model as used within the Shared Analysis project quantified a set of scenarios for the electricity and steam generation sector.

The projections for the sectors were designed to be consistent with the rest of the energy system. Scenarios that reduce emissions are assumed to simulate a response of the entire energy system to globally imposed emission constraints. In this sense, the scenarios are top-down oriented, since the model suggests how to allocate to the sectors the global emission reduction effort. The model follows an explicit representation of technologies, engineering constraints and plants. It should be qualified as an engineering economic model.

For the electricity and steam generation system, the model answers to the following question: what is the least total cost operation and configuration (including new investment) for the system that produces electricity and steam, separately and/or jointly, so as to meet the demand, while satisfying represent technical, fuel availability and emission restrictions constraints.

The following sections use the results of the PRIMES model emanating from a large series of scenarios and sensitivity analysis runs performed to analyse how the power and steam generation sector reacts to different emission limitation targets for 2010. The purpose is to assess the sector's adjustment possibilities in view of exploring appropriate sectoral objectives in the EU. The sections present this analysis per sub-sector (renewables, cogeneration, etc.). It needs to be emphasised that the results are obtained using the entire PRIMES model and not just from sectoral models.

The PRIMES model is fairly detailed and incorporates the following mechanisms:

a) Multiple time periods and capital vintages.

b) Time variation (typical days per season) synchronisation for the following: demand for electricity and steam, availability of renewable energy sources, fuel prices (if prices differ by load), operation of plants and imports/exports.

c) Many existing and new technologies for power generation, steam production and cogeneration.

d) Varying technical-economic characteristics of technologies according to plant size, time (technical progress), cogeneration type and optionally learning-by-doing.

e) Multiple fuels represented in spot market conditions or contracts. Multiple renewable sources with time-varying availability constraints.

f) Time variability of imports/exports of electricity under spot market or contract conditions.

g) Three stylised companies (utilities, industrial auto-producers, middle-size independent power producers) with customisable and distinct plant ownership, customer accessibility and distribution possibilities.

h) Emission of several pollutants and representation of abatement technologies.

i) Several policy instruments including: taxes, subsidies, emission constraints, renewable generation constraints, cogeneration constraints etc.

j) Multiple discount rates (according to company type and over time), parameters that reflect institutional arrangements for the opening of the market and coefficients that reflect pricing regimes (marginal cost pricing, average cost pricing or mixtures).

k) Inputs from other PRIMES modules: demand for electricity and steam per sector (together with their time pattern) and basic fuel prices.

l) Outputs to other PRIMES modules: demand for fuels, prices of electricity and steam per sector.

m) Basic results: electricity and steam balance (inputs, outputs), production per plant, investment in new plants, economic costs and prices, emissions, market structure, imports and exports.

n) Time horizon: 1995 to 2030 (by 5year period); Country coverage: all EU Member States; and Data sources: EUROSTAT, UNIPEDE, EPIC, E3TDB and others.

The current model has been calibrated on data available at the end of 1998. The base year is 1995. The electricity and steam model of PRIMES cannot be exactly calibrated to base year statistics. Only approximate calibration is possible. For the year 2000 the model is partially calibrated and the results depend mostly on known expansion and decommissioning plans.

6.1. Renewable energy forms in electricity and steam generation

6.1.1. Is the current PRIMES baseline still valid in relation to short-run trends?

The current baseline scenario is compared for the years 1995 to 2000 by using the following sources of information:

- EUROSTAT Survey on Renewables (available in 1999),
- EUROSTAT revised energy balance-sheets (latest data available for 1997),
- European Wind Energy Association (latest information available in the Association site, January 2000), and
- UNIPEDE latest EURPROG report (June 1998).

Table 24 summarizes the comparison between the PRIMES baseline and the latest EUROSTAT statistics.

Table 24: Evolution of renewables in electricity and steam production for the short-run

	EUROSTAT survey			PRIMES results		
	1995	1997	diff.	1995	2000	diff.
Electricity production, TWh						
Hydro	291.1	300.6	9.5	286.2	311.1	24.9
Wind energy	4.1	7.3	3.3	3.1	22.3	19.2
Geothermal heat	3.5	4.0	0.5	2.5	4.8	2.4
Biomass/Waste	22.6	27.2	4.6	33.5	45.0	11.5
Steam production, TWh						
Biomass/Waste	195.1	213.3	18.1	172.4	191.5	19.0
of which from CHP	55.8	72.2	16.4	74.2	88.2	14.0

Source: PRIMES

Differences for the base year 1995 are due to the fact that the data used for calibration of PRIMES were older than the currently available survey of EUROSTAT. These differences mainly concern wind and biomass. However, given that renewable energy forms have a small share in total electricity production (accounting for about 14% of total electricity production, but only for 1.7% if large hydro plants are excluded), the differences in the base year have few consequences on the scenario projection.

In the period 1995 to 2000, the fastest growth is observed for wind energy. The other renewable energy forms grow at more moderate rates.

The comparison of PRIMES results with recent information on short run trends gives rise to the following remarks:

- The trend in production form hydro plants is adequately captured by PRIMES; 1996 and 1997 as surveyed by EUROSTAT were statistically dry years, whereas PRIMES assumes "normal" hydraulic conditions.
- The trends concerning the use of biomass and waste for electricity production are also adequately captured in the model run; however, probably the increase in the use of biomass and waste in steam production and cogeneration is slightly underestimated in PRIMES.
- According to PRIMES results the installed capacity of wind turbines will reach a total of 8.4 GW in 2000 (compared to only 1.9 GW in operation in 1995). This projection is slightly lower (by 536 MW) compared to the recent estimation of European Wind Energy Association (EWEA), according to which the wind park totalled 8.9 GW at the end of 1999.

Table 25 decomposes this difference by Member State.

Table 25: Wind turbines capacity – Differences between EWEA data and PRIMES results

Country	Total MW installed by end of 1999	PRIMES results for 2000	Difference
Austria	42	189	-147
Belgium	9	139	-130
Denmark	1700	1250	450
Finland	38	76	-38
France	19	324	-305
Germany	4444	3969	475
Greece	121	141	-20
Ireland	68	165	-97
Italy	281	583	-302
Luxemburg	10		10
Netherlands	409	342	67
Portugal	57	30	27
Spain	1180	566	614
Sweden	195	67	129
United Kingdom	343	539	-196
TOTAL EU	8916	8380	536

Source: PRIMES

This table shows how sensitive is the deployment of wind (and the probable forecasting error) on the development of wind promotion policies. Countries that developed active wind promotion policies experienced fast growth in wind power and the model underestimated this development (see the cases of Denmark, Germany and Spain). Other countries that did not develop such policies still face stagnation and the model over-estimated the evolution (e.g. Austria, Belgium, France, Italy, United Kingdom).

In brief, the scenario needs to revisit some renewables cases for the short run projection, in particular for wind power. However, the implications on CO_2 and total energy will be very small given the small share of renewable energy forms in total electricity production. The trends in the short-run are well captured by PRIMES, but the exact timing of the development largely depends on the amplitude and the effectiveness of current policies promoting renewables, which substantially differ by country.

6.1.2. What is the basic mechanism reflected in the PRIMES baseline scenario towards 2010?

The PRIMES model simulates an economic "private" behaviour of electricity/steam producers under progressively competitive markets. Under this context, the model projects the future use and investment in renewable energies. Public policies to promote renewables are represented through subsidisation of capital costs for renewable plants and through obligations applicable on electricity market regulation.

The baseline scenario assumes the following:

- Renewable technologies progress over time (lower capital cost) at rather smooth rates, without experiencing any major technological breakthrough.
- The electricity market liberalisation advances in the short-run and reaches complete amplitude towards the end of the next decade.
- Current policies promoting renewables (e.g. subsidisation) continue and apply in all Member States.
- The baseline scenario does not assume public authorities imposing strong constraints favouring renewables (e.g. emission control, non fossil fuels obligation, etc.) in electricity market regulation.
- Prices of fossil fuels grow very smoothly[30], electricity prices drop (lower marginal costs) and generation technologies using fossil fuels also progress at substantial rates (lower capital costs, improved efficiency).

Under the circumstances described above, the baseline scenario shows a rather limited deployment of renewable energies, except for wind energy, and more moderately for the use of waste. Regarding wind energy, there is significant growth but its contribution falls well short of potential. The combination of pressures under the competitive market and the low prices of fossil fuels largely explain these baseline trends. More detailed remarks about baseline trends are as follows:

- The development of hydro concerns only small-scale run-of-river hydro, which is limited in volume. It is assumed that large hydro is about totally exploited in the EU.
- The deployment of wind energy is noticeable, reaching 22 GW in 2010 (from 8.4 GW in 2000). This is in line with previous targets of the EWEA (25 GW), but well below targets they set recently (60 GW).[31] As mentioned earlier, the uncertainty surrounding wind power largely depends on public policies because the pressures in the increasingly competitive environment will tend to limit the growth of wind power.
- The baseline projection shows a rather significant exploitation of the potential of electricity production from waste (landfill gas and others) but no development of new biomass (energy crops). This is related to conservative expectations about infrastructure and agricultural policies that could support new biomass.

[30] The present rise in oil prices has not been included in the baseline used in this report.

[31] In the context of the updated baseline scenario, (Scenarios Related to the Security of Supply of the European Union, Report for EU15. Report prepared for the DG Transport and Energy of the European Commission, November 2000), in which energy prices were revised to reflect recent trends, installed capacity of wind turbines in 2010 is projected to reach 48 GW. Thus, under the new baseline conditions 80% of the target set by EWEA would be met. Due to lack of time, it was not possible to use this updated baseline as the basis for the analysis in this report, though.

Table 26: Evolution of renewables as projected in PRIMES baseline (EU14)

	2000	2010	increment from 2000
Electricity production, TWh			
Total renewables	383.2	440.8	57.5
Hydro	311.1	308.6	-2.5
Wind energy	22.3	60.3	38.1
Geothermal heat	4.8	5.5	0.7
Biomass/Waste	45.0	66.3	21.3
of which from new biomass	0.7	0.4	-0.2
% in total electricity production	15.0	14.6	
Steam production, TWh			
Biomass/Waste	191.5	210.3	18.8
of which from new biomass	1.2	2.1	0.9
% in total steam production	17.1	16.2	
Installed capacities, GW			
Total renewables	123.6	138.4	14.8
Biomass-Waste	4.4	4.7	0.3
Hydro	109.8	110.7	0.9
Wind Turbines	8.4	21.9	13.5
Geothermal	1.0	1.1	0.1
Solar	0.0	0.0	0.0
Tidal	0.0	0.0	0.0
% in total installed capacity	20.2	19.3	

Source: PRIMES

Table 26 illustrates the evolution of renewable energy forms in power and steam generation under baseline conditions between 2000 and 2010. The table shows that the renewable energies remain a small part of overall energy in the EU, despite the fast growth in wind power and, to a lesser extent, waste and biomass. Furthermore the growth of renewable energy forms in power and steam generation is slightly lower than total electricity and steam production. Consequently, renewable energy forms lose in terms of market shares both as regards electricity and steam generation and as regards installed generation capacities (this result is heavily influenced by the preponderance of large hydro-electric plants in the renewables category).

6.1.3. How does the sector adjust when the system meets the Kyoto target for 2010?

In this section we draw conclusions by observing how the sector adjusts when the whole energy system reduces CO_2 emissions to meet the Kyoto commitment. At a system-wide level, the PRIMES model simulates a least cost allocation of the emission reduction effort to the various sectors.

The results show that, in order to comply with Kyoto targets in 2010, the power and steam generation system of the EU undergoes the biggest changes. It is more cost-effective to undertake relatively pronounced emission reduction in power generation than in just about any other energy consuming sector. The adjustments span a variety of domains, including changes in fuel mix (more natural gas), reorientation of investment choices, changes of dispatching priorities, and the high use of carbon-free sources such as renewables and nuclear. For the latter the additional possibilities are very small given the short-term horizon of the Kyoto target (2010).

Regarding renewable energy forms, the results show a relatively important contribution to emissions reduction in the power and steam sector.

There are three categories of renewable energies that are by and large not affected by the emission reduction effort. These are large hydropower, geothermal generation and traditional biomass (wood). These energy forms are constrained by supply and their expansion possibilities are limited further by local considerations (including environmental problems). It should be remembered that large hydropower and traditional biomass represent a large fraction of total renewables currently exploited in the European Union. For this reason the results as aggregated for the whole of renewables show little change from baseline.

Under the emission reduction effort in a short-term horizon, such as 2010, the following mechanisms become apparent in the model results.

a) Demand for electricity and steam is reduced from baseline, due to demand-side measures.

b) Carbon free sources, such as renewables, are used as much as possible, at given installed capacities. Therefore, their share in electricity production increases. This is also the case for large hydropower.

c) On top of the baseline trends, additional investment is undertaken in those renewable energy forms for which expansion under economic and market competitive conditions is possible. To this respect, the results show a significant development of wind energy, additional to the baseline.

d) In the Kyoto scenario, the capacity of wind power is projected to reach 38.5 GW in 2010 (5% of total capacity), which is in correspondence with the new target of EWEA (40GW). In that sense it can be argued that the updated EWEA targets were set considering the context of the Kyoto commitment for the EU. Under these circumstances, wind electricity increases by 71% compared to the baseline, representing 3.5% of total electricity production (2% in baseline).

e) Under emission constraints it is cost-effective to further exploit waste and biomass. For the Kyoto target it is not cost effective to develop new biomass (energy crops) but to further exploit existing biomass and waste sources. This goes far beyond the baseline: 80% higher electricity production from biomass/waste in 2010, representing 4% of total electricity produced (2.2% in baseline). Similarly steam generation from existing biomass and waste increases from baseline levels (25% more). The transformation input of biomass-waste increases by 48% compared to baseline, reaching 45 Mtoe in 2010 (31 Mtoe in baseline).

In total, according to the model results, adjusting to the Kyoto target leads to a higher share of renewable electricity: 18% in 2010 instead of 14% in the baseline. This is obtained under market competition conditions. The high use of renewables corresponds to 13% of CO_2 emission reduction in the power and steam generation sector.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

The conclusions about further emission abatement through this sector are drawn from a large series of model runs varying according to the severity of the total emission reduction target. For each such target a least-cost allocation of the abatement effort is analysed through the PRIMES model.

We observe how the results concerning renewables change when varying the total emission reduction target. This is an indication of the economic potential of the sector in the context of collective emission abatement efforts. This evaluation is the result of system-wide analysis.

The analysis for the sector of renewable energies in electricity/steam production shows that the potential can be seen under three categories:

1. Renewable forms that are already largely exploited in the baseline cannot further expand to contribute to emission reduction. This is the

case for large hydro and high enthalpy geothermal heat. In terms of annual electricity production the potential seems to be up to 310 TWh and 7-8 TWh, respectively.

2. Renewable forms that are nearly competitive under baseline conditions and for which the analysis indicates that it is cost-effective to expand at almost linear proportion to the emission reduction target. This is the case for wind power, small hydro and traditional biomass/waste energy.

   2.1. It is cost-effective to linearly increase the deployment of wind energy when seeking higher total emission reduction. To reach Kyoto, wind power is expected to produce 71% more than in the baseline, where as to reach an emission reduction target two times stricter than Kyoto, wind is asked to produce 120% to 140% more than in the baseline. The economic potential of contribution from wind seems to reach an upper bound that corresponds roughly to 150 TWh (6-7% of total electricity production) and 55 GW for 2010. The technical potential is of course much higher. Both potentials depend on the assumption concerning the characteristics and possibilities of offshore wind for which the assumptions for 2010 are rather conservative.

   2.2. Small hydro plants also expand linearly to contribute to emission reductions. In the context of the Kyoto target production from small hydro increases by 50% from baseline levels while if an emission reduction target two times stricter than Kyoto is imposed the increase from baseline reaches 115%. However, the technical potential of small hydro is rather limited in the EU. Consequently the economic potential contribution from small hydro does not exceed 10 TWh (0.5% of total electricity production) and 5.5 GW for 2010.

   2.3. It is also cost-effective, within systems analysis to increase exploiting the potential from traditional biomass/waste energy to produce electricity and steam. Electricity production from this energy form can reach a level higher by 50-60 % compared to baseline (up to 110 TWh) while the corresponding increase as regards steam production does not exceed 25% (up to 250 TWh of steam).

3. Renewable energy forms that are novel and commercially immature at present. They show a significant growth only beyond a certain threshold. Such a threshold comes from the fact that the system faces a high emission reduction target and is facing high compliance costs. The technical potential of renewables in these cases starts to be exploited when the marginal cost approximates the overall marginal abatement cost. Once penetration has started deployment could be fast according to the mechanisms of the model. Such cases are: new biomass, solar and tidal electricity.

   3.1. The development of new biomass energy forms can be considerable in theory, but it depends on supply conditions (infrastructure, agriculture policy, etc.). In any case, it is necessary to operate at significantly higher electricity production costs before allowing the development of new biomass on economic grounds. The potential for 2010 is rather limited, because of the short-term horizon: electricity production from new biomass (energy crops) is estimated to reach up to 70 TWh, starting to be significant at costs corresponding to “double Kyoto” emission reduction targets. This result could be different if public policies acting in favour of biomass infrastructure and agriculture were developed. The model runs do not consider the implementation of such policies. Also regarding the use of biomass to produce biofuels (to be used concurrently to oil products), the scenarios take a conservative point of view for many reasons: in a short-run (2010) perspective the refineries would face excessively high stranded costs as they have recently invested to meet Auto-oil requirements; large upstream investments are needed in the domain of biomass production, as mentioned above; pollution problems (in the cities) when using biofuels are still a matter of controversy.

3.2. Solar and tidal electricity also need high overall electricity generation costs to develop in the short term. The estimations as regards the economic potential of these energy forms in the horizon to 2010 are conservative: 4.5 and 1.5 TWh respectively.

In the presence of high emission reduction targets, the economic potential of renewables in total electricity production is estimated to grow by up to 27%. This is the combined effect of the increased penetration of emerging renewable energy forms (with a significant unexploited potential in the baseline), the maximum utilisation of renewable energy forms that are highly exploited even under baseline conditions and the decrease in electricity and steam demand because of the adoption of demand-side measures. Up to 22% of CO_2 emission reduction in power and steam generation sector can be achieved through the increased use of renewable energies in the sector, in a horizon to 2010.

Table 27: Electricity production from renewable energy forms under different emission reduction constraints

	Baseline				Kyoto			
	Total from renewables	of which from Wind	Renewables in total electricity production	Wind capacity	Total from renewables	of which from Wind	Renewables in total electricity production	Wind capacity
	TWh		%	GW	TWh		%	GW
Austria	43.6	1.3	63.8	0.47	46.1	2.7	69.3	0.96
Belgium	3.4	2.5	3.4	0.75	7.0	5.8	7.0	1.70
Denmark	10.3	7.3	23.2	3.37	12.1	9.9	29.5	4.71
Finland	25.2	1.5	27.7	0.49	29.4	2.7	33.4	0.86
France	78.8	2.1	13.4	1.04	89.8	8.9	14.8	4.24
Germany	54.7	22.9	9.0	8.19	75.3	33.7	13.1	12.36
Greece	7.3	1.9	10.2	0.54	9.7	2.8	15.4	0.80
Ireland	2.9	1.7	8.7	0.54	5.6	3.2	17.9	1.07
Italy	55.8	6.5	16.7	2.39	65.5	12.1	20.3	4.73
Netherlands	4.7	1.5	3.6	0.61	8.5	4.2	7.0	1.66
Portugal	15.0	0.0	23.8	0.03	18.1	0.2	30.6	0.12
Spain	50.4	6.7	20.2	2.08	68.5	8.9	28.1	2.78
Sweden	75.1	0.0	46.5	0.07	75.8	0.0	47.6	0.07
United Kingdom	13.6	4.4	2.8	1.34	25.3	8.2	5.4	2.47
TOTAL EU	440.8	60.3	14.6	21.90	536.6	103.3	18.2	38.52

	Two times Kyoto				Four times Kyoto			
	Total from renewables	of which from Wind	Renewables in total electricity production	Wind capacity	Total from renewables	of which from Wind	Renewables in total electricity production	Wind capacity
	TWh		%	GW	TWh		%	GW
Austria	47.1	3.6	71.8	1.27	47.9	4.0	79.8	1.47
Belgium	9.3	7.6	9.3	2.24	12.6	9.2	14.3	2.69
Denmark	12.4	10.6	31.3	4.94	19.2	12.4	59.0	5.71
Finland	31.8	3.1	36.9	0.98	33.0	4.0	43.7	1.27
France	95.8	14.5	15.8	6.31	97.4	17.1	17.1	7.55
Germany	97.2	44.2	17.5	15.79	112.5	41.4	22.9	15.79
Greece	10.0	3.1	17.3	0.88	8.7	2.8	19.4	0.78
Ireland	7.5	3.9	24.9	1.37	9.0	4.6	34.9	1.48
Italy	70.8	14.8	23.0	5.69	77.7	20.1	28.4	7.43
Netherlands	8.8	4.5	7.6	1.78	10.4	6.3	10.2	2.51
Portugal	20.9	0.2	36.7	0.13	24.0	0.5	49.7	0.30
Spain	78.7	9.5	34.0	2.97	82.8	10.7	39.9	3.33
Sweden	76.8	1.0	48.6	0.50	73.1	0.9	48.7	0.40
United Kingdom	24.7	7.5	5.5	2.80	34.4	10.7	8.9	3.23
TOTAL EU	591.8	128.0	20.7	47.64	642.6	144.6	25.2	53.94

Source: PRIMES

6.2. Nuclear energy in electricity and steam generation

6.2.1. Is the current PRIMES baseline still valid in relation to short-run trends?

The current baseline scenario projects an increase in electricity production from nuclear by 8.5% in 2000 compared to 1995 levels. According to EUROSTAT statistics nuclear production in 1995-1997 increased by 6%.

Nuclear capacity is project to expand by 4.5 GW in the 1995-2000 period (commissioning of nuclear plants under construction in France) to reach 136.4 GW (representing 22% to 23% of total installed capacity).

The short-term forecasts about electricity production from nuclear plants assume high average reliability of the plants and hence high utilisation rates. This has been confirmed in the statistics for the period 1995 to 1999, except for some contrary cases that represent a small fraction of total existing plants. If the average reliability comes back in the coming decade at historically average levels (which are lower than those assumed in the baseline) then electricity production from nuclear will be lower and the impacts on CO_2 will be adverse.

6.2.2. What is the basic mechanism reflected in the PRIMES baseline scenario towards 2010?

The baseline assumptions on nuclear capacity have taken into account decommissioning schedules that have been confirmed by national experts and authorities within the process of the Shared Analysis study in 1999. It is assumed that ongoing projects building new nuclear capacity (in France and Finland) will be completed before 2010. Because of the short time horizon to 2010 it is assumed that there will be no additional potential for further nuclear capacity expansion. The discussions in Germany and Belgium regarding nuclear strategy do not affect the situation up to 2010. At the EU level the baseline scenario can be described shortly as follows:

- In absolute terms, nuclear production will increase from 2000 to 2010 by 1.5% to reach 895 TWh reflecting possible higher utilisation rates for existing plants. However, the share of nuclear power in total electricity production drops to 29.5% in 2010 (from 35% in 1995 and 2000).
- Installed nuclear capacity will remain stable (at 135.8 GW in 2010, including new commissioning of plants at present under construction). As total electricity demand increases, the share of nuclear in total power capacity will decrease to 18.3% in 2010 from 22.3% in 2000.

Table 28: Nuclear power in the baseline

	in 1995		in 2000		in 2010	
Country	GW Installed	as % of total installed capacity	GW Installed	as % of total installed capacity	GW Installed	as % of total installed capacity
Belgium	5.9	37.3	5.9	37.2	5.9	28.3
Finland	2.4	15.9	2.4	14.6	2.6	14.5
France	66.7	56.8	71.9	58.5	71.9	52.7
Germany	25.1	21.3	25.1	21.2	24.7	18.8
Netherlands	0.5	2.6	0.5	2.4	0.0	0.0
Spain	7.5	16.2	7.5	15.1	7.5	11.7
Sweden	10.4	30.0	9.8	26.8	9.8	26.3
United Kingdom	13.4	16.2	13.4	14.0	12.7	10.2
TOTAL EU	131.9	23.1	136.4	22.3	135.1	18.8
	in 1995		in 2000		in 2010	
Country	TWh produced	as % of total electricity production	TWh produced	as % of total electricity production	TWh produced	as % of total electricity production
Belgium	41	56.2	47	54.2	45	45.1
Finland	19	30.1	21	27.2	22	24.7
France	377	77.0	411	75.6	432	73.4
Germany	154	29.0	170	31.0	168	27.6
Netherlands	4	5.0	4	4.4	0	0.0
Spain	55	33.6	58	30.2	58	23.2
Sweden	70	47.2	70	45.1	70	43.2
United Kingdom	89	26.7	100	26.3	101	20.8
TOTAL EU	810	35.1	880	34.4	895	29.6

Source: PRIMES

6.2.3. How does the sector adjust when the system meets the Kyoto target for 2010?

Emission constraints in a short horizon, like that of 2010, cannot significantly affect nuclear energy. Capacity expansion is not possible given the long lead-times needed for nuclear commissioning. Nuclear energy being free of carbon has to be used as much as possible to comply with the emission reduction target at least cost. Therefore under emission restrictions nuclear capacities are utilised at maximum rates, despite the relative decrease of total electricity production due to the adoption of demand–side electricity saving measures in emission limitation scenarios. Under baseline conditions there is also interest to maximise the use of existing nuclear capacity, for economic reasons (low variable operating costs).

Therefore, within the horizon to 2010 and under the Kyoto emission reduction constraint, nuclear electricity generation remains stable at the level of the baseline. As total electricity demand decreases, the share of nuclear electricity increases, so nuclear energy contributes to CO_2 emissions reduction. Under the Kyoto constraint, the contribution of nuclear energy to CO_2 emissions reduction in the power and steam generation sector is about 17%.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

For the reasons mentioned above the system facing higher emission reduction targets cannot readily affect nuclear electricity in the short horizon to 2010. Within such a horizon the potential for nuclear production may reach TWh per year, which represents roughly a share of 30% that may be even higher when total electricity production decreases because of demand-side saving measures.

6.3. Changes in the fuel mix and Cogeneration

6.3.1. Sector coverage in PRIMES

Because of the importance of power generation in meeting future energy needs, the possible development of cogeneration of heat and power and the possible emergence of various types of new players (generators) in the market, the PRIMES model represents the whole power and steam/heat production sector in the same sub-model. The modelling includes the following cases:

- Power generation by utilities and independent power producers
- Cogeneration in large plants belonging to utilities, usually through a backpressure technology; possibility to deliver steam/heat to industrial users or to district heating networks
- Cogeneration of industrial steam through various technologies (extracting-condensing) that may vary in their heat-to-power ratio; competition with generation using industrial boilers with or without heat recovery from industrial processing plants
- Steam and power units of refineries
- Cogeneration and boilers that produce heat distributed in district heating networks; consideration of large and small district heating or cooling networks for both the residential and the tertiary sectors.

6.3.2. Foundations of the baseline scenario

Starting from 1999, the European Union has established a progressive liberalisation of the electricity market. Although probably not reflected in the official statistics that are available for the period 1995 to 1997, there is evidence that the electricity market players have anticipated the liberalisation developments even before 1999. They have therefore undergone changes in their choices about fuel and technology of plants. Under the new market conditions, the investors seek a higher return on capital than public utilities have in the past and generally prefer choices involving lower capital expenditure in response to increased perceived risks associated with the more competitive market environment.

These market developments coincide with the spectacular progress in the gas turbine technologies and the ensuing dramatic improvement of the efficiency of gas turbine combined cycle plants.

As has been analysed in detail in the recently published "European Union Energy Outlook to 2020", the drivers of change in the liberalised electricity market are mainly the gas-firing power technologies. The gas turbine combined cycle technologies, the simple gas turbines, the steam-injection CHP gas turbines and similar technologies at different plant sizes; they have all exhibited considerable progress over the recent years in both their costs and efficiency. In addition these technologies have enabled closing the gap in cost terms between small and large generators, a gap that has contributed to highly centralised generation in the past. Under market conditions such cost-efficient technologies, with small cost-size gradient, enable the emergence of new players in the market, including small generators, auto-producers, middle-size independent producers, etc. It is assumed that these factors drive diversification in power generation, decentralisation of conversion and the emergence of a variety of new generators exploiting the economic opportunities.

These factors (technology and market) also drive the development of cogeneration under baseline conditions. It should be stressed that the baseline scenario assumes low natural gas prices in the coming decade. If gas prices evolved differently (for example because of high oil prices driving gas prices up) the development of cogeneration would be much lower than projected in the current analysis. Similarly, high gas prices would have a considerable impact on the fuel mix, offsetting the expected shifts in favour of gas and to the detriment of solid fuels. The analysis has identified that the power sector will be very sensitive to the price of natural gas and its competitiveness vis-à-vis solid fuels in the coming two decades.

Regarding cogeneration of power and steam, three cases are considered:

- Small-scale cogeneration that exploit a niche market. There are many examples: cogeneration using landfill gas and waste also justified in terms of the costs of waste management; specific industrial processes that use high volume and base-load steam; large complexes of office buildings that may cover high demand for heating, cooling and electricity through cogeneration. Those cases of small-scale cogeneration might not have been exploited in the past for many reasons ranging from technology availability to monopolistic market protection. It is expected that such cases will develop strongly in the context of liberalised markets.
- Medium-scale cogeneration (mostly industrial). Its development can be partly justified because of auto-consumption of steam/electricity but certainly needs attractive electricity market prices to develop. These cases become economically attractive when the generator can build bigger cogeneration plants than the size of his needs in order to be competitive and sell substantial excess quantities of electricity to the market. The success of these cases in the market is uncertain and will depend on many factors, including market prices and market power. For example, if powerful market players decrease the electricity market prices and

use in excess their old reserve capacities, middle size cogeneration could suffer because its success largely depends on its competitiveness in the electricity market. This explains why cogeneration effectively suffers in some Member States, at present.

- Large-scale cogeneration based on the massive waste heat of large power generation plants of utilities. Except some small-scale niche-market opportunities, there are few chances to observe development of these cases under the liberalised market. Massive investments in district heating networks are needed to develop large-scale cogeneration, which are unlikely to be financed under market liberalisation conditions.

The cost-effectiveness of gas powered technologies in enabling conversion decentralisation and cogeneration also depends on the relative price of natural gas when comparing gas contracts of large utilities to prices for small generators and co-generators. To facilitate the deployment of the latter in the liberalised markets, the differential of gas prices relative to the size of the consumer has to decrease. Gas market liberalisation, gas-to-gas competition and the establishment of multiple gas trading transactions in Europe could greatly drive fair pricing in the gas supply market. This is the aim of the gas market liberalisation, also established by the European Union, as an essential complement to the electricity market liberalisation.

The baseline scenario assumes that these joint expected developments will succeed. The analysis showed that a fundamental condition is that primary gas supply prices remain relatively competitive allowing for substantial fuel mix shifts in favour of gas (and to the detriment of solid fuels, mostly hard coal), the decentralisation of generation, the exploitation of the economic potential of cogeneration (both for industrial steam and district heating) and the general lowering of prices. Evidently such developments are favourable to the environment, regarding both acidification and climate change.

6.3.3. Is the current PRIMES baseline still valid?

All recent information and statistics confirm the rapid penetration of natural gas in power generation and cogeneration. Generation from solid fuels is reduced, especially from hard coal (generation from lignite is rather stable). Also generation from oil is reduced.

A comparison between latest EUROSTAT statistics and the PRIMES projection for the short run regarding the evolution of fossil fuels in power and steam generation is provided in Table 29.The PRIMES projection for the short-term horizon to 2000 seems in line with the evolution of transformation input in the 1995-1997 period.

As projected by PRIMES, the growth of electricity produced from natural gas between 1995 and 2000 (+72%) is well above the corresponding growth in steam produced by natural gas. This is due to the fact that the commissioning of new GTCC plants is currently the main cause for the rapid penetration of natural gas.

Capacity in GTCC plants more than doubles in 2000 reaching 59 GW (10% of total installed capacity) compared to 24.5 GW in 1995 (4.5% of total installed capacity). Capacity of other thermal power plants decreases by more than 10 GW in the same period. For the limited time horizon to 2000 both capacity expansion and decommissioning have been crosschecked with statistical information available at the latest EURPROG report of UNIPEDE.

Table 29: Transformation input of fossil fuels in power and steam generation (in Mtoe) for the short-run

	EUROSTAT statistics			PRIMES results		
	1995	1997	% change	1995	2000	% change
Total fossil	269	264	-1.9	343	350	2.1
Solid fuels	164	150	-8.5	171	150	-12.5
Liquid fuels	45	40	-10.8	89	78	-12.0
Natural gas	61	75	22.8	77	116	50.7

Source: PRIMES

The shift towards natural gas leads to an improvement of energy efficiency in electricity production by 3 percentage points between 1995 and 2000 (from 35% to 38%).

In 1995, about 9% of electricity production and 46.5% of steam production was produced by cogeneration (CHP) units. According to the latest EUROSTAT statistics steam production from CHP units increased by 13.5% between 1995 and 1997. The PRIMES projection for 2000 indicates an increase of 8% in steam production from CHP units since 1995 (representing more than 48% of total steam produced in 2000).

A strong increase in electricity production from CHP units (+23.5% from 1995 to 2000 accounting for more than 10% of total electricity production in 2000) is also projected. According to the latest information available from the European Association for the Promotion of Cogeneration (COGEN Europe) in 1999, effectively about 10% of total electricity production in the EU was from CHP units.

On the basis of capacity expansion and decommissioning plans as available at the latest report EURPROG report of UNIPEDE and other statistical sources (e.g. EPIC) the capacity of cogeneration units increases between 1995 and 2000 by 17 GW to reach 13.5% of total installed capacity (11% in 1995). The bulk of the investment in cogeneration plants concerns natural gas fired units (mainly commissioned by independent producers) the capacity of which increases by 11 GW in 2000 from 1995 levels. Total CHP capacity in the EU is at present around 82 GW.

Table 30: Evolution of electricity production from fossil fuels, EU 2000-2010

Electricity production, TWh (incl. Cogeneration)	1995	2000	2010	% change 2000-2010
Total fossil	1171	1299	1688	44.2
Solid fuels	670	575	499	-25.5
Liquid fuels (excl. refinery gas)	179	170	105	-41.7
Natural gas and other gas fuels	322	554	1085	237.1
% in total electricity production	50.8	50.7	55.8	
Installed capacities, GW (incl. Cogeneration)	1995	2000	2010	increment 2000-2010
Total thermal	325.1	352.6	443.6	91.0
of which GTCC	24.5	59.0	208.6	149.5
% in total installed capacity	57.0	57.6	61.9	

Source: PRIMES

In some Member States there are signs that the drop in electricity market prices that is due to market liberalisation caused a slowdown, even a closure, of some cogeneration projects and plants. Reports (from COGEN Europe) indicate that this is more noticeable in Germany. The PRIMES results for the short-term do confirm such a trend. For example industrial steam produced with CHP is projected to decrease in Germany in 2000 compared to 1995. This is due to the combined effect of abandoning backpressure technologies because gas-turbine techniques are more competitive in the context of the liberalised market, and the fall of electricity market prices. However, the PRIMES baseline scenario, assumes that this is a temporary phenomenon and that in the longer term, when there will be no more possibilities for drastically lower prices (since initial rents will vanish), the economic opportunities for cogeneration will be exploited. As a consequence the baseline scenario is optimistic about the development of cogeneration in a horizon to 2010, in all Member States including Germany.

The further penetration of natural gas is confirmed in the baseline scenario as shown in the following (see also Table 30):

- Capacity of GTCC plants is projected to increase to 210 GW (30% of total installed capacity) in 2010 (+150 GW from 2000 level). Installed capacities of thermal power plants increase by 91 GW in the same period (capacities in other thermal plants decreasing by more than 80 GW between 2000 and 2010). This means that the GTCC technology remains the dominant choice in the EU power generation system in the horizon to 2010.
- Electricity production from natural gas reaches 36% of total electricity produced (21.5% in 2000) corresponding to a growth of 96% from 2000 to 2010 (+530 TWh). Electricity production from coal decreases by 13% in 2010 while that from oil products decreases by almost 40%.

In the baseline energy efficiency of electricity generation improves further as a result of investing in GTCC power plants and reaches on average 43.5% in 2010 (38% in 2000), which is unprecedented in the history of power generation. At low gas prices, this restructuring also allows for unprecedented low electricity generation costs explaining why prices drop and technologies such as renewables and nuclear become economically less attractive and hardly penetrate the market in a horizon to 2010. Furthermore the shift towards natural gas leads to an improvement of carbon intensity in power and steam generation by 11% from 2000 (20% better than 1995).

Table 31: Evolution of cogeneration under baseline, EU 2000-2010

	2000	2010	% change
Cogeneration production (TWh)			
Electricity	259	478	84.2
Steam	539	802	48.9
Shares in %			
Share of CHP in Electricity Generation	10.1	15.8	
Share of CHP in Steam Generation	48.1	61.9	

Source: PRIMES

Table 32: Cogeneration capacities under baseline, EU 2000-2010

Country	in 1995		in 2000		in 2010	
	GW Installed	as % of total installed capacity	GW Installed	as % of total installed capacity	GW Installed	as % of total installed capacity
Austria	2.9	16.3	3.1	16.9	4.6	21.2
Belgium	2.0	12.9	1.8	11.6	3.4	16.3
Denmark	7.2	64.8	8.1	66.6	7.0	53.1
Finland	5.9	39.3	6.5	39.9	8.6	47.0
France	3.0	2.5	2.9	2.4	10.1	7.4
Germany	18.6	15.8	22.4	19.0	23.6	17.9
Greece	0.4	4.7	0.7	5.9	1.0	6.8
Ireland	0.1	2.5	0.1	1.9	0.3	4.4
Italy	6.7	9.8	10.9	14.0	10.2	12.0
Netherlands	6.4	30.3	9.1	40.9	14.0	48.3
Portugal	0.8	8.2	0.9	8.5	1.4	9.5
Spain	2.1	4.6	2.4	4.8	6.4	9.9
Sweden	3.5	10.1	5.6	15.3	8.1	21.7
United Kingdom	5.1	6.2	7.3	7.6	36.6	29.4
TOTAL EU	64.7	11.4	81.8	13.4	134.9	18.8

Source: PRIMES

In terms of steam generation, the share of cogeneration increases steadily in the baseline and reaches 62% by 2010 (from 48% in 2000). Industrial steam remains the driver for this evolution, while the developments in the domestic sector (households and tertiary) are noticeable and start becoming a substantial market for co-generated heating and cooling.

Electricity generation from cogeneration plants exhibits also a significant increase of almost 85% between 2000 and 2010. As a result the share of electricity produced by cogeneration units reaches 16% in 2010 from 10% in 2000.

The above results imply that with current policies and competitive natural gas prices the prospects for developing cogeneration are very favourable. Total installed capacity of cogeneration units could increase under baseline conditions by 53 GW and amount to 135 GW in 2010 (19% of total installed capacity) in the EU. As can be seen in Table 32 the market opportunities for cogeneration differ significantly across EU Member States. These reflect structural characteristics of the power and steam generation sector (as is the case of France), demand structure and volume, for example Greece and Ireland with few energy intensive industrial sectors, and natural gas supply conditions. Investment in cogeneration units between 2000 and 2010 is close to 70 GW. About 60 GW are based on GTCC technologies and small gas turbine units.

Table 33: Production from cogeneration in the baseline, EU 2000-2010

Country	in 1995		in 2000		in 2010	
	TWh	as % of total electricity production	TWh	as % of total electricity production	TWh	as % of total electricity production
Austria	9.2	16.7	10.4	17.9	13.8	20.2
Belgium	3.4	4.7	5.4	6.2	9.3	9.3
Denmark	13.8	37.4	19.1	47.6	21.0	47.4
Finland	20.9	32.8	32.4	42.9	45.3	49.9
France	8.1	1.7	9.9	1.8	33.7	5.7
Germany	37.0	7.0	41.6	7.6	95.9	15.8
Greece	0.7	1.8	1.0	1.9	3.2	4.5
Ireland	0.4	2.5	0.8	3.3	1.8	5.4
Italy	28.7	12.1	42.2	15.5	55.4	16.6
Netherlands	25.0	30.8	35.9	38.6	57.6	44.6
Portugal	3.4	10.3	3.4	8.2	7.2	11.3
Spain	11.3	6.9	12.2	6.4	30.3	12.1
Sweden	9.6	6.5	18.3	11.7	23.0	14.3
United Kingdom	38.4	11.6	26.7	7.0	80.0	16.6
TOTAL EU	210.0	9.1	259.4	10.1	477.6	15.8

Source: PRIMES

Table 34: Industrial steam production from CHP units in the baseline, EU

Country	in 1995		in 2000		in 2010	
	TWh	as % of industrial steam demand	TWh	as % of industrial steam demand	TWh	as % of industrial steam demand
Austria	13.8	94.4	13.7	86.8	16.6	92.8
Belgium	6.0	23.9	7.1	26.0	12.3	40.2
Denmark	0.5	4.3	1.6	12.2	5.6	40.6
Finland	45.5	95.8	53.9	97.2	62.5	92.9
France	29.3	24.5	33.2	26.4	56.4	43.0
Germany	53.4	30.0	36.0	20.8	106.5	53.7
Greece	0.1	1.3	1.2	11.6	4.2	42.0
Ireland	1.4	26.8	2.1	33.0	3.4	40.6
Italy	73.6	60.6	65.0	52.4	93.6	68.4
Netherlands	30.1	40.0	36.8	45.8	56.7	59.4
Portugal	12.1	77.8	9.7	63.5	15.5	87.5
Spain	23.9	34.6	28.0	40.1	47.2	61.3
Sweden	15.4	35.6	23.9	53.2	27.3	58.4
United Kingdom	62.6	52.4	64.6	51.8	94.0	65.4
TOTAL EU	367.8	42.9	376.7	42.5	601.7	60.5

Source: PRIMES

6.3.4. How does the sector adjust when the system meets the Kyoto target for 2010?

As mentioned earlier, the power and steam generation system of the EU seems to be the sector that can adjust in the most cost-effective way so as to reduce emissions within the perspective of complying with the Kyoto commitment of Europe. The systems analysis has shown that the power and steam generation system is more flexible and can undertake a larger emission reduction obligation than other sectors. In this light the overall emission reduction imposed by Kyoto translates into substantially lower carbon intensity (carbon emissions per unit of output generated). This is obtained roughly half by using more carbon free sources (mostly renewables) per unit of output, and half by using more natural gas per unit of output produced by fossil energy.

Regarding the fossil fuel mix, whereas in the baseline scenario solid fuels and gas accounted for roughly 47% and 35% respectively, there is a radical reversal when complying with the Kyoto commitment. As a share of total electricity produced by fossil fuels, the share of gas in the baseline (64%) goes up to 80% in the emission reduction case. The systems analysis shows that this is one of the most cost-effective measures.

The change in fuel mix is possible through further investment in GTCC power plants and the under-utilisation of existing capacities for other thermal power plants.

- Capacity of GTCC plants exceeds 220 GW in 2010 (+10 GW from baseline). Higher utilisation rates for GTCC plants leads to a more significant increase of electricity production from natural gas (1222 TWh, +12.5% from baseline levels) accounting for 41.5% of total electricity production (36% in baseline).
- The share of solid fuels in total electricity production drops to 7.5% (16.5% in the baseline) corresponding to a decrease in input for power and steam generation of more than 75 Mtoe (-55% from baseline levels). Similarly, consumption of liquid fuels in power and steam generation decreases by about 20 Mtoe from baseline levels. The share of liquids in total electricity production decreases from 3.5% in the baseline to 2.5%.
- Capacity of thermal power plants (except GTCC) remains stable at baseline levels indicating significant under-utilisation.
- Thermal efficiency of power plants for electricity generation reaches 46%, higher by almost 3 percentage points compared to the baseline, while carbon intensity in power and steam generation decreases by 20% compared to the baseline. This is, however, the combined effect of changes in the fuel mix and the increased use of nuclear and renewable energy forms.

In total, changes in the fuel mix are the most important factor in CO_2 emissions reduction in power and steam generation accounting for 55% of the reduction achieved. The fuel mix in favour of natural gas implies a 6% increase gas imports to the EU from the baseline. This from a security of supply point-of-view is quite manageable. The increase is rather small partly because total electricity production decreases as a result of demand-side electricity saving measures.

Compared with the developments in the baseline to the 2010 horizon, only a small further penetration of heat and power cogeneration is observed when the system is required to meet the Kyoto target. The analysis shows that at the system level there exist other more cost-effective measures to meet the Kyoto target than substantially expanding cogeneration. The same analysis also shows that, in the presence of more ambitious emission reduction targets, further expansion of cogeneration becomes one of the cost-effective measures.

For the Kyoto target, the analysis indicates priority for measures such as steam/heat savings on the demand side, electricity savings, expansion of renewables and higher investment in base-load large GTCC plants. The baseline capacity cogeneration is already considerable in 2010 because of market liberalisation, low gas prices and technological progress. Under these circumstances, cogeneration seems to exploit the most economical opportunities, in cases such as heavy users of steam, use of landfill gas, and other niche-type of markets. Expanding beyond that level does not seem a priority, unless ambitious emission reduction targets are set, implying the power and steam system having to face high costs.

The systems analysis reveals that there are some non-linearities in the expansion of cogeneration under various emission reduction levels. There is slow development under low emission targets, also due to the high development of cogeneration in the baseline, and then considerable acceleration beyond a certain threshold regarding emission targets and costs. An engineering analysis on a project-by-project basis would show that cogeneration is beneficial for emissions and very cost-effective. However, after exploiting the most economic potential (as it already happens in the baseline), the cost-effectiveness of additional cogeneration projects may be obstructed by the following factors: a) cogeneration is also using fossil fuels, so carbon-free sources having higher priority reduce the potential of cogeneration, b) demand-side saving of steam and heat also reduces the potential of cogeneration, c) expanding further base-load GTCC plants to gain maximum electricity generation efficiency also limits the market opportunities of cogenerators to sell excess electricity to the grid.

How the sector adjusts to allow for higher emission abatement?
(This section contains additional information and can be ignored if the focus is the first commitment period (2008-2012) of the Kyoto Protocol)

When the energy system, as a whole, is expected to reduce emissions of carbon more (for example to meet a target two or four times stricter than Kyoto), then the easy adjustment possibilities for the power generation sector are rapidly exhausted. In the domain of fuel mix changes few additional possibilities exist.

High emission reduction targets induce a significant decrease of demand for electricity and steam as a consequence of demand-side measures. The drop in demand can reach 22.5% and 20% respectively compared to baseline. Despite this decrease nuclear electricity experiences a slight increase while the penetration of renewable energy forms (especially wind energy) is also accelerated. So priority is given to power generation by carbon free sources. The remaining load for thermal fossil power plants is significantly altered: the load is smaller in volume and different in shape (smaller part in base-load). This induces changes in the technology choices of generators. The systems analysis shows that under ambitious emission reduction targets, the following changes in the domain of fossil fuels are cost-effective in the power generation sector:

- Further contribution of GTCC technologies is not possible. GTCC plants have to operate close to base-load to obtain the high efficiency of the combined cycle. If they operate more in load following mode, their efficiency decreases sharply, reaching that of simple gas turbines, which can be as low as 38%. As a result in the context of high emission reduction targets they are not so attractive and lose market share in terms of capacity, dropping down to less than 20% of total installed capacity for an emission reduction target four times higher than Kyoto (55 GW less than in baseline where GTCC plants accounted for 30% of total installed capacity).

- Fuel cells, despite their high cost, reach 20GW or 3% of the market from almost zero in the context of the Kyoto target. Additional investments are also projected for ultra-supercritical plants, the capacity of which increases by 18GW from baseline levels. Of course fuel cells at the same time provide efficient cogeneration which also contributes to emission reduction.

The share of electricity generation from fossil fuels drops to 40% of total production (51.5% under Kyoto, 56% in baseline). The corresponding shares for natural gas are 32%, 41.5% and 36%.

The contribution of further changes in the fuel mix to total emissions reduction in power and steam generation becomes more and more limited as higher emission reduction targets are analysed at system-wide level. While under the Kyoto constraint they are very cost-effective (accounting for 55% of CO_2 emissions reduction in power and steam generation), in the case of stricter emission reduction targets their economic potential becomes limited. For example in the case of an emission reduction target "four times Kyoto" the contribution of changes in the fuel mix to emissions reduction in power and steam generation drops to 18%.

When the system faces ambitious emission reduction targets, the contribution of cogeneration becomes substantial and combines with progressive decentralisation of generation. Further expansion of large GTCC technology is not anymore a cost-effective priority; instead fuel cells and efficient gas turbines with steam injection expand more. These technologies are amenable to cogeneration applications and are also suitable for decentralised siting. Nevertheless the contribution of carbon free sources (mostly renewables) and demand-side savings becomes more and more important, a trend that restricts the market domain for the development of cogeneration. However, despite this market segment reduction, cogeneration expands substantially.

The above results are very sensitive with respect to the price and other supply conditions of the fuels used in power and steam generation. The following elements are crucial:

- The expectations about secure supply of natural gas at low prices. Under pessimistic expectations, the above-mentioned role of natural gas and GTCC technology could be neutralised.
- The development of infrastructure and agricultural measures to obtain a higher supply potential for biomass; this could greatly facilitate the development of cogeneration under carbon restrictions and could lead to very different conclusions regarding the potential of cogeneration in Europe.

Table 35: Electricity production from fossil fuels under different emission reduction constraints

	Baseline				Kyoto			
	Total from fossil	of which from Natural Gas	Fossils in total electricity production	Carbon intensity	Total from fossil	of which from Natural Gas	Fossils in total electricity production	Carbon intensity
	TWh		%	t of CO2 per MWh	TWh		%	t of CO2 per MWh
Austria	24.8	23.7	36.2	0.13	20.4	19.8	30.7	0.11
Belgium	51.7	47.6	51.5	0.21	45.2	44.1	45.2	0.18
Denmark	34.1	15.5	76.8	0.29	29.0	21.3	70.5	0.21
Finland	43.2	16.3	47.6	0.21	36.4	24.3	41.2	0.14
France	77.3	57.6	13.2	0.09	86.2	76.1	14.2	0.08
Germany	384.1	174.3	63.3	0.37	336.0	210.5	58.6	0.30
Greece	64.0	20.9	89.8	0.65	53.0	21.8	84.6	0.55
Ireland	30.9	22.1	91.3	0.41	25.8	20.8	82.1	0.33
Italy	278.8	205.8	83.3	0.34	256.3	244.8	79.7	0.26
Netherlands	124.6	105.7	96.4	0.30	112.9	112.1	93.0	0.25
Portugal	48.2	26.7	76.2	0.38	41.0	36.1	69.4	0.22
Spain	141.5	77.3	56.7	0.31	117.1	87.8	48.1	0.22
Sweden	16.6	7.0	10.3	0.06	13.6	8.3	8.5	0.05
United Kingdom	368.7	284.5	76.4	0.32	339.7	294.4	73.1	0.27
TOTAL EU	1688.3	1085.1	55.8	0.27	1512.5	1222.2	51.4	0.21
	Two times Kyoto				Four times Kyoto			
	Total from fossil	of which from Natural Gas	Fossils in total electricity production	Carbon intensity	Total from fossil	of which from Natural Gas	Fossils in total electricity production	Carbon intensity
	TWh		%	t of CO2 per MWh	TWh		%	t of CO2 per MWh
Austria	18.5	17.9	28.2	0.10	12.2	11.4	20.2	0.08
Belgium	42.3	41.6	42.6	0.16	27.5	27.0	31.4	0.13
Denmark	27.1	23.3	68.7	0.18	13.4	11.3	41.0	0.12
Finland	31.9	25.8	37.1	0.12	20.2	18.7	26.7	0.09
France	79.2	69.8	13.1	0.08	40.3	34.6	7.1	0.06
Germany	291.8	180.3	52.5	0.26	215.4	107.4	43.8	0.24
Greece	47.6	17.2	82.7	0.56	36.2	5.3	80.6	0.63
Ireland	22.5	19.7	75.1	0.28	16.9	14.9	65.1	0.23
Italy	237.0	233.8	77.0	0.24	195.5	194.7	71.6	0.21
Netherlands	107.5	106.8	92.4	0.25	86.9	86.3	85.7	0.22
Portugal	36.1	32.5	63.3	0.20	24.3	24.0	50.3	0.15
Spain	94.7	70.1	40.9	0.18	66.7	47.7	32.2	0.14
Sweden	11.4	8.1	7.2	0.04	7.1	5.1	4.7	0.03
United Kingdom	323.5	290.1	72.2	0.26	246.7	229.9	63.9	0.22
TOTAL EU	1371.3	1137.1	48.0	0.19	1009.1	818.5	39.5	0.16

Source: PRIMES

Table 36: Electricity production from CHP under different emission reduction constraints

TWh	Baseline	Kyoto	Two times Kyoto	Four times Kyoto
Austria	13.8	14.0	13.5	9.7
Belgium	9.3	9.3	9.4	10.6
Denmark	21.0	14.5	14.4	11.6
Finland	45.3	42.0	42.7	33.6
France	33.7	36.1	38.8	24.4
Germany	95.9	80.1	88.0	70.9
Greece	3.2	3.3	2.7	4.3
Ireland	1.8	1.9	2.1	4.0
Italy	55.4	50.9	54.9	76.1
Netherlands	57.6	60.1	56.1	62.2
Portugal	7.2	5.5	6.3	7.3
Spain	30.3	31.9	31.3	41.7
Sweden	23.0	23.2	22.0	20.2
United Kingdom	80.0	74.0	68.1	81.7
TOTAL EU	477.6	447.0	450.4	458.3
% in total electricity	Baseline	Kyoto	Two times Kyoto	Four times Kyoto
Austria	20.2	21.1	20.6	16.2
Belgium	9.3	9.3	9.5	12.0
Denmark	47.4	35.3	36.5	35.7
Finland	49.9	47.6	49.6	44.4
France	5.7	5.9	6.4	4.3
Germany	15.8	14.0	15.8	14.4
Greece	4.5	5.3	4.6	9.5
Ireland	5.4	6.1	7.0	15.4
Italy	16.6	15.8	17.8	27.8
Netherlands	44.6	49.6	48.2	61.4
Portugal	11.3	9.4	11.1	15.2
Spain	12.1	13.1	13.6	20.1
Sweden	14.3	14.6	13.9	13.5
United Kingdom	16.6	15.9	15.2	21.2
TOTAL EU	15.8	15.2	15.8	17.9

Source: PRIMES

6.4. Conclusion

One of the major conclusions to emerge from this analysis is the crucial role that the electricity and steam generation may be called 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 the sector are not only due to market forces, such as the relative price 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 Baseline scenario) and transparency on fuel costs are of great importance. These include non-fossil fuel obligations, subsidies or other measures in support of renewables, difficulties of insurance for nuclear plants, fair tariffs for co-generation, R&D support for promising generation technologies etc. Thus, the task of the regulator becomes even more important in monitoring and ensuring the implementation of a number of potential policy initiatives related to the sector.

7. Allocation of effort among sectors and emissions

7.1. Introduction

According to the undertakings in the Kyoto Protocol of December 1997, the EU is committed to reduce its greenhouse gas (GHGs) emissions in the 2008-12 period to a level that is 8% below that of 1990. This is equivalent to a reduction of GHGs in 2010 by about 316 Mt CO_2 from their 3938 Mt CO_2-equivalent level in 1990.[32] The GHGs covered are CO_2 (energy and non-energy related emissions), methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride. For the three synthetic gases the protocol gives countries the option of using 1995 as base year.

In the context of the study, a meta-model was constructed in order to evaluate the potential contribution of the different Member States and sectors in achieving the Kyoto targets. The analysis combined marginal abatement cost curves regarding both CO2 (constructed by using the PRIMES model, i.e. following a top-down approach) and non-CO2 emissions (derived from the GENESIS bottom-up analysis[33]) by Member State.

7.2. Methodology

Carbon constraints have been applied as global constraints in solving the PRIMES model in order to arrive at the preferred allocation of energy and emissions reduction, as suggested by the model itself.

The mechanism through which the carbon constraint is attained involves the attribution of an appropriate economic value to the reduction of emissions of carbon. Equivalently, the ability to emit carbon obtains a scarcity value and is allocated an implicit price. There are corresponding changes in the relative prices, reflecting the carbon emissions that each commodity or activity involves, and which economic agents, i.e. producers and consumers of energy, have to face. This, of course, leads to adjustments in the behaviour of agents. The latter tend to shift away from activities that involve emissions.

The analysis starts from the baseline scenario, which reflects policies and trends without including specific efforts to reduce CO_2 emissions. Starting from the baseline, for each scenario the model was run in order to compute the least cost solution corresponding to the level of CO_2 emissions in 2010 that is implied by the constraint. The model determines the allocation of effort by sector within each Member State that is necessary to meet the global constraint, implicitly assuming the existence of a full trading regime of emissions within the country.

The analysis focuses on the differences between the results of each emissions reduction scenario and the results of the baseline. These differences span the whole energy system, showing changes that are necessary to reach the lower emission level at least overall cost. Such changes, as already discussed in previous chapters may concern behaviour in using energy, structural changes in energy uses and processes, possible accelerated adoption of new technologies, changes in the fuel mix, etc. The exploration of the series of least cost solutions, varying according to the magnitude of the emission reduction level, provides an extensive set of information revealing the priority of changes that are cost effective by

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[32] All quantities of GHGs in this chapter refer to megatonnes (10^6) of CO_2 equivalent.

[33] 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

sector and country, and their nature. This information can be used to support the design of concrete policies and measures.

The model provides simultaneous estimations of the marginal cost of avoided emissions and of the energy system costs of these changes, by sector and Member State. Following a least cost methodology, the marginal costs plotted against the varying levels of emission reduction (i.e. the model-based marginal abatement cost for CO2 emissions) can be used as a basis for defining a distribution of the emission reduction effort by country and by sector.

The corresponding marginal abatement cost curves for non-CO2 greenhouse gases have been constructed on the basis of the bottom-up analysis performed on the possible measures and their impacts in reducing non-CO2 greenhouse gases (by ordering measures in an ascending cost order against cumulative non-CO2 greenhouse gases reduction).

7.3. Results of the meta-model

Under reasonable assumptions for the period to 2010 (the baseline scenario), it is unlikely that the EU will meet its Kyoto undertakings, total greenhouse gases emissions increasing by 3.2%. Table 37 illustrates the projected emission growth for greenhouse gases under baseline conditions by Member State. As can be seen, while CO2 emissions are projected (through the use of PRIMES model) to increase by 6.7% between 1990 and 2010, emissions for non-CO2 greenhouse gases are projected (through bottom-up analysis performed by ECOFYS) to exhibit a decrease of 6.8% in the same period.

Table 37: Evolution of greenhouse gas emissions under baseline conditions excluding the ACEA Agreement

	CO2 emissions			non-CO2 greenhouse gases emissions			total greenhouse gases emissions		
	Mt CO2 eq.		% change	Mt CO2 eq.		% change	Mt CO2 eq.		% change
	1990	2010		1990	2010		1990	2010	
Austria	55.0	54.7	-0.4	25.7	28.5	10.7	80.7	83.2	3.2
Belgium	104.8	124.3	18.6	33.7	35.1	4.2	138.5	159.4	15.1
Denmark	52.7	54.5	3.5	21.3	20.2	-4.9	73.9	74.7	1.1
Finland	51.3	73.6	43.3	14.9	14.0	-5.8	66.3	87.6	32.2
France	352.4	389.0	10.4	188.0	175.7	-6.5	540.4	564.7	4.5
Germany	951.6	820.7	-13.8	231.5	187.4	-19.1	1183.1	1008.1	-14.8
Greece	70.9	107.5	51.6	27.5	27.4	-0.2	98.4	134.9	37.1
Ireland	30.1	42.7	42.0	27.8	31.5	13.2	57.8	74.1	28.1
Italy	388.0	429.2	10.6	127.7	131.6	3.1	515.7	560.8	8.7
Netherlands	153.0	205.1	34.0	57.5	51.8	-10.0	210.5	256.8	22.0
Portugal	39.1	66.4	70.0	25.3	27.3	7.9	64.3	93.7	45.6
Spain	201.9	272.9	35.2	101.5	107.9	6.4	303.3	380.8	25.6
Sweden	50.5	62.8	24.2	19.2	23.1	20.4	69.8	85.9	23.2
United Kingdom	566.9	570.9	0.7	167.6	134.1	-20.0	734.5	705.0	-4.0
TOTAL EU	3068.1	3274.1	6.7	1070.2	996.9	-6.8	4138.3	4271.0	3.2

Source: PRIMES, ECOFYS, AEA Technologies

There are very large differences in the trends of greenhouse gas emissions growth among EU Member States. Only two Member States manage to reduce emissions below 1990 namely, Germany and United Kingdom. In Austria, Denmark and France a near stabilisation of emissions in 2010 at their 1990 level is observed. In all other Member States there are significant increases in emissions between 1990 and 2010 varying from 8.7 % in Italy to more than 45 % in Portugal. These huge divergences between EU countries reflect a large number of factors including economic growth and changing market structures.

In addition to the above, a variant was examined so as to estimate the potential impact of the ACEA Agreement (not included in the Shared Analysis baseline) in achieving the

Kyoto target. The impact of the introduction of the ACEA agreement in the baseline case is to reduce energy demand for liquid fuels by 28 Mtoe in 2010 compared to the baseline. As a consequence CO_2 emissions increase by only 4.1% from 1990 levels in 2010 compared to 6.7 % in the baseline (-80 Mt CO2). However, the EU does not achieve the Kyoto commitment. Table 38 illustrates the projected evolution of CO_2 emissions by Member State in the baseline case. It should be noted that the impact of the ACEA agreement was examined only in the context of energy related CO2 emissions, i.e. emissions of non-CO2 greenhouse gases are assumed not to change due to the introduction of the agreement. However, the ACEA agreement is not expected to have an impact on transport-related non-CO_2 emissions.

Table 38: Evolution of greenhouse gas emissions under baseline conditions including the ACEA agreement

	CO2 emissions			non-CO2 greenhouse gases emissions			total greenhouse gases emissions		
	Mt CO2 eq.		% change	Mt CO2 eq.		% change	Mt CO2 eq.		% change
	1990	2010		1990	2010		1990	2010	
Austria	55.0	53.0	-3.6	25.7	28.5	10.7	80.7	81.5	1.0
Belgium	104.8	121.7	16.2	33.7	35.1	4.2	138.5	156.8	13.3
Denmark	52.7	53.5	1.5	21.3	20.2	-4.9	73.9	73.7	-0.3
Finland	51.3	72.4	41.0	14.9	14.0	-5.8	66.3	86.4	30.5
France	352.4	376.2	6.8	188.0	175.7	-6.5	540.4	551.9	2.1
Germany	951.6	800.3	-15.9	231.5	187.4	-19.1	1183.1	987.7	-16.5
Greece	70.9	106.1	49.6	27.5	27.4	-0.2	98.4	133.5	35.7
Ireland	30.1	41.9	39.3	27.8	31.5	13.2	57.8	73.3	26.8
Italy	388.0	418.0	7.7	127.7	131.6	3.1	515.7	549.6	6.6
Netherlands	153.0	201.4	31.6	57.5	51.8	-10.0	210.5	253.2	20.3
Portugal	39.1	64.9	66.2	25.3	27.3	7.9	64.3	92.2	43.3
Spain	201.9	266.4	32.0	101.5	107.9	6.4	303.3	374.3	23.4
Sweden	50.5	60.2	19.2	19.2	23.1	20.4	69.8	83.4	19.5
United Kingdom	566.9	557.3	-1.7	167.6	134.1	-20.0	734.5	691.4	-5.9
TOTAL EU	3068.1	3193.3	4.1	1070.2	996.9	-6.8	4138.3	4190.3	1.3

Source: PRIMES, ECOFYS, AEA Technologies

In evaluating the effort required in achieving the Kyoto target for the EU and its allocation to the different Member States and sectors the approach retained accepts the flexibility of the Kyoto Protocol to develop the most economically efficient approach to meet the Kyoto target. In this case, emission reductions for each EU Member State are not those set according to the Burden Sharing Agreement, but are based on least-cost considerations within the EU.

Table 39 illustrates the effort allocated to the different pollutants emission reduction in the context of a full-flexibility regime (i.e. potential for emission trading across Member States, sectors and pollutants). The meta-model results illustrate that this effort should be concentrated in reducing non-CO2 greenhouse gases emissions (-17.4% from 1990 levels) whereas reduction of CO2 emissions is limited to –4.7% from 1990 levels. However, in absolute terms reduction of CO2 emissions (-350 Mt CO2 from baseline levels in 2010) is more than 3 times higher compared to that of non-CO2 greenhouse gases (-113 Mt CO2 equivalent). As regards the distribution of effort within the energy system as regards the reduction of CO2 emissions the role of the supply side is significantly higher compared to that of the demand side (–209 Mt CO2 and -142 Mt CO2 correspondingly from baseline levels in 2010). This is the case even if industrial boilers emissions are allocated in the demand side (second part of the table). The detailed results of the meta-model regarding the decomposition of effort among the different sectors and pollutants by Member State can be found in Appendix VI. The marginal abatement cost for achieving the Kyoto target within the EU is estimated at about 31.6 Euro'99 per tn of CO2 equivalent avoided.

Table 39: Least-cost allocation reduction objectives per sector when the EU reaches the Kyoto target jointly, excluding the ACEA Agreement

	Baseline scenario			Emission reduction from 1990 levels		Compliance cost
	industrial boilers emissions allocated in demand side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4138.3	4271.0	3.2	-331.1	-8.0	31.6
CO2 emissions	3068.1	3274.1	6.7	-144.6	-4.7	31.6
demand side	1936.6	2107.1	8.8	16.4	0.8	
industry	561.4	448.7	-20.1	-152.3	-27.1	
transport	734.8	994.1	35.3	215.4	29.3	
domestic	640.4	664.2	3.7	-46.8	-7.3	
supply side	1131.5	1167.0	3.1	-160.9	-14.2	
utilities	835.8	772.3	-7.6	-199.5	-23.9	
industrial generators	123.7	253.7	105.1	72.2	58.3	
other generators	0.0	27.9	-	22.3	-	
boilers	114.6	57.3	-50.0	-51.6	-45.0	
fuel extraction and refining	57.5	55.9	-2.7	-4.4	-7.6	
Non-CO2 GHGs emissions	1070.2	996.9	-6.8	-186.5	-17.4	31.6
CO2 (other)	164.4	183.1	11.4	17.7	10.8	
CH4	461.7	380.1	-17.7	-117.0	-25.3	
N2O	376.3	317.0	-15.8	-93.9	-24.9	
HFC	52.3	84.2	61.1	0.3	0.6	
PFC	10.0	25.5	154.0	8.7	86.6	
SF6	5.5	6.9	26.1	-2.3	-41.2	
	industrial boilers emissions allocated in supply side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4138.3	4271.0	3.2	-331.1	-8.0	31.6
CO2 emissions	3068.1	3274.1	6.7	-144.6	-4.7	31.6
demand side	1799.6	2036.2	13.1	94.9	5.3	
industry	424.4	377.9	-11.0	-73.8	-17.4	
transport	734.8	994.1	35.3	215.4	29.3	
domestic	640.4	664.2	3.7	-46.8	-7.3	
supply side	1268.5	1237.9	-2.4	-239.4	-18.9	
utilities	835.8	772.3	-7.6	-199.5	-23.9	
industrial generators	123.7	253.7	105.1	72.2	58.3	
other generators	0.0	27.9	-	22.3	-	
boilers	251.6	128.2	-49.0	-130.1	-51.7	
fuel extraction and refining	57.5	55.9	-2.7	-4.4	-7.6	
Non-CO2 GHGs emissions	1070.2	996.9	-6.8	-186.5	-17.4	31.6
CO2 (other)	164.4	183.1	11.4	17.7	10.8	
CH4	461.7	380.1	-17.7	-117.0	-25.3	
N2O	376.3	317.0	-15.8	-93.9	-24.9	
HFC	52.3	84.2	61.1	0.3	0.6	
PFC	10.0	25.5	154.0	8.7	86.6	
SF6	5.5	6.9	26.1	-2.3	-41.2	

Source: PRIMES, ECOFYS, AEA Technologies

The economic interpretation of the costs for the economy arising from the above marginal abatement cost is complex. The imposition of a carbon emission constraint induces an external cost to the carbon-consuming agents compared to baseline conditions. Under such a constraint, the system bears a net loss of welfare (compared to baseline) for each ton of CO_2 equivalent avoided equal to the marginal abatement cost corresponding to that ton. Therefore, the total loss of welfare implied by an emission constraint is equal to the area (the integral) below the marginal abatement cost curve.

The total welfare cost of reaching the emission objectives is about $€_{99}$ 6.6 billion per year in 2010 (0.1% of EU GDP in 2010). This estimation comes from partial equilibrium analysis since PRIMES covers only the energy demand and supply system, the rest of the economy being considered unchanged under the imposition of emission reduction targets. Consequently the above estimation does not include any macro-economic indirect effects resulting from the allocation of larger funds in energy demand and supply to obtain higher efficiency and less carbon intensity. Furthermore, any deviation from a least cost allocation, which as already described is assumed among the different demand and supply sectors, for example because of policy implementation failure, could entail higher compliance costs.

The various economic sectors are affected differently by the imposition of the carbon constraint in 2010. The costs differ among sectors depending on their energy intensity. The results of PRIMES show effects on costs, due to CO2 emissions reduction, varying by sector. The average cost of sectoral output (industrial product) in 2010 increases by 1.5-6% for energy intensive industries and by 0.2-0.7% for non-energy intensive sectors (compared to baseline scenario). The energy cost for the service sectors increases by 1.2%, however implying a small increase in total cost of the sector. The cost of transportation increases by 1.5% for passengers and by 2.3% for freight. Spending by households on energy fuel purchases and energy-using equipment increases by roughly 8%. The total cost incurred by the average EU household for all kinds of energy services and related equipment increases by 4.5%. In absolute terms, this is equivalent to $€_{99}$ 78 per household per year. However, it must be stressed out that that these costs do not include additional costs resulting from higher prices for e.g. industrial goods in other sectors. The costs incurred by the power and steam generation sector relate to higher capital expenditures (more expensive plant technology), the costs induced from stranded capital, and the high fuel costs needed for fuel switching. The average power and steam generation cost increases by 15% compared to baseline. Despite this significant increase production of electricity and steam decreases by just 2.0% from baseline levels in 2010. The cumulative investment expenditures for power and steam generation would also rise by about 4%.

As already discussed, the incorporation of the ACEA/JAMA/KAMA agreement in the baseline scenario leads to a reduction of emissions by about 80 Mt CO2 from baseline levels in 2010. Consequently, the achievement of the Kyoto target is facilitated leading to a reduction of the marginal abatement cost down to $€_{99}$ 20.3 per tn of CO2 equivalent avoided (-36%). The total welfare cost of reaching the emission targets is $€_{99}$ 3.7 billion per year in 2010 (0.06% of EU GDP in 2010). This means that the implementation of the ACEA/JAMA/KAMA agreement results in a net benefit of $€_{99}$ 2.9 billion per year in 2010 (assuming that agreement does not imply additional costs to consumers). Furthermore the implementation of the agreement has side effects on all sectors due to the lower marginal abatement cost of achieving the Kyoto target. The average cost of sectoral output (industrial product) in 2010 increases by 0.8-5% for energy intensive industries[34] and by 0.1-0.5% for non-energy intensive sectors (compared to baseline scenario). The energy cost for the service sectors increases by 0.75%. The cost of transportation increases by 1% for passengers and by 1.6% for freight. The additional cost per household for all kinds of energy services and related equipment increases by $€_{99}$ 56 per household per year. The average power and steam generation cost increases by 10% while production of electricity and steam decreases by 1.5% from baseline levels in 2010. The cumulative investment expenditures for power and steam generation also rise by about 2.4%.

[34] Iron and steel, building materials, non-ferrous metals, paper and pulp and chemicals.

Table 40 illustrates the effort allocated to the different pollutants emission reduction in the context of the second case examined, i.e. achievement of the Kyoto target with the ACEA Agreement included in the baseline scenario.

<u>Table 40: Least-cost allocation reduction objectives per sector when the EU reaches the Kyoto target jointly, including the ACEA Agreement</u>

	Baseline scenario including ACEA agreement			Emission reduction from 1990 levels		Compliance cost
	industrial boilers emissions allocated in demand side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4138.3	4190.3	1.3	-331.1	-8.0	20.3
CO2 emissions	3068.1	3193.3	4.1	-146.0	-4.8	20.3
demand side	1936.6	2032.6	5.0	-25.5	-1.3	
industry	561.4	449.5	-19.9	-145.9	-26.0	
transport	734.8	919.0	25.1	152.0	20.7	
domestic	640.4	664.1	3.7	-31.6	-4.9	
supply side	1131.5	1160.7	2.6	-120.4	-10.6	
utilities	835.8	771.9	-7.6	-169.0	-20.2	
industrial generators	123.7	250.5	102.6	79.5	64.3	
other generators	0.0	27.7	-	25.7	-	
boilers	114.6	55.5	-51.6	-52.0	-45.4	
fuel extraction and refining	57.5	55.1	-4.1	-4.7	-8.2	
Non-CO2 GHGs emissions	1070.2	996.9	-6.8	-185.1	-17.3	20.3
CO2 (other)	164.4	183.1	11.4	17.7	10.8	
CH4	461.7	380.1	-17.7	-117.0	-25.3	
N2O	376.3	317.0	-15.8	-93.9	-24.9	
HFC	52.3	84.2	61.1	1.7	3.2	
PFC	10.0	25.5	154.0	8.7	86.6	
SF6	5.5	6.9	26.1	-2.3	-41.2	
	industrial boilers emissions allocated in supply side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4138.3	4190.3	1.3	-331.1	-8.0	20.3
CO2 emissions	3068.1	3193.3	4.1	-146.0	-4.8	20.3
demand side	1799.6	1960.7	9.0	50.6	2.8	
industry	424.4	377.6	-11.0	-69.7	-16.4	
transport	734.8	919.0	25.1	152.0	20.7	
domestic	640.4	664.1	3.7	-31.6	-4.9	
supply side	1268.5	1232.6	-2.8	-196.6	-15.5	
utilities	835.8	771.9	-7.6	-169.0	-20.2	
industrial generators	123.7	250.5	102.6	79.5	64.3	
other generators	0.0	27.7	-	25.7	-	
boilers	251.6	127.4	-49.4	-128.1	-50.9	
fuel extraction and refining	57.5	55.1	-4.1	-4.7	-8.2	
Non-CO2 GHGs emissions	1070.2	996.9	-6.8	-185.1	-17.3	20.3
CO2 (other)	164.4	183.1	11.4	17.7	10.8	
CH4	461.7	380.1	-17.7	-117.0	-25.3	
N2O	376.3	317.0	-15.8	-93.9	-24.9	
HFC	52.3	84.2	61.1	1.7	3.2	
PFC	10.0	25.5	154.0	8.7	86.6	
SF6	5.5	6.9	26.1	-2.3	-41.2	

Source: PRIMES, ECOFYS, AEA Technologies

A variant was also examined assuming the existence of a full trading regime between sectors and pollutants within each Member State, but no trading across Member States, each of which is assumed to comply with the target set in the context of the Burden

Sharing Agreement,[35] while including the ACEA/JAMA/KAMA agreement in the baseline.

Table 41: Allocation reduction objectives per sector when the EU Member States reach the Kyoto target according to the Burden Sharing Agreement, including the ACEA Agreement

	Baseline scenario including ACEA agreement			Emission reduction from 1990 levels		Compliance cost
	industrial boilers emissions allocated in demand side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4137.1	4189.0	1.3	-327.2	-7.9	41.8
CO2 emissions	3068.1	3193.3	4.1	-136.0	-4.4	41.8
demand side	1936.6	2032.6	5.0	-11.3	-0.6	
industry	561.4	449.5	-19.9	-142.3	-25.4	
transport	734.8	919.0	25.1	152.7	20.8	
domestic	640.4	664.1	3.7	-21.7	-3.4	
supply side	1131.5	1160.7	2.6	-124.8	-11.0	
utilities	835.8	771.9	-7.6	-164.5	-19.7	
industrial generators	123.7	250.5	102.6	73.1	59.1	
other generators	0.0	27.7	-	24.6	-	
boilers	114.6	55.5	-51.6	-53.7	-46.9	
fuel extraction and refining	57.5	55.1	-4.1	-4.3	-7.4	
Non-CO2 GHGs emissions	1069.0	995.6	-6.9	-191.1	-17.9	41.8
CO2 (other)	163.8	182.5	11.5	17.7	10.8	
CH4	461.1	379.6	-17.7	-122.1	-26.5	
N2O	376.3	317.0	-15.8	-93.8	-24.9	
HFC	52.3	84.1	60.7	2.8	5.4	
PFC	10.0	25.4	153.7	6.2	62.2	
SF6	5.5	6.9	26.1	-2.0	-36.8	
	industrial boilers emissions allocated in supply side					
	Mt CO2 eq.		% change	Mt CO2 eq.	% change from 1990	Euro99/tn of CO2 eq. Avoided
	1990	2010				
Total GHGs	4137.1	4189.0	1.3	-327.2	-7.9	41.8
CO2 emissions	3068.1	3193.3	4.1	-136.0	-4.4	41.8
demand side	1799.6	1960.7	9.0	61.4	3.4	
industry	424.4	377.6	-11.0	-69.7	-16.4	
transport	734.8	919.0	25.1	152.7	20.8	
domestic	640.4	664.1	3.7	-21.7	-3.4	
supply side	1268.5	1232.6	-2.8	-197.4	-15.6	
utilities	835.8	771.9	-7.6	-164.5	-19.7	
industrial generators	123.7	250.5	102.6	73.1	59.1	
other generators	0.0	27.7	-	24.6	-	
boilers	251.6	127.4	-49.4	-126.3	-50.2	
fuel extraction and refining	57.5	55.1	-4.1	-4.3	-7.4	
Non-CO2 GHGs emissions	1069.0	995.6	-6.9	-191.1	-17.9	41.8
CO2 (other)	163.8	182.5	11.5	17.7	10.8	
CH4	461.1	379.6	-17.7	-122.1	-26.5	
N2O	376.3	317.0	-15.8	-93.8	-24.9	
HFC	52.3	84.1	60.7	2.8	5.4	
PFC	10.0	25.4	153.7	6.2	62.2	
SF6	5.5	6.9	26.1	-2.0	-36.8	

Source: PRIMES, ECOFYS, AEA Technologies

[35] In June 1999 the EU Member States agreed to meet the Kyoto target of -8% so that the target for each Member State was different from one another. The targets were: Austria -13,0%; Belgium -7,5%; Denmark -21,0%; Finland 0,0%; France 0,0%; Germany -21,0%; Greece 25,0%; Ireland 13,0%; Italy -6,5%; Luxembourg-28,0%; Netherlands-6,0% ; Portugal 27,0% ; Spain 15,0% ; Sweden 4,0% and the UK-12,5% .

As expected the marginal abatement cost of achieving the Kyoto target in this case increases due to the imperfection (partial character) of optimising across the full range of flexibility within the EU Member States. More specifically the marginal abatement cost of achieving the Kyoto target for the EU more than doubles compared to the full flexibility scenario to reach 41.8 Euro'99 per tn of CO2 equivalent avoided. The total welfare cost of reaching the emission target would be $€_{99}$ 7.5 billion per year in 2010 (0.11% of EU GDP in 2010). However, a very interesting finding is that the allocation of effort across pollutants and sectors at the EU level remains very similar to the results obtained from the full flexibility scenario. On the other hand significant discrepancies are observed as regards the emission reduction achieved at the level of each member state and the corresponding marginal cost (see Table 42).

Table 42: Comparison between full flexibility and Burden Sharing scenario (including the ACEA Agreement)

	Full flexibility scenario				Burden Sharing scenario			
	% change from 1990				% change from 1990			
	CO2 emissions	non-CO2 GHGs emissions	Total emissions	Compliance cost	CO2 emissions	non-CO2 GHGs emissions	Total emissions	Compliance cost
Austria	-11.1%	3.2%	-6.6%	20.3	-18.2%	-1.9%	-13.0%	52.8
Belgium	8.9%	-6.3%	5.2%	20.3	-6.9%	-9.3%	-7.5%	91.8
Denmark	-12.0%	-11.1%	-11.7%	20.3	-23.2%	-15.4%	-21.0%	53.0
Finland	22.7%	-10.8%	15.2%	20.3	4.8%	-16.5%	0.0%	53.1
France	0.0%	-16.0%	-5.6%	20.3	6.8%	-13.8%	-0.4%	1.3
Germany	-22.1%	-27.9%	-23.2%	20.3	-19.4%	-27.6%	-21.0%	11.5
Greece	29.4%	-8.0%	18.9%	20.3	37.7%	-7.9%	25.0%	11.1
Ireland	24.7%	4.7%	15.1%	20.3	20.7%	4.7%	13.0%	32.1
Italy	-2.3%	-6.3%	-3.3%	20.3	-6.1%	-7.9%	-6.5%	34.5
Netherlands	20.7%	-26.3%	7.9%	20.3	4.3%	-33.5%	-6.0%	105.8
Portugal	52.0%	-7.8%	28.5%	20.3	49.6%	-7.9%	27.0%	23.1
Spain	18.7%	-8.4%	9.6%	20.3	26.7%	-8.3%	15.0%	12.0
Sweden	9.8%	8.4%	9.4%	20.3	4.5%	2.8%	4.0%	41.4
United Kingdom	-10.2%	-31.2%	-15.0%	20.3	-7.0%	-31.0%	-12.5%	11.5
TOTAL EU	-4.8%	-17.3%	-8.0%	20.3	-4.4%	-17.9%	-7.9%	41.8

Source: PRIMES, ECOFYS, AEA Technologies

The detailed results of the meta-model regarding the decomposition of effort among the different sectors and pollutants at the level of the EU under the three scenarios examined can be found in Appendix VI, while detailed results by Member State (only including the results according to the burden sharing agreement) are provided in a separate volume.

7.4. Impacts on power generation sector

As this study has shown, the emission reduction potential from power generation sector is significant. Thus, the impacts in terms of fuel switching and energy production of reaching the Kyoto target are given in tables 43-46.

In table 43 it can be seen how fuel consumption would be affected in the power generation sector as a result of achieving the Kyoto Protocol in a least cost manner. As it can be seen, there would be a decrease in overall fuel consumption (by 26 Mtoe being a 4% reduction from 2010 baseline). In addition, there would be a decrease in the use of high carbon value fuels (coal, lignite and peat) and an increase in low carbon value fuels (natural gas). However, the increase in the use of natural gas is estimated at 13% from the baseline of 2010, which is considered relatively small.

The impact of the fuel switching on CO_2 emissions can be seen in Table 44. The importance of fuel switching is demonstrated (almost two thirds of low cost emission reduction options are identified here) but the role of renewable energy is significant.

About a third of the CO_2 reduction effort is due to additional use of renewable energy, notably wind and biomass.

Finally, in table 45, the effect of reaching the Kyoto target on electricity and steam generation both jointly and separately. The generation of electricity and steam from low or non-carbon sources increases significantly (e.g. wind generation would increase by 45%).

Table 43: Impact of the achievement of the Kyoto target with least cost on fuel consumption (including the ACEA Agreement)

Fuel Consumption Mtoe	1995	Baseline 2010	Kyoto target 2010	Difference in GWh	Difference in %
Domestically Produced Coal	58	6	6	0	0%
Imported Coal	63	83	49	-34	-41%
Lignite and Peat	51	47	38	-9	-20%
Fuel Oil and other oil products except diesel and refinery gas	62	45	37	-9	-19%
Diesel Oil	4	5	5	0	-5%
Natural Gas	77	160	181	21	13%
Byproducts (derived gas and refinery gas)	28	34	34	0	0%
Nuclear Energy (in thermal units)	205	227	225	-2	-1%
Biomass-Waste	22	31	38	7	23%
Hydrogen	0	0	0	0	0%
Methanol	0	0	0	0	0%
TOTAL	570	639	613	-26	-4%

Table 44: Decomposition of CO2 emissions reduction (including the ACEA Agreement)

	Mt CO2 avoided	% structure
change of fossil fuel mix	*-96.7*	*60.2*
cogeneration	*-6.4*	*4.0*
efficiency gains in supply side	*-11.6*	*7.2*
nuclear energy	*-3.4*	*2.1*
renewables	*-42.2*	*26.3*
- biomass-waste	-28.5	17.7
- hydro	-1.5	0.9
- wind and others	-12.3	7.6
refineries and energy branch	*-0.5*	*0.3*
Total	*-160.7*	*100.0*

As can be seen from table 46 the achievement of the Kyoto target would increase the production from renewable energy by 1,8 GWh for electricity (being an 13% increase in addition to the growth in the baseline of 2010) and of 3.1 GWh for steam production (up by 19% from baseline. In sum, the share of renewable energy is boosted significantly due to the achievement of the Kyoto target.

Table 45: Table: Impact of the achievement of the Kyoto target with least cost on electricity and steam generation (including the ACEA Agreement)

Electricity and Steam Production by Energy Form (incl. CHP) GWh	**1995**	**Baseline 2010**	**Kyoto target 2010**	**Difference in GWh**	**Difference in %**
Solids except lignite and peat	576	562	356	-206	-37%
Lignite and Peat	235	284	231	-53	-19%
Oil products except diesel oil and refinery gas	434	358	296	-61	-17%
Diesel Oil	27	34	34	0	1%
Natural Gas, Derived Gas and Refinery Gas	793	1524	1701	176	12%
Nuclear Energy	810	895	889	-6	-1%
Biomass (new)	0	3	26	24	880%
Waste (all types)	207	274	310	36	13%
Hydrogen	0	0	0	0	0%
Methanol	0	0	0	0	0%
Hydro of Utilities	285	307	305	-2	-1%
Hydro of Other Generators	1	2	2	0	30%
Wind	3	60	88	27	45%
Solar	0	0	0	0	-2%
Ocean	0	0	0	0	0%
Geothermal	2	6	5	-1	-13%
TOTAL	3373	4308	4243	-64	-1%

Electricity Production by Energy Form (incl. CHP) GWh	**1995**	**Baseline 2010**	**Kyoto target 2010**	**Difference in GWh**	**Difference in %**
Solids except lignite and peat	485	341	207	-134	-39%
Lignite and Peat	184	156	126	-30	-19%
Oil products except diesel oil and refinery gas	174	88	72	-17	-19%
Diesel Oil	9	13	14	1	8%
Natural Gas, Derived Gas and Refinery Gas	320	1086	1180	94	9%
Nuclear Energy	810	895	889	-6	-1%
Biomass (new)	0	0	13	13	2683%
Waste (all types)	34	66	77	11	16%
Hydrogen	0	0	0	0	0%
Methanol	0	0	0	0	0%
Hydro of Utilities	285	307	305	-2	-1%
Hydro of Other Generators	1	2	2	0	30%
Wind	3	60	88	27	45%
Solar	0	0	0	0	-2%
Ocean	0	0	0	0	0%
Geothermal	2	6	5	-1	-13%
TOTAL	2306	3022	2978	-44	-1%

Steam Production by Energy Form (incl. CHP) GWh	**1995**	**Baseline 2010**	**Kyoto target 2010**	**Difference in GWh**	**Difference in %**
Solids except lignite and peat	91	220	149	-72	-32%
Lignite and Peat	51	128	105	-23	-18%
Oil products except diesel oil and refinery gas	260	269	224	-45	-17%
Diesel Oil	18	21	20	-1	-4%
Natural Gas, Derived Gas and Refinery Gas	473	438	521	83	19%
Biomass (new)	0	2	13	11	498%
Waste (all types)	173	208	233	25	12%
Hydrogen	0	0	0	0	0%
Methanol	0	0	0	0	0%
TOTAL	1066	1286	1266	-21	-2%
Corresponding CO2 emissions (Mt CO2)	1269	1233	1072	-161	-13%

Table 46: Selected indicators of changes in renewable production according to the achievement of the Kyoto target with least cost on electricity and steam generation (including the ACEA Agreement)

Indicators	1995	Baseline 2010	Kyoto target 2010	Difference in GWh	Difference in %
Ratio of renewables in production (%)					
- Electricity Production (incl. CHP)					
- Total Renewables	14,1	14,6	16,4	1,8	13%
- Renewables except Hydro of Utilities	1,7	4,4	6,2	1,8	40%
- Renewables except Hydro of Utilities and biomass	0,3	2,2	3,2	0,9	42%
- Steam Production (only boilers)					
- Total Renewables	16,2	16,3	19,5	3,1	19%
Ratio of Non Fossil Fuels in Production (%)					
- Electricity Production (incl. CHP)	49,2	44,2	46,3	2,1	5%
- Steam Production (only boilers)	16,2	16,3	19,5	3,1	19%

APPENDIX I

The PRIMES Energy System Model

History

The development of the PRIMES energy system model has been supported by a series of research programmes of the European Commission. The model has been successfully peer reviewed by the European Commission in 1997-1998.

The construction of the PRIMES energy model started in 1993 and from the beginning the aim was to focus on market-related mechanisms influencing the evolution of energy demand and supply and the context for technology penetration in the market. The PRIMES model also was designed to serve as an energy policy markets analysis tool including the relationships between energy policy and technology assessment. The need to represent the growing process of market liberalisation, also motivated PRIMES and other modellers to adopt market-oriented modelling approaches giving rise to models often called "new generation models" like in the US the models IFFS and NEMS (US/DOE).

The model version 1 has been used in 1997 in the evaluation of the set of policies and measures envisaged by the European Commission in the negotiation phase for the Kyoto conference for climate change. The current version of the model (version 2 of PRIMES) formulated as a non-linear mixed complementarity (MCP) problem and solved under GAMS/CPLEX/PATH is fully operational and calibrated on 1995 data-set for all European Union Member States. During the 1998-1999 period, version 2 of PRIMES has been used to prepare the European Union Energy and Emissions Outlook for the Shared Analysis project of the European Commission, DG XVII. It has been also extensively used for DG Environment and started to be used at government level in the EU.

Scope and Objectives

PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the European Union (EU) Member States. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply match the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships.

The model is behavioural but also represent in an explicit and detailed way the available energy demand and supply technologies and pollution abatement technologies. The system reflects considerations about market economics, industry structure, energy/environmental policies and regulation. These are conceived so as to influence market behaviour of energy system agents. The modular structure of PRIMES reflects a distribution of decision making among agents that decide individually about their supply, demand, combined supply and demand, and prices. Then the market integrating part of PRIMES simulates market clearing.

PRIMES is a general purpose model. It is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon. It is modular and allows either for a unified model use or for partial use of modules to support specific energy studies.

The model can support policy analysis in the following fields:

- ? standard energy policy issues: security of supply, strategy, costs etc

- ? environmental issues
- ? pricing policy, taxation, standards on technologies
- ? new technologies and renewable sources
- ? energy efficiency in the demand-side
- ? alternative fuels
- ? energy trade and EU energy provision
- ? conversion decentralisation, electricity market liberalisation
- ? policy issues regarding electricity generation, gas distribution and refineries.

A fundamental assumption in PRIMES is that producers and consumers both respond to changes in price. The factors determining the demand for and the supply of each fuel are analysed and represented, so they form the demand and/or supply behaviour of the agents. Through an iterative process, the model determines the economic equilibrium for each fuel market. Price-driven equilibrium is considered in all energy and environment markets, including Europe-wide clearing of oil and gas markets, as well as Europe-wide networks, such as the Europe-wide power grid and natural gas network.

Although behavioural and price driven, PRIMES simulates in detail the technology choice in energy demand and energy production. The model explicitly considers the existing stock of equipment, its normal decommissioning and the possibility for premature replacement. At any given point in time, the consumers or producer selects the technology of the energy equipment on an economic basis and can be influenced by policy (taxes, subsidies, regulation) market conditions (tariffs etc.) and technology changes (including endogenous learning and progressive maturity on new technologies)

Due to the heterogeneity of the energy market no single methodology can adequately describe all demand, supply and conversion processes. On the other hand, the economic structure of the energy system itself facilitates its representation through largely separable individual units, each performing a number of individual functions.

Based on these principles, **PRIMES is organised around a modular design representing in a different manner fuel supply, energy conversion and end-use of demand sectors**. The individual modules vary in the depth of their structural representation. The modularity feature allows each sector to be represented in the way considered appropriate, highlighting the particular issues important for the sector, including the most expedient regional structure. The electricity module covers the whole Europe, while representing chronological load curves and dispatching at the national level. The natural gas market also expands over the whole Europe. However, coal supply, refineries and demand operate at the national level. Furthermore, the modularity allows any single sector or group of sectors to be run independently for stand alone analysis.

Features of Sub Models

The supply modules simulate both the operation and the capacity expansion activities. The dynamic relationships involve stock-flow relations (for example capital accumulation), inertia in the penetration of new technologies, backward looking expectations (more formally, the model uses adaptive expectations) and consumer habits. Thus, the model integrates static and a dynamic solution under myopic anticipation. Also, the model fully integrates the national within the multinational energy system (for oil refinery, gas supply to Europe and generation and trade of electricity).

Demand is evaluated at a national level. Electricity dispatching and capacity expansion are determined at a national level, depending however on a complex market allocation mechanism, operating through the electricity grid, Europe-wide. The natural gas distribution market clears at a multinational level, even wider than the European Union. The refinery sector operates at a national level, but capacities, market shares and prices depend heavily on Europe-wide competition. Primary energy supply, for example coal and lignite supply curves, has, on the other hand, a national-specific character. Finally, energy savings, technology progress in power generation, abatement technologies, renewables and alternative fuels (biomass, methanol, hydrogen) are determined at each country-specific energy system.

Cost evaluation modules and price-setting mechanisms are at the core of the model. The formers are attached to each energy supply module. The cost module considers total revenue requirements of the sector (based on total costs and other accounting costs) and allocates payments over the consumers, according to a general Ramsey pricing rules (parameters are user selected). The pricing parameters reflect alternative industrial economic circumstances and are linked to marginal and average values from the sector's optimisation. For example, these rules consider a peak-synchronisation characterisation of consumers or average cost rating of energy demand by consumers. The allocation of payments is further determined, by also considering eventual cross-subsidisation policy or other distortions. In brief, the price-setting mechanism reflects the design considerations for the market clearing regimes. The value of parameters in these cost-pricing modules can be altered, in policy scenarios, to reflect structural change.

Prices of purchased fuels depend also on cost-supply curves that are exogenously specified, but operate within the equilibrium process. Such curves are used for all primary energy supply, including EU gas supply, coal, biomass and even renewable sources to reflect land availability constraints. They are also defined for imports.

Technology

As mentioned, PRIMES has been designed to support technology assessment at the energy system level. The dynamics, as simulated by the model, influence the penetration of new technologies.

Several parameters and formulations are built-in to represent non-economic factors that affect the velocity of new technology penetration. For example, the modules include learning by doing curves, parameters that represent subjective perception of technology costs as seen by consumers, standards, etc. These can be used to represent market failures or inertia that may deprive the system from cost-effective technology solutions.

In addition, market related factors, as represented within the optimisation modules, can also explain the lack of decision for the most cost-effective solutions. These factors are related to the individual character of decision maker's optimality and this is represented in the model by design (different optimality conditions per module) and through the use of parameters, as for example by varying the discount rates with the consumer size.

Policy parameters can of course change the optimality conditions and influence technology choice and penetration. The model can in addition simulate accompanying policies that aim at structural improvements that may maximise the effects of policy measures. For example, true cost pricing, removal of barriers, new funding mechanisms etc. can be reflected to changes of parameters that will influence technology choices and penetration.

Environment

The mechanisms relating pollution with energy activities, also involving pollution abatement choices, are fully integrated into PRIMES. The optimisation modules simultaneously consider energy and environment costs. Constraints are built in to represent environmental regulation. The technology choice mechanisms also consider abatement equipment. Policy measures dedicated to pollution can affect optimality and can also be accompanied with policy aiming at structural change. Finally, a module computes dispersion and deposition of emitted pollutants.

The main policy instruments for the environment, as considered in PRIMES, are:

- ? Regulation by sector (in the form of a constraint of emissions by sector);
- ? Regulation by country (in the form of a global constraint taking into account emissions from all modules);
- ? Taxation for the environment. This can be either exogenously given (in which case the emissions are not explicitly limited) or endogenously (as the shadow price of the constraint binding the emissions);
- ? Pollution permits. A separate market for pollution permits is implemented in the model. The different sectors can therefore trade (sell or buy) permits based on their initial endowment;
- ? Subsidisation of abatement costs for electricity and steam.

Policy Instruments

Special care has been devoted to the representation of various policy instruments in the model. For some policy instruments, it is straightforward to build scenario variants and to evaluate the implications. For other instruments, the analysis is more sophisticated and has to combine evaluations outside the model with results from model runs.

Economic and fiscal instruments constitute an obvious case of straightforward use of the model. Taxes, excise, VAT, carbon etc., are explicitly represented for all energy forms and uses. Fully detailed tax scenarios can be assessed, including differentiation of rates by sector, combination with subsidies and exemptions, harmonisation across Member States, etc. The consequences of higher taxation for costs of derived energy forms (e.g. steam, electricity) are endogenously treated.

Other economic instruments, like the tradable emission rights (pollution permits) are also formulated in PRIMES. Other measures such as new funding mechanisms for energy technologies, information campaigns and measures aiming at removal of barriers, can be evaluated at the energy system level (regarding their total effects) through the built in mechanisms of PRIMES, like perceived costs, risk premium, etc.

Command and control regulation, that is the pursuit of objectives through administrative processes, can be analysed through the use of constraints and binding within the optimisation modules. The model can evaluate the effectiveness and compute proxies to the shadow cost of regulation. Emission norms, efficiency norms, regulations such as the "Non Fossil Fuel Obligation" can be represented and analysed.

Voluntary agreements are one of the cases for which the model-based analysis must be combined with ad hoc evaluation. Voluntary agreements can be represented as constraints within the optimisation modules. However, in reality, they are not necessarily imperative constraints, since deviations may be possible, although involving higher costs for the consumer. In such cases, voluntary agreements are possible when deviations are threatened by the risk of considerably higher costs. PRIMES has not such a mechanism built in. However, after evaluations outside the model, the analyst can formulate constraints, do sensitivity analysis with the model and compare shadow prices to known higher cost threats.

Demand-side Management and Integrated Resource Planning is also another example for which the model is not entirely sufficient. PRIMES, being explicit in technology representations, includes electricity consumption technologies and uses in all consumption modules. To each use, the model associates generic load patterns, the aggregation of which over the consumers' electricity uses gives the load shape faced by electricity generation. A DSM measure can be simulated by a change either in the shape or the area (efficiency) of a particular electricity use. This will alter the optimality conditions of electricity generation and will probably imply cost savings. Externally to the model, the analyst has to evaluate implementation costs of the measure and allocate the bearing of the costs between the consumer and the generator. In such a way, he can carry out cost-benefit analysis to evaluate DSM measures. The concept of Integrated Resource Planning seems now old fashioned within the on going liberalisation of markets[36]. At the energy system level, PRIMES is a complete tool for IRP evaluations, but the model is totally inadequate if IRP is to be carried out at the generator level.

To study the general issue of internalisation of externalities one has to use an accounting framework for externalities[37], consider internalisation through economic instruments (thus compare them for effectiveness, as mentioned before) or define a regulation scheme that will oblige the actors to take into account external costs. Total cost pricing was recently brought up in the debate as a means to regulate decision-making. Total cost (that is including external costs) can be imposed in all optimisation modules of PRIMES. This will influence technology choice and pricing throughout the system.

The PRIMES Model Application for the European Union

Model Nomenclature

Regions: 15 European Union countries

Fuel types: 24 energy forms in total; Coal, Lignite and Peat, Crude-oil, Residual Fuel Oil, Diesel Oil, Liquefied Petroleum Gas, Kerosene, Gasoline, Naphtha, Other oil products, Bio-fuels, Natural and derived gas, Thermal Solar (active), Geothermal low and high enthalpy, Steam (industrial and distributed heat), Electricity, Biomass and Waste, Hydrogen, Solar electricity, Wind, Hydro.

Demand Sectors:

Residential: The residential sector distinguishes five categories of dwelling. These are defined according to the main technology used for space heating. They may use secondary heating as well. At the level of the sub-sectors, the model structure defines the categories of dwellings, which are further subdivided in energy uses. The electric appliances for non heating and cooling are considered as a special sub-sector, which is independent of the type of dwelling. Four energy use types are defined per dwelling type.

Commercial: ***The commercial and agriculture sector distinguishes*** 4 sub-sectors. At the level of the sub-sectors, the model defines energy services, which are further subdivided in energy uses defined according to the pattern of technology. In total 7 sub-sectors and more than 30 end-use technology types are defined.

Industry: ***The industrial model separately formulates*** 9 industrial sectors, namely iron and steel, non ferrous, chemicals, building materials, paper and pulp, food drink tobacco, engineering, textiles, other industries other industries. For each sector different sub-sectors are defined (in total about 30 sub-sectors, including recycling of materials). At the level of each sub-sector a number of different energy uses are represented (in total about 200 types of energy use technologies are defined).

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[36] If the concept is limited to the obligation of generators to do IRP, instead of the society.

[37] For example, EXTERNE results.

Transports: The transport sector distinguishes passenger transport and goods transport as separate sectors. They are further subdivided in sub-sectors according to the transport mean (road, air, etc.). At the level of the sub-sectors, the model structure defines several technology types (car technology types, for example), which correspond to the level of energy use.

Transport modes: for urban passengers car, public transport, motorcycle, non urban passengers: car, bus, rail, air, navigation; for freight transport truck, rail, air, navigation. 6 to 10 alternative technologies for each mode (car, bus, truck); more limited number of alternatives for rail, air and navigation

Supply Sectors:

Electricity production: 148 different plant types per country for the existing thermal plants; 678 different plant types per country for the new thermal plants; 3 different plant types per country for the existing reservoir plants; 30 different plant types per country for the existing intermittent plants. Chronological load curves, interconnections, network representation; three typical companies per country; Cogeneration of power and steam, district heating

Refineries: 4 refineries with typical refinery structure; 6 typical refining units (cracking, reforming etc.)

Natural gas: Regional supply detail (Europe, Russia, Middle Africa, North Sea etc.); Transportation, distribution network

Time Horizon

PRIMES is a long-term model that is being set to consider the period 1990-2030, running by period of 5 years.

Output (*Dynamic Annual Projections in Specific Units)*

Full detailed EUROSTAT Energy Balance sheets per country and per year

Energy demand at the above mentioned classification

Energy costs, producer and consumer prices

Power generation park, load curves, load factors, investment and marginal costs (central systems, combined heat-power, exchanges)

Refining units, expansion, costs

Natural gas transport and distribution: flows, capacities, costs

Endogenous treatment of energy savings and new technologies

Atmospheric emissions (CO_2, NO_x, SO_2, N_2O, CH_4, VOC, PM), abatement equipment and standards

Case Studies and Planning Applications

Energy and environment technology assessment

Energy system implications of policy instruments for the environment (taxation, abatement standards, pollution permits, ...)

All issues of energy policy, investment plans and energy pricing policy

European energy market integration, European networks

Energy system implications and forecasting for the penetration of new energy technologies in energy savings, energy demand, power generation etc.

Energy supply to Europe: dependency and vulnerability analysis for natural gas and oil.

Required Infrastructure

Hardware: PC Pentium with Windows '95 or Alpha Digital Equipment running NT-Windows with 128MB RAM or higher

Software: GAMS Ver. 2.25 with PATH solver and Cplex (or OSL)

MS EXCEL ver. 7.0 or later

The Power and Steam Generation Sub Model of PRIMES

The aim of the electricity and steam sub-model of PRIMES is to simulate the behaviour of agents that use fuels and other energy forms to produce, transmit and distribute electricity, industrial steam and district heating. This behaviour concerns the choice of equipment and the fuel mix to satisfy demand, the setting of selling prices and the purchase of fuels from the energy markets. The model design is adapted to the very nature of the energy forms produced in this sub-model, related to the impossibility to use storage, the high degree of capital intensive equipment and the importance of technology choice for energy strategy.

The emergence of heat and power cogeneration possibilities and the prospects for increasing decentralisation of production led to the adoption of a unified modelling for power and steam production. On the contrary, the previous version of PRIMES has considered a separation between centralised electricity and the independent production of steam and electricity, the latter being modelled within the demand sub-models of PRIMES. That design has put more emphasis on the self-supply character of cogeneration, since such a situation has prevailed in the market for a long period of time. The emergence of efficient smaller scale technologies and the opening of the markets to competition created new prospects for cogeneration and independent production. The modelling needs then to tightly integrate producers of different nature, regarding for example economies of scale and market opportunities, into a single framework that will mimic the operation of the market.

The new version of PRIMES puts emphasis on the different nature of producers that will operate in the market and the interaction between electricity and steam markets, as enabled by cogeneration. For example, it is necessary to distinguish producers according to their scale, but also according to the captive markets they might address. A utility can exploit high economies of scale, but can hardly benefit from the market of steam, as steam cannot be self-consumed. On the contrary, an industrial independent producer will operate at smaller plant size, loosing competitiveness as far as the economies of scale are concerned, but obtaining benefits from a high base load demand for steam that he can supply. A company operating at the level of local authorities may obtain benefits from niche markets (renewables, district heating), but it will face a highly fluctuating demand for heat and electricity.

The representation of different technologies that are now available or will be available in the future is a major focus of the model, as it is intended to also serve for strategic analyses on technology assessment. To support such analyses, the model uses a large list of alternative technologies and differentiates their technical-economic characteristics according to the plant size, the fuel types, the cogeneration techniques, the country and the type of producer. A model extension is also designed aiming at representing a non-linear cycle of the penetration of new technologies, for which learning through experience (and other industrial economic features) relates penetration with the technology performance.

The differences between the producer types play an important role in their ability to obtain interesting natural gas supply contracts. This issue seems to become very important in the future, as natural gas is emerging as the key fuel because of technology progress and environmental constraints. Again, a unified modelling approach is necessary to analyse the differentiated effects of natural gas for producers that differ as described above.

Both the market allocation from the producer perspective and the effects of natural gas supply conditions need a consideration of the time pattern of demand, production and fuel supply. In addition, the corresponding loads have to be considered in chronological terms, as serious limitations would arise if using load duration monotone curves, because of the need to analyse the synchronisation of the time patterns of electricity consumption, steam consumption and fuel supply (such as natural gas).

The consideration of intermittent energy sources, such as the renewables, also requires a representation of chronological curves, as the random availability of the source over time can be approximated. Nevertheless, the correct modelling of intermittent production also requires a representation of geographical characteristics of production and transmission and a modelling of congestion over the electricity networks. Obviously, such features are necessary to adequately represent the market for steam and heat. Such features have not been yet introduced in PRIMES, as the model mainly aims to serve for integrated strategic analyses. The algebraic coding of the electricity and steam sub-model of PRIMES is enough generic and abstract, to provide a consistent framework for model expansion in the future, along the geographical or network congestion research lines.

The development of independent power and/or steam producers and their market forces heavily depend on the prevailing institutional regime in the market. In the past, market regulation, cross-subsidisation and the importance of returns to scale in power production has deprived small independent producers to enter the market. Exceptions have arisen in specific cases in which the scale of self-consumption or the existence of by-product fuels has permitted the survival of independent producers. The expectations for the future are different. New technologies allow for competitive production at a smaller scale, while the institutional regime in the market is increasingly opening to competition.

To represent these market dynamics, the model design preferred the representation of representative companies operating under a market competitive regime. For example, the exchanges of electricity and steam between the companies are performed under marginal cost pricing in the model. This choice has a limitation, as it cannot represent transitory phenomena of oligopolistic nature that might prevail in the market. However, a full competitive regime has been preferred as PRIMES puts emphasis on strategic analysis. Constraints regarding for example the degree of opening of the market can be introduced in the model through parameters regulating market allocation to producers.

In addition, constraints that would increase the inertia of the market are introduced in the form of contracts. These apply to both the exchanges between the companies and the provisions of fuels.

Decision-making by electric utilities (or steam producers) may be considered in three different, yet interrelated, problems:

? the *strategic capacity expansion problem* which concerns the choice of new plants for construction, so as to meet future demand at a least long-run generation cost;

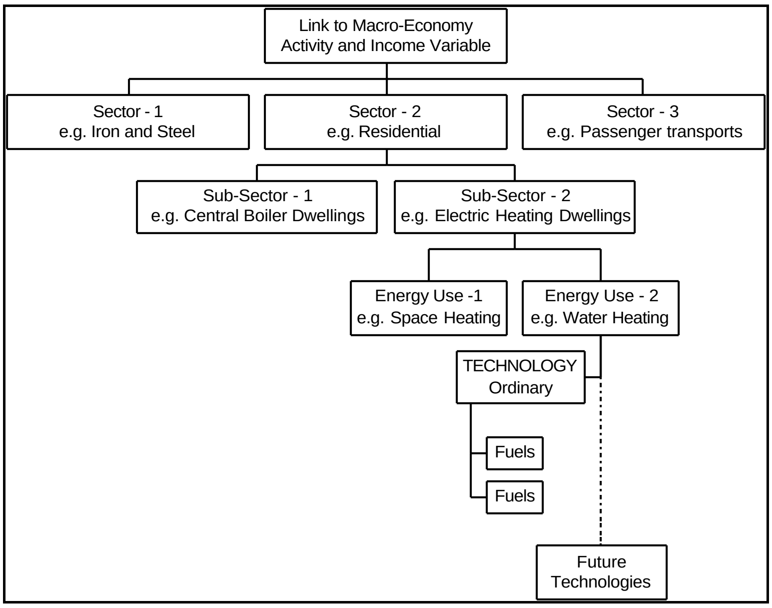
? the *operational plant selection and utilisation problem* which concerns the choice of existing plants to be committed in the system, so as to meet load at a least operation cost;

? the *cost evaluation and pricing policy* that has to be in conformity both with the long-term financial objectives of the company and with the aim to influence demand load.

In the electricity and steam sub-model of PRIMES, the representation of the above decision problems is in accordance with the optimal pattern of supply behaviour in a competitive equilibrium market. In particular, we formulate long run marginal cost principles for capacity expansion and short run marginal costing for dispatching and plant commitment. However, for price setting we formulate Ramsey pricing, which is close to average cost pricing, and we interpret this choice as representative of both the regulated monopoly and the monopolistic competition market regimes.

General Structure of the Demand Side Sub Models

The demand-side sub-models of PRIMES V.2 have a uniform structure. Each sub-model represents a sector that is further decomposed into sub-sectors and then into energy uses. A technology operates at the level of an energy use and utilises energy forms (fuels). The following graphic illustrates the hierarchical decomposition of the demand-side models.



The data that are necessary to calibrate the model for a base year (1995) and a country (all EU Member States) can be divided in the following categories.

- Macro-economic data that correspond to demographics national accounts, sectoral activity and income variables. These data usually apply to sectors.
- Structure of energy consumption along the above-described tree in the base year and structure of activity variables (production, dwellings, passenger-kilometres, etc.). Some indicators regarding specific energy consumption are also needed for calibration. The data bases MURE, IKARUS, ODYSSE and national sources have been used.
- Technical-economic data for technologies and sub-sectors (e.g. capital cost, unit efficiency, variable cost, lifetime, etc.).

APPENDIX II

Transformation of EUROSTAT energy balance sheets into PRIMES data

The basic source of data for energy consumption by sector and fuel is EUROSTAT (detailed energy balance sheets). By using additional information (surveys of cogeneration operation and capacities and surveys on boilers), the balance sheets have been modify in order to represent explicitly the production of steam.

According to PRIMES definitions, steam includes industrial steam and distributed heat (at small or large scale). In the balance sheets, EUROSTAT reports on steam production in the transformation input/output only if the producers sell that steam. If the steam, irrespectively of the way it is produced (e.g. a boiler or a CHP plant), is used for self-consumption only, EUROSTAT accounts for only the fuels used to produce that steam and includes these fuels in final energy consumption. The PRIMES database consists in introducing that steam (for self-consumption) in the final energy consumption tables of the balance sheets and inserting the fuels used to produce that steam in the table of transformation input and output. This is necessary for the model to calibrate to a base year that properly accounts for the existing cogeneration activities (even if they are used for self-generation of steam).

The following table illustrates the differences between EUROSTAT energy balance sheets (as available in 1998) and data as used in PRIMES model after the re-allocation of energy requirements for steam production by industrial sectors, as well as in refineries, in power and steam generation sector.

	Energy balance 1990 (ktoe)					CO2 emissions 1990 (Mt CO2)		
	EUROSTAT		PRIMES			EUROSTAT	PRIMES	
	Final energy demand	*of which steam*	Final energy demand	*of which steam*	*Input in industrial boilers*			
Total Industry	266026	3671	256931	55144	60568	571378	424285	
Iron and steel	55311	68	55293	189	139	175147	174748	
Non-ferrous metals	11304	0	11304	0	0	16240	16240	
Chemicals	51552	1571	48017	22564	24527	96675	26206	
Building materials	36417	0	36417	0	0	98142	98142	
Paper and pulp	29365	176	26454	13748	16482	29460	10586	
Food, drink, tobacco	22738	818	21103	11218	12035	46197	10677	
Textiles	9225	244	8529	4656	5108	42142	39278	
Engineering	25297	569	25167	1419	980	17190	2136	
Other industries	24819	225	24647	1351	1298	50185	46272	
Energy Branch	86520		55903	30617		129057	56840	
	Transformation input		Transformation input	*of which in ind. Boilers*				*of which in ind. Boilers*
Total power and steam generation	279706		365467	85761		991990	1211300	219310
Utilities	237935		237935			859584	859584	
District heating	9880		9880			30860	30860	
Industrial Autoproducers	31892		117653	85761		101547	320857	219310

Source: EUROSTAT, PRIMES

It should also be noted that EUROSTAT database includes a category for final consumption in industry, which incorporates fuel consumption that is not allocated in a specific sector. In general, biomass-waste consumption is allocated in this category and not in specific industrial sectors. In the context of Shared Analysis a discussion has been made with experts and institutes on where to allocate consumption of biomass-waste and it has been agreed that in most of the cases this is consumption of the paper and pulp sector for steam production. Finally, it should be mentioned that when calibrating the PRIMES model the split between agriculture and services was not available and therefore it was based on assumptions, which, however, underestimate fuel consumption in agriculture.

APPENDIX III

Correspondence between NACE coding and EUROSTAT energy balance sheets

The following table summarises the correspondance between NACE codes and EUROSTAT energy balances

EUROSTAT	NACE Divisions
Energy sector	NACE 10, 11, 12, 23 and 40
Industry	Industry
Iron and steel	NACE 27.1,27.2,27.3,27.51,27.52
Ore-extraction (except fuels)	NACE 13, 14
Non ferrous metals	NACE 27.4,27.53,27.54
Chemical industry	NACE 24
Non-metallic mineral products	NACE 26
Paper, pulp and printing	NACE 21, 22
Food, drink and tobacco	NACE 15, 16
Textile, leather and clothing	NACE 17, 18, 19
Engineering and other metal	NACE 28, 29, 30, 31, 32, 34, 35
Other non-classified	NACE 20, 25, 33, 36, 37, 45
Transport	NACE 60, 61 and 62
Residential	NACE 95
Commercial and Public Services	NACE 41, 50, 51, 52, 55, 63, 64, 65, 66, 67, 70, 71, 72, 73, 74, 75, 80, 85, 90, 91, 92, 93, 99
Agriculture	NACE 01, 02, 05

Detailed definition for NACE codes

27.1	Manufacture of basic iron and steel and of ferro-alloys (ECSC)
27.2	Manufacture of tubes
27.3	Other first processing of iron and steel and production of non-ECSC
27.51	Casting of iron
27.52	Casting of steel
13	Mining of metal ores
14	Other mining and quarrying
27.4	Manufacture of basic precious and non-ferrous metals
27.53	Casting of light metals
27.54	Casting of other non-ferrous metals

24	Manufacture of chemicals and chemical products
26	Manufacture of other non-metallic mineral products
21	Manufacture of pulp, paper and paper products
22	Publishing, printing, and reproduction of recorded media
15	Manufacture of food products and beverages
16	Manufacture of tobacco products
17	Manufacture of textiles
18	Manufacture of wearing apparel; dressing and dyeing of fur
19	Tanning and dressing leather; manufacture of luggage, handbags, saddlery, harness and footwear
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment n.e.c
30	Manufacture of office machinery and computers
31	Manufacture of electrical machinery and apparatus n.e.c
32	Manufacture of radio, television and communication equipment and apparatus
34	Manufacture of motor vehicles, trailers, and semi-trailers
35	Manufacture of other transport equipment
20	Manufacture of wood and of products of wood and cork, except furniture
25	Manufacture of rubber and plastic products
33	Manufacture of medical, precision and optical instruments, watches and clocks
36	Manufacture of furniture
37	Recycling
45	Construction
60	Land Transport: transport via pipelines
61	Water transport
62	Air transport
95	Private households with employed persons
41	Collection, purification and distribution of water
50	Sale, maintenance and repair of motor vehicles and motorcycles: retail sale of automotive fuel
51	Wholesale trade and commission trade, except of motor vehicles and motor cycles
52	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
55	Hotels and restaurants
63	Supporting and auxiliary transport activities; activities for travel agencies
64	Post and telecommunications
65	Financial intermediation, except compulsory social security
66	Insurance and pension funding, except compulsory social security
67	Activities auxiliary to financial intermediation

70	Real estate activities
71	Renting of machinery and equipment without operator and of personal and household goods
72	Computer and related activities
73	Research and development
74	Other business activities
75	Public administration and defence; compulsory social security
80	Education
85	Health and social work
90	Sewage and refuse disposal, sanitation, and similar activities
91	Activities of membership organizations n.e.c
92	Recreational, cultural and sporting activities
93	Other service activities
99	Extra-territorial organizations and bodies
01	Agriculture, hunting and related service activities
02	Forestry, logging, and related service activities
05	Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing

APPENDIX IV

List of participants in expert workshops

Experts Workshop “Transport sector” November 23, 1999, DG Environment, Brussels

Name	Organisation
Experts	
Jean-François Cayot	CLEPA, European Association of Automotive Suppliers
Francisco de la Chesnaye	US EPA
Mats Fredriksson	TEXACO, European Fuels Co-ordinator
Frazer Goodwin	European Federation for Transport and Environment
Winfried Hartung	Adam Opel AG, ITDC PT Legal and Performance Data
Reid Harvey	US EPA
Peter Heinze	Concawe
Tony Houseman	European Association of Aerospace Industries, Environment and Policy
Manfred Kalivoda	PsiA-Kalivoda Consult
Yves Maroger	Renault SA
Jürgen Reifig	European Asphalt Pavement Association c/o DAV
Klaus Schindler	Volkswagen AG
Consultants	
Judith Bates	AEA Technology Environment
David Moon	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Chris Hendriks	Ecofys Energy and Environment
Leonidas Mantzos	National Technical University of Athens
Commission Staff	
Stefan Winkelbauer	Transport DG E.1 “Analysis and development of transport policy”
Heinz Jansen	Economic and financial Affairs DG E.4“ Environmental policy, transport and energy”
Vicenc Pedret Cusco	Transport DG E.1 “Analysis and development of transport policy”
Leonidas Kioussis	Transport DG C.4 “Airport Policy, environment and other common policies”
Marianne Wenning	Environment DG A.2 ““Climate Change”

Suzanne Doschko	Entreprise DG B.5 “Access to finance and Community programmes”
Daniel Mailliet	Environment DG A.2 “Climate change”
Günter Hörmandinger	Environment DG D.3 “Air quality, urban environment, noise, transport and energy”
Thomas Verheye	Environment DG B.2 Economic Analyses and Employment Unit
Matti Vainio	Environment DG B.2 Economic Analyses and Employment Unit

Experts Workshop “Energy supply” March 29, 2000, DG Environment, Brussels

Name	**Organisation**
Eivind Aarebrot	Statoil
Rob Bradley	Climate Network Europe
Marc Darras	Gaz de France
Jürgen Engelhard	Rheinbraun AG
Margot Loudon	Eurogas (European Union of the Natural Gas Industry)
Mercedes Marin	COGEN Europe
Bo Nelson	Vattenfall
Nick Otter	ABB Alstom Power
Beate Raabe	International Association of Oil and Gas Producers
Stephan Singer	WWF European Policy Office
Björn Sund	Norsk Hydro, Research Technology
Helmut Warsch	Siemens
Gerd Weber	German Coal Mining Association
Arturos Zervos	European Wind Energy Association
Consultants	
Judith Bates	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Pantelis Capros	NTUA - E3M – Lab
David de Jager	Ecofys Energy and Environment
Chris Hendriks	Ecofys Energy and Environment
Commission staff	
Timo Aaltonen	TREN.B.1 Sectorial Economy
Jaime Garcia	TREN.A.3 Environment
Marc Hayden	ECFIN.E.4 Environmental policy, transport and energy
Peter Horrocks	ENV.D.3 Air quality, urbain environement, noise, transport &

	energy
Marco Loprieno	ENV.A.2 Climate change
Aphrodite Mourelatou	European Environment Agency
Matti Vainio	ENV.B.2 Economic Analyses and Employment
Beatriz Yordi	DG TREN.D.1 Promotion des énergies et maîtrise de la demande

Experts Workshop "Industry" and "Commercial and Residential sector", March 30, 2000, DG Environment, Brussels

Name	**Organisation**
Experts	
Paul Ashford	Caleb Management Services Limited (EUROACE)
Rob Bradley	Climate Network Europe
Valérie Callaud	EUROPIA
Giovanni Cinti	Italcementi Group, C.T.G. S.p.A
Christine De Laeter	Dow Benelux NV Powerplant
Aymon de Reydellet	Saint Gobain Isover, Environnement et risques industriels
Mats Fredriksson	Texaco
Graham Funnell	UK Steel Association
Anu Karessuo	Finnish Forest Industries Federation Environmental Manager
Paul Laffont	Saint Gobain Isover Dir. Environnement et Normalisation
Lars Nilsson	Lund University Department of environmental and energy systems studies
Erik Nordheim	European Aluminium Association
Stephan Singer	WWF European Policy Office
Helmut Warsch	Siemens
Consultants	
Judith Bates	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Pantelis Capros	National Technical University of Athens
Jeroen de Beer	Ecofys Energy and Environment
Chris Hendriks	Ecofys Energy and Environment
Commission staff	
Timo Aaltonen	TREN.B.1
Suzanne Doschko	ENTR.E.1
Marc Hayden	ECFIN.E.4 Environmental policy, transport and energy
Peter Horrocks	ENV.D.3, Air quality, urban environment, noise, transport & energy

Daniel Johansson	European Commission ENTR.D.4 ICT & electronic commerce
Marco Loprieno	ENV.A2 Climate change unit
Stefan Lorenz-Meyer	ENTR.E.2
Åsa Malmstrom	ENTR.G.5
Aphrodite Mourelatou	European Environment Agency
Annika Nilsson	Commission DG ENV D.3
Norbert Theis	DG ENTR.E.3
Matti Vainio	ENV B.2, Economic analyses and employment

Experts Workshop "Transport sector" March 30, 2000, DG Environment, Brussels

Name	**Organisation**
Experts	
Jean-François Cayot	c/o CLEPA, European Association of Automotive Suppliers
Mats Fredriksson	Texaco
Jean-Loup Gauducheau	Agence de L'Environnement et de l'Energie
Frazer Goodwin	European Federation for Transport and Environment
Winfried Hartung	Adam Opel AG ITDC PT Legal & Performance Data
Alain Henry	TREMOVE
Stephan Singer	WWF European Policy Office
J.W. Turner	ACEA (European Automobile Manufacturers Association) Consultant
Consultants	
Judith Bates	AEA Technology Environment
Kornelis Blok	Ecofys Energy and Environment
Professor Pantelis Capros	National Technical University of Athens, E3M – Lab
Chris Hendriks	Ecofys Energy and Environment
Commission Staff	
Timo Aaltonen	TREN.B.1 Economie sectorielle
Franz-Xavier Soeldner	TREN.A.3 Environment
Jaime Garcia-Rodriguez	TREN.A.3 Environment
Matti Vainio	ENV.B.2 Economic Analyses & Employment
Stefan Vergote	ENTR.F.5

APPENDIX V

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.

APPENDIX VI

Sectoral analysis of impacts of alternative emission reduction objectives in the EU energy system

Results obtained from PRIMES Model Runs for energy related CO2 emissions in the EU can be found on:

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

in the following file:

TD App 6.pdf

APPENDIX VII

Meta-model analysis results for the EU

Results obtained from meta-model run combining PRIMES results for CO2 emissions and ECOFYS results for non-CO2 greenhouse gases.

Three scenarios were examined with two alternative presentations of results, i.e. emissions of industrial boilers allocated to industrial sectors or to the energy supply sector.

	Scenario	In/excl. ACEA agreement in the baseline	Allocation of industrial boilers
EUwACEA1	EU-wide objectives	including ACEA agreement in the baseline	industrial boilers allocated to industrial sectors
EUwACEA2	EU-wide objectives	including ACEA agreement in the baseline	industrial boilers allocated to energy industries
MSwACEA1	Member State based objectives	including ACEA agreement in the baseline	industrial boilers allocated to industrial sectors
MSwACEA2	Member State based objectives	including ACEA agreement in the baseline	industrial boilers allocated to energy industries
EUnACEA1	EU-wide objectives	excluding ACEA agreement from the baseline	industrial boilers allocated to industrial sectors
EUnACEA2	EU-wide objectives	excluding ACEA agreement from the baseline	industrial boilers allocated to energy industries

In the tables on the next pages the results are presented for all three scenario's with industrial boilers allocated to industrial sectors (TD App 7.pdf).

Complete EU and Member State results of the meta-analysis can be found on:

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

in the following files:

European Union.pdf

Austria.pdf

Belgium.pdf

Denmark.pdf

Finland.pdf

France.pdf

Germany.pdf

Greece.pdf

Ireland.pdf

Italy.pdf

Netherlands.pdf

Portugal.pdf

Spain.pdf

Sweden.pdf

United Kingdom.pdf

EU (EU-wide implementation including ACEA agreement)

industrial boilers allocated to industrial sectors

marginal cost: 20.28 Euro'99 per t of CO2 eq.

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
	Emissions in 1990 or 1995	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Energy supply																
CO2 (fuel related)	1131.5	1160.7	1011.1	-10.6%	-12.9%											149.7
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0	-	-	0.0
CH4	12.4	12.4	12.4	0.0%	0.0%						12.4	12.4	12.4	0.0%	0.0%	0.0
N2O	41.9	28.6	26.8	-35.9%	-6.1%						41.9	28.6	26.8	-35.9%	-6.1%	1.7
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	4.0	4.0	3.2	-20.0%	-20.0%						4.0	4.0	3.2	-20.0%	-20.0%	0.8
Sub-total	1189.8	1205.7	1053.5	-11.5%	-12.6%						58.3	45.0	42.5	-27.1%	-5.7%	152.2
Fossil fuel extraction, transport and distribution																
CO2 (fuel related)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	94.6	60.5	50.8	-46.3%	-15.9%						94.6	60.5	50.8	-46.3%	-15.9%	9.6
N2O	0.3	0.3	0.3	0.0%	0.0%						0.3	0.3	0.3	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	94.9	60.8	51.1	-46.1%	-15.8%						94.9	60.8	51.1	-46.1%	-15.8%	9.6
Industry																
CO2 (fuel related)	561.4	449.5	415.6	-26.0%	-7.6%	489.4	523.3	459.8	-6.0%	-12.1%	1050.8	972.8	875.4	-16.7%	-10.0%	34.0
CO2 (other)	156.8	175.6	174.5	11.3%	-0.6%						156.8	175.6	174.5	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.2	29.6	-42.0%	-43.3%						51.1	52.2	29.6	-42.0%	-43.3%	22.6
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	894.1	758.9	664.9	-25.6%	-12.4%	489.4	523.3	459.8	-6.0%	-12.1%	1383.4	1282.1	1124.8	-18.7%	-12.3%	93.9
Transport																
CO2 (fuel related)	734.8	919.0	886.8	20.7%	-3.5%	25.4	34.3	29.4	15.8%	-14.4%	760.2	953.3	916.1	20.5%	-3.9%	32.2
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	5.2	3.1	3.1	-41.1%	0.0%						5.2	3.1	3.1	-41.1%	0.0%	0.0
N2O	11.8	37.8	37.8	220.6%	0.0%						11.8	37.8	37.8	220.6%	0.0%	0.0
HFC	1.2	24.6	18.0	1347.6%	-26.9%						1.2	24.6	18.0	1347.6%	-26.9%	6.6
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	753.1	984.4	945.6	25.6%	-3.9%	25.4	34.3	29.4	15.8%	-14.4%	778.4	1018.7	975.0	25.3%	-4.3%	38.8
Households																
CO2 (fuel related)	447.5	443.7	419.8	-6.2%	-5.4%	344.5	302.6	263.4	-23.6%	-13.0%	792.0	746.3	683.2	-13.7%	-8.5%	23.9
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	1.7	0.6	-	-62.7%						0.0	1.7	0.6	-	-62.7%	1.1
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	447.5	445.4	420.4	-6.0%	-5.6%	344.5	302.6	263.4	-23.6%	-13.0%	792.0	748.0	683.8	-13.7%	-8.6%	25.0
Services																
CO2 (fuel related)	175.6	194.1	164.0	-6.6%	-15.5%	272.2	300.5	258.6	-5.0%	-14.0%	447.9	494.7	422.6	-5.6%	-14.6%	30.1
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	5.7	5.7	-	0.0%						0.0	5.7	5.7	-	0.0%	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	175.6	199.9	169.8	-3.3%	-15.1%	272.2	300.5	258.6	-5.0%	-14.0%	447.9	500.4	428.3	-4.4%	-14.4%	30.1
Agriculture																
CO2 (fuel related)	17.3	26.3	24.9	44.1%	-5.2%	0.0	0.0	0.0	-	-	17.3	26.3	24.9	44.1%	-5.2%	1.4
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	193.8	177.7	169.7	-12.4%	-4.5%						193.8	177.7	169.7	-12.4%	-4.5%	8.0
N2O	205.8	193.9	187.7	-8.8%	-3.2%						205.8	193.9	187.7	-8.8%	-3.2%	6.2
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	416.9	397.9	382.3	-8.3%	-3.9%	0.0	0.0	0.0	-	-	416.9	397.9	382.3	-8.3%	-3.9%	15.6
Waste																
CO2 (fuel related)	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0
CO2 (other)	7.6	7.6	7.6	0.0%	0.0%						7.6	7.6	7.6	0.0%	0.0%	0.0
CH4	155.1	126.0	108.2	-30.3%	-14.1%						155.1	126.0	108.2	-30.3%	-14.1%	17.8
N2O	3.7	3.7	3.7	0.0%	0.0%						3.7	3.7	3.7	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	166.4	137.3	119.5	-28.2%	-13.0%	0.0	0.0	0.0	-	-	166.4	137.3	119.5	-28.2%	-13.0%	17.8
All sectors																
CO2 (fuel related)	3068.1	3193.3	2922.1	-4.8%	-8.5%						3068.1	3193.3	2922.1	-4.8%	-8.5%	271.2
CO2 (other)	164.4	183.1	182.1	10.8%	-0.6%						164.4	183.1	182.1	10.8%	-0.6%	1.1
CH4	461.7	380.1	344.7	-25.3%	-9.3%						461.7	380.1	344.7	-25.3%	-9.3%	35.4
N2O	376.3	317.0	282.4	-24.9%	-10.9%						376.3	317.0	282.4	-24.9%	-10.9%	34.6
HFC	52.3	84.2	54.0	3.2%	-35.9%						52.3	84.2	54.0	3.2%	-35.9%	30.3
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	5.5	6.9	3.2	-41.2%	-53.4%						5.5	6.9	3.2	-41.2%	-53.4%	3.7
Total	4138.3	4190.3	3807.2	-8.0%	-9.1%						4138.3	4190.3	3807.2	-8.0%	-9.1%	383.0

EU (EU-wide implementation including ACEA agreement)

industrial boilers allocated to industrial sectors

marginal cost: 20.28 Euro'99 per t of CO2 eq.

Industrial sectors

	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Iron and steel																
CO2 (fuel related)	172.6	133.9	120.3	-30.3%	-10.2%	56.6	41.7	37.8	-33.1%	-9.2%	229.2	175.6	158.1	-31.0%	-10.0%	13.6
CO2 (other)	23.4	24.3	24.3	4.0%	0.0%						23.4	24.3	24.3	4.0%	0.0%	0.0
CH4	0.2	0.2	0.2	0.0%	0.0%						0.2	0.2	0.2	0.0%	0.0%	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	196.2	158.4	144.7	-26.2%	-8.6%	56.6	41.7	37.8	-33.1%	-9.2%	252.7	200.1	182.6	-27.8%	-8.7%	13.6
Non-ferrous metals																
CO2 (fuel related)	15.2	12.5	12.0	-21.1%	-3.6%	41.3	19.8	17.2	-58.4%	-13.4%	56.5	32.3	29.2	-48.3%	-9.6%	0.4
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	7.7	6.5	1.0	-87.3%	-84.9%						7.7	6.5	1.0	-87.3%	-84.9%	5.5
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	24.4	21.8	13.0	-46.7%	-40.5%	41.3	19.8	17.2	-58.4%	-13.4%	65.6	41.7	30.2	-54.0%	-27.6%	8.8
Chemicals																
CO2 (fuel related)	96.4	51.4	45.1	-53.2%	-12.3%	119.4	135.5	119.8	0.4%	-11.5%	215.8	186.9	165.0	-23.5%	-11.7%	6.3
CO2 (other)	11.4	14.2	14.2	25.0%	0.0%						11.4	14.2	14.2	25.0%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	108.2	48.2	21.5	-80.1%	-55.4%						108.2	48.2	21.5	-80.1%	-55.4%	26.7
HFC	26.5	7.2	0.4	-98.6%	-95.0%						26.5	7.2	0.4	-98.6%	-95.0%	6.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	242.6	121.1	81.3	-66.5%	-32.8%	119.4	135.5	119.8	0.4%	-11.5%	362.0	256.6	201.1	-44.4%	-21.6%	39.8
Building Materials																
CO2 (fuel related)	95.2	92.0	89.2	-6.3%	-3.0%	35.8	28.7	24.7	-31.0%	-14.1%	130.9	120.7	113.9	-13.1%	-5.7%	2.8
CO2 (other)	105.8	119.6	118.5	12.0%	-0.9%						105.8	119.6	118.5	12.0%	-0.9%	1.1
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	201.0	211.6	207.7	3.3%	-1.8%	35.8	28.7	24.7	-31.0%	-14.1%	236.8	240.3	232.4	-1.9%	-3.3%	3.9
Paper and Pulp																
CO2 (fuel related)	28.9	21.7	19.7	-31.8%	-9.1%	40.2	84.1	72.7	80.8%	-13.5%	69.1	105.8	92.4	33.7%	-12.6%	2.0
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	28.9	21.7	19.7	-31.8%	-9.1%	40.2	84.1	72.7	80.8%	-13.5%	69.1	105.8	92.4	33.7%	-12.6%	2.0
Food, drink and tobacco																
CO2 (fuel related)	45.5	31.0	26.4	-42.0%	-14.7%	43.6	72.2	64.3	47.5%	-11.0%	89.1	103.2	90.7	1.8%	-12.1%	4.6
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	3.8	0.0	-	-100.0%						0.0	3.8	0.0	-	-100.0%	3.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	45.5	34.8	26.4	-42.0%	-24.0%	43.6	72.2	64.3	47.5%	-11.0%	89.1	107.0	90.7	1.8%	-15.3%	8.4
Other industries																
CO2 (fuel related)	107.6	107.1	102.9	-4.4%	-4.0%	152.6	141.2	123.3	-19.2%	-12.7%	260.2	248.3	226.2	-13.1%	-8.9%	4.2
CO2 (other)	16.2	17.5	17.5	7.5%	0.0%						16.2	17.5	17.5	7.5%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	4.7	4.7	4.7	0.0%	0.0%						4.7	4.7	4.7	0.0%	0.0%	0.0
HFC	24.5	41.2	29.2	19.2%	-29.0%						24.5	41.2	29.2	19.2%	-29.0%	12.0
PFC	2.3	19.0	17.7	659.8%	-6.6%						2.3	19.0	17.7	659.8%	-6.6%	1.3
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	155.4	189.4	172.0	10.7%	-9.2%	152.6	141.2	123.3	-19.2%	-12.7%	308.0	330.7	295.3	-4.1%	-10.7%	17.5
Total industry																
CO2 (fuel related)	561.4	449.5	415.6	-26.0%	-7.6%	489.4	523.3	459.8	-6.0%	-12.1%	1050.8	972.8	875.4	-16.7%	-10.0%	34.0
CO2 (other)	156.8	175.6	174.5	11.3%	-0.6%						156.8	175.6	174.5	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.2	29.6	-42.0%	-43.3%						51.1	52.2	29.6	-42.0%	-43.3%	22.6
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Total industry	894.0	758.8	664.9	-25.6%	-12.4%	489.4	523.3	459.8	-6.0%	-12.1%	1383.3	1282.1	1124.7	-18.7%	-12.3%	93.9

EU (EU-wide implementation including ACEA agreement) — industrial boilers allocated to industrial sectors

marginal cost: 20.28 Euro'99 per t of CO2 eq.

Transport sector (CO2)

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
	Emissions in 1990 or 1995	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by transport mean																
road	623.5	741.2	724.5	16.2%	-2.3%						623.5	741.2	724.5	16.2%	-2.3%	16.7
train	9.1	1.7	1.5	-83.1%	-8.2%	25.4	34.3	29.4	15.8%	-14.4%	34.5	36.0	30.9	-10.4%	-14.1%	0.1
aviation	81.6	149.5	134.8	65.2%	-9.8%						81.6	149.5	134.8	65.2%	-9.8%	14.7
inl. navigation	20.6	26.5	26.0	26.3%	-2.2%						20.6	26.5	26.0	26.3%	-2.2%	0.6
by transport activity (base year: 1995)																
passenger	545.2	608.8	588.9	8.0%	-3.3%						545.2	608.8	588.9	8.0%	-3.3%	19.9
freight	254.4	310.2	297.8	17.1%	-4.0%						254.4	310.2	297.8	17.1%	-4.0%	12.3
Sub-total	734.8	919.0	886.8	20.7%	-3.5%	25.4	34.3	29.4	15.8%	-14.4%	760.2	953.3	916.1	20.5%	-3.9%	32.2

EU (EU-wide implementation including ACEA agreement) — industrial boilers allocated to industrial sectors

marginal cost: 20.28 Euro'99 per t of CO2 eq.

Energy supply (CO2)

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
	Emissions in 1990 or 1995	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by generator																
industrial generators	123.7	250.5	203.2	64.3%	-18.9%											47.3
other generators	0.0	27.7	25.7	-	-7.2%											2.0
utilities	835.8	771.9	666.8	-20.2%	-13.6%											105.0
boilers in	114.6	55.5	62.6	-45.4%	12.8%											-7.1
industry	0.0	0.0	0.0	-	-											0.0
refineries	73.8	42.4	50.7	-31.3%	19.4%											-8.3
district heating	40.8	13.0	11.9	-70.9%	-8.8%											1.2
fuel extraction and refining	57.5	55.1	52.8	-8.2%	-4.3%											2.4
Sub-total	1131.5	1160.7	1011.1	-10.6%	-12.9%											149.7

EU (Burden Sharing scenario including ACEA agreement)

industrial boilers allocated to industrial sectors

marginal cost: 41.84 Euro'99 per t of CO2 eq.

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
	Emissions in 1990 or 1995	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Energy supply																
CO2 (fuel related)	1131.5	1160.7	1006.7	-11.0%	-13.3%											154.0
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0	-	-	0.0
CH4	12.4	12.4	12.4	0.0%	0.0%						12.4	12.4	12.4	0.0%	0.0%	0.0
N2O	41.9	28.6	26.9	-35.6%	-5.8%						41.9	28.6	26.9	-35.6%	-5.8%	1.6
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	4.0	4.0	3.5	-14.1%	-14.1%						4.0	4.0	3.5	-14.1%	-14.1%	0.6
Sub-total	1189.8	1205.7	1049.5	-11.8%	-13.0%						58.3	45.0	42.8	-26.5%	-4.9%	156.2
Fossil fuel extraction, transport and distribution																
CO2 (fuel related)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	94.6	60.4	48.6	-48.6%	-19.5%						94.6	60.4	48.6	-48.6%	-19.5%	11.8
N2O	0.3	0.3	0.3	0.0%	0.0%						0.3	0.3	0.3	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	94.9	60.7	48.9	-48.4%	-19.4%						94.9	60.7	48.9	-48.4%	-19.4%	11.8
Industry																
CO2 (fuel related)	561.4	449.5	419.1	-25.4%	-6.8%	489.4	523.3	454.0	-7.2%	-13.2%	1050.8	972.8	873.1	-16.9%	-10.2%	30.5
CO2 (other)	156.2	175.0	173.9	11.3%	-0.6%						156.2	175.0	173.9	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.1	31.1	-39.1%	-40.3%						51.1	52.1	31.1	-39.1%	-40.3%	21.0
PFC	10.0	25.4	16.3	62.2%	-36.1%						10.0	25.4	16.3	62.2%	-36.1%	9.2
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	893.5	758.1	666.9	-25.4%	-12.0%	489.4	523.3	454.0	-7.2%	-13.2%	1382.8	1281.4	1120.9	-18.9%	-12.5%	91.2
Transport																
CO2 (fuel related)	734.8	919.0	887.6	20.8%	-3.4%	25.4	34.3	30.1	18.9%	-12.1%	760.2	953.3	917.7	20.7%	-3.7%	31.4
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	5.2	3.1	3.1	-41.1%	0.0%						5.2	3.1	3.1	-41.1%	0.0%	0.0
N2O	11.8	37.8	37.8	220.6%	0.0%						11.8	37.8	37.8	220.6%	0.0%	0.0
HFC	1.2	24.6	17.8	1331.7%	-27.7%						1.2	24.6	17.8	1331.7%	-27.7%	6.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	753.1	984.4	946.2	25.6%	-3.9%	25.4	34.3	30.1	18.9%	-12.1%	778.4	1018.7	976.3	25.4%	-4.2%	38.2
Households																
CO2 (fuel related)	447.5	443.7	423.2	-5.4%	-4.6%	344.5	302.6	264.4	-23.3%	-12.6%	792.0	746.3	687.6	-13.2%	-7.9%	20.5
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	1.7	0.8	-	-53.6%						0.0	1.7	0.8	-	-53.6%	0.9
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	447.5	445.4	424.0	-5.2%	-4.8%	344.5	302.6	264.4	-23.3%	-12.6%	792.0	748.0	688.3	-13.1%	-8.0%	21.4
Services																
CO2 (fuel related)	175.6	194.1	172.4	-1.8%	-11.2%	272.2	300.5	258.2	-5.2%	-14.1%	447.9	494.7	430.5	-3.9%	-13.0%	21.8
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	5.7	5.5	-	-3.8%						0.0	5.7	5.5	-	-3.8%	0.2
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	175.6	199.9	177.9	1.3%	-11.0%	272.2	300.5	258.2	-5.2%	-14.1%	447.9	500.4	436.1	-2.6%	-12.9%	22.0
Agriculture																
CO2 (fuel related)	17.3	26.3	23.1	33.8%	-12.0%	0.0	0.0	0.0	-	-	17.3	26.3	23.1	33.8%	-12.0%	3.2
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	193.4	177.4	169.0	-12.6%	-4.7%						193.4	177.4	169.0	-12.6%	-4.7%	8.4
N2O	205.8	193.9	187.7	-8.8%	-3.2%						205.8	193.9	187.7	-8.8%	-3.2%	6.2
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	416.6	397.5	379.8	-8.8%	-4.5%	0.0	0.0	0.0	-	-	416.6	397.5	379.8	-8.8%	-4.5%	17.8
Waste																
CO2 (fuel related)	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0
CO2 (other)	7.5	7.5	7.5	0.0%	0.0%						7.5	7.5	7.5	0.0%	0.0%	0.0
CH4	155.1	125.9	105.5	-31.9%	-16.2%						155.1	125.9	105.5	-31.9%	-16.2%	20.4
N2O	3.7	3.7	3.7	0.0%	0.0%						3.7	3.7	3.7	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	166.3	137.2	116.8	-29.8%	-14.9%	0.0	0.0	0.0	-	-	166.3	137.2	116.8	-29.8%	-14.9%	20.4
All sectors																
CO2 (fuel related)	3068.1	3193.3	2932.0	-4.4%	-8.2%						3068.1	3193.3	2932.0	-4.4%	-8.2%	261.3
CO2 (other)	163.8	182.5	181.5	10.8%	-0.6%						163.8	182.5	181.5	10.8%	-0.6%	1.1
CH4	461.1	379.6	339.1	-26.5%	-10.7%						461.1	379.6	339.1	-26.5%	-10.7%	40.6
N2O	376.3	317.0	282.5	-24.9%	-10.9%						376.3	317.0	282.5	-24.9%	-10.9%	34.5
HFC	52.3	84.1	55.2	5.4%	-34.4%						52.3	84.1	55.2	5.4%	-34.4%	28.9
PFC	10.0	25.4	16.3	62.2%	-36.1%						10.0	25.4	16.3	62.2%	-36.1%	9.2
SF6	5.5	6.9	3.5	-36.8%	-49.9%						5.5	6.9	3.5	-36.8%	-49.9%	3.4
Total	4137.1	4189.0	3810.0	-7.9%	-9.0%						4137.1	4189.0	3810.0	-7.9%	-9.0%	379.0

EU (Burden Sharing scenario including ACEA agreement)

industrial boilers allocated to industrial sectors

marginal cost: 41.84 Euro'99 per t of CO2 eq.

Industrial sectors

	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Iron and steel																
CO2 (fuel related)	172.6	133.9	120.7	-30.1%	-9.9%	56.6	41.7	37.6	-33.5%	-9.7%	229.2	175.6	158.3	-30.9%	-9.9%	13.3
CO2 (other)	23.4	24.3	24.3	4.0%	0.0%						23.4	24.3	24.3	4.0%	0.0%	0.0
CH4	0.2	0.2	0.2	0.0%	0.0%						0.2	0.2	0.2	0.0%	0.0%	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	196.2	158.4	145.1	-26.0%	-8.4%	56.6	41.7	37.6	-33.5%	-9.7%	252.7	200.1	182.7	-27.7%	-8.7%	13.3
Non-ferrous metals																
CO2 (fuel related)	15.2	12.5	12.1	-20.6%	-3.0%	41.3	19.8	17.6	-57.3%	-11.2%	56.5	32.3	29.7	-47.4%	-8.0%	0.4
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	7.7	6.5	1.0	-87.3%	-84.9%						7.7	6.5	1.0	-87.3%	-84.9%	5.5
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	24.4	21.8	13.1	-46.4%	-40.1%	41.3	19.8	17.6	-57.3%	-11.2%	65.6	41.7	30.7	-53.3%	-26.4%	8.8
Chemicals																
CO2 (fuel related)	96.4	51.4	45.6	-52.7%	-11.4%	119.4	135.5	118.1	-1.0%	-12.8%	215.8	186.9	163.7	-24.1%	-12.4%	5.9
CO2 (other)	11.4	14.2	14.2	25.0%	0.0%						11.4	14.2	14.2	25.0%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	108.2	48.2	21.5	-80.1%	-55.4%						108.2	48.2	21.5	-80.1%	-55.4%	26.7
HFC	26.5	7.2	0.4	-98.6%	-95.0%						26.5	7.2	0.4	-98.6%	-95.0%	6.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	242.6	121.1	81.8	-66.3%	-32.5%	119.4	135.5	118.1	-1.0%	-12.8%	362.0	256.6	199.9	-44.8%	-22.1%	39.3
Building Materials																
CO2 (fuel related)	95.2	92.0	89.2	-6.3%	-3.1%	35.8	28.7	25.1	-30.0%	-12.8%	130.9	120.7	114.2	-12.8%	-5.4%	2.8
CO2 (other)	105.8	119.6	118.5	12.0%	-0.9%						105.8	119.6	118.5	12.0%	-0.9%	1.1
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	201.0	211.6	207.7	3.3%	-1.8%	35.8	28.7	25.1	-30.0%	-12.8%	236.8	240.3	232.8	-1.7%	-3.1%	3.9
Paper and Pulp																
CO2 (fuel related)	28.9	21.7	19.7	-31.8%	-9.0%	40.2	84.1	69.2	71.9%	-17.8%	69.1	105.8	88.9	28.6%	-16.0%	2.0
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	28.9	21.7	19.7	-31.8%	-9.0%	40.2	84.1	69.2	71.9%	-17.8%	69.1	105.8	88.9	28.6%	-16.0%	2.0
Food, drink and tobacco																
CO2 (fuel related)	45.5	31.0	28.1	-38.3%	-9.4%	43.6	72.2	63.2	45.1%	-12.5%	89.1	103.2	91.3	2.5%	-11.6%	2.9
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	3.8	0.4	-	-88.5%						0.0	3.8	0.4	-	-88.5%	3.4
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	45.5	34.7	28.5	-37.4%	-18.0%	43.6	72.2	63.2	45.1%	-12.5%	89.1	107.0	91.7	3.0%	-14.3%	6.3
Other industries																
CO2 (fuel related)	107.6	107.1	103.8	-3.5%	-3.1%	152.6	141.2	123.2	-19.2%	-12.8%	260.2	248.3	227.0	-12.7%	-8.6%	3.3
CO2 (other)	15.7	16.9	16.9	7.8%	0.0%						15.7	16.9	16.9	7.8%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	4.7	4.7	4.7	0.0%	0.0%						4.7	4.7	4.7	0.0%	0.0%	0.0
HFC	24.5	41.1	30.3	23.5%	-26.3%						24.5	41.1	30.3	23.5%	-26.3%	10.8
PFC	2.3	18.9	15.3	556.2%	-19.4%						2.3	18.9	15.3	556.2%	-19.4%	3.7
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	154.8	188.7	170.9	10.4%	-9.4%	152.6	141.2	123.2	-19.2%	-12.8%	307.4	330.0	294.2	-4.3%	-10.9%	17.8
Total industry																
CO2 (fuel related)	561.4	449.5	419.1	-25.4%	-6.8%	489.4	523.3	454.0	-7.2%	-13.2%	1050.8	972.8	873.1	-16.9%	-10.2%	30.5
CO2 (other)	156.2	175.0	173.9	11.3%	-0.6%						156.2	175.0	173.9	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.1	31.1	-39.1%	-40.3%						51.1	52.1	31.1	-39.1%	-40.3%	21.0
PFC	10.0	25.4	16.3	62.2%	-36.1%						10.0	25.4	16.3	62.2%	-36.1%	9.2
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Total industry	893.4	758.0	666.8	-25.4%	-12.0%	489.4	523.3	454.0	-7.2%	-13.2%	1382.8	1281.3	1120.9	-18.9%	-12.5%	91.2

EU (Burden Sharing scenario including ACEA agreement) **industrial boilers allocated to industrial sectors**

marginal cost: 41.84 Euro'99 per t of CO2 eq.

Transport sector (CO2)

	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by transport mean																
road	623.5	741.2	726.8	16.6%	-1.9%						623.5	741.2	726.8	16.6%	-1.9%	14.4
train	9.1	1.7	1.6	-82.8%	-6.7%	25.4	34.3	30.1	18.9%	-12.1%	34.5	36.0	31.7	-8.1%	-11.9%	0.1
aviation	81.6	149.5	133.2	63.3%	-10.9%						81.6	149.5	133.2	63.3%	-10.9%	16.3
inl. navigation	20.6	26.5	26.0	26.4%	-2.1%						20.6	26.5	26.0	26.4%	-2.1%	0.6
by transport activity (base year: 1995)																
passenger	545.2	608.8	588.4	7.9%	-3.4%						545.2	608.8	588.4	7.9%	-3.4%	20.4
freight	254.4	310.2	299.2	17.6%	-3.5%						254.4	310.2	299.2	17.6%	-3.5%	11.0
Sub-total	734.8	919.0	887.6	20.8%	-3.4%	25.4	34.3	30.1	18.9%	-12.1%	760.2	953.3	917.7	20.7%	-3.7%	31.4

EU (Burden Sharing scenario including ACEA agreement) **industrial boilers allocated to industrial sectors**

marginal cost: 41.84 Euro'99 per t of CO2 eq.

Energy supply (CO2)

	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by generator																
industrial generators	123.7	250.5	196.7	59.1%	-21.5%											53.8
other generators	0.0	27.7	24.6	-	-11.3%											3.1
utilities	835.8	771.9	671.3	-19.7%	-13.0%											100.6
boilers in	114.6	55.5	60.8	-46.9%	9.7%											-5.4
industry	0.0	0.0	0.0	-	-											0.0
refineries	73.8	42.4	49.5	-32.9%	16.7%											-7.1
district heating	40.8	13.0	11.4	-72.2%	-12.9%											1.7
fuel extraction and refining	57.5	55.1	53.2	-7.4%	-3.5%											1.9
Sub-total	1131.5	1160.7	1006.7	-11.0%	-13.3%											154.0

EU (EU-wide implementation excluding ACEA agreement) — industrial boilers allocated to industrial sectors

marginal cost: 31.62 Euro'99 per t of CO2 eq.

Emission (Mt of CO2 equivalent)	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
	Emissions in 1990 or 1995	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Energy supply																
CO2 (fuel related)	1131.5	1167.0	970.6	-14.2%	-16.8%											196.4
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0	-	-	0.0
CH4	12.4	12.4	12.4	0.0%	0.0%						12.4	12.4	12.4	0.0%	0.0%	0.0
N2O	41.9	28.6	26.8	-35.9%	-6.1%						41.9	28.6	26.8	-35.9%	-6.1%	1.7
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	4.0	4.0	3.2	-20.0%	-20.0%						4.0	4.0	3.2	-20.0%	-20.0%	0.8
Sub-total	1189.8	1212.1	1013.1	-14.9%	-16.4%						58.3	45.0	42.5	-27.1%	-5.7%	199.0
Fossil fuel extraction, transport and distribution																
CO2 (fuel related)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CO2 (other)	0.0	0.0	0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	94.6	60.5	50.8	-46.3%	-15.9%						94.6	60.5	50.8	-46.3%	-15.9%	9.6
N2O	0.3	0.3	0.3	0.0%	0.0%						0.3	0.3	0.3	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	94.9	60.8	51.1	-46.2%	-15.9%						94.9	60.8	51.1	-46.2%	-15.9%	9.6
Industry																
CO2 (fuel related)	561.4	448.7	409.1	-27.1%	-8.8%	489.4	525.8	442.4	-9.6%	-15.9%	1050.8	974.5	851.5	-19.0%	-12.6%	39.6
CO2 (other)	156.8	175.6	174.5	11.3%	-0.6%						156.8	175.6	174.5	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.2	28.2	-44.7%	-45.9%						51.1	52.2	28.2	-44.7%	-45.9%	24.0
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	894.1	758.1	657.1	-26.5%	-13.3%	489.4	525.8	442.4	-9.6%	-15.9%	1383.4	1283.9	1099.5	-20.5%	-14.4%	100.9
Transport																
CO2 (fuel related)	734.8	994.1	950.2	29.3%	-4.4%	25.4	35.0	28.4	12.2%	-18.8%	760.2	1029.1	978.7	28.7%	-4.9%	43.9
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	5.2	3.1	3.1	-41.1%	0.0%						5.2	3.1	3.1	-41.1%	0.0%	0.0
N2O	11.8	37.8	37.8	220.6%	0.0%						11.8	37.8	37.8	220.6%	0.0%	0.0
HFC	1.2	24.6	18.0	1347.6%	-26.9%						1.2	24.6	18.0	1347.6%	-26.9%	6.6
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	753.1	1059.6	1009.1	34.0%	-4.8%	25.4	35.0	28.4	12.2%	-18.8%	778.4	1094.6	1037.5	33.3%	-5.2%	50.5
Households																
CO2 (fuel related)	447.5	443.7	412.0	-7.9%	-7.1%	344.5	304.2	252.4	-26.7%	-17.0%	792.0	747.9	664.4	-16.1%	-11.2%	31.7
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	1.7	0.6	-	-62.7%						0.0	1.7	0.6	-	-62.7%	1.1
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	447.5	445.4	412.7	-7.8%	-7.4%	344.5	304.2	252.4	-26.7%	-17.0%	792.0	749.6	665.1	-16.0%	-11.3%	32.8
Services																
CO2 (fuel related)	175.6	194.2	157.0	-10.6%	-19.2%	272.2	302.1	247.4	-9.1%	-18.1%	447.9	496.3	404.4	-9.7%	-18.5%	37.2
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	5.7	5.7	-	0.0%						0.0	5.7	5.7	-	0.0%	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	175.6	199.9	162.7	-7.3%	-18.6%	272.2	302.1	247.4	-9.1%	-18.1%	447.9	502.0	410.1	-8.4%	-18.3%	37.2
Agriculture																
CO2 (fuel related)	17.3	26.3	24.6	42.1%	-6.6%	0.0	0.0	0.0	-	-	17.3	26.3	24.6	42.1%	-6.6%	1.7
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	193.8	177.7	169.7	-12.4%	-4.5%						193.8	177.7	169.7	-12.4%	-4.5%	8.0
N2O	205.8	193.9	187.7	-8.8%	-3.2%						205.8	193.9	187.7	-8.8%	-3.2%	6.2
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	416.9	397.9	381.9	-8.4%	-4.0%	0.0	0.0	0.0	-	-	416.9	397.9	381.9	-8.4%	-4.0%	15.9
Waste																
CO2 (fuel related)	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0	0.0	0.0	-	-	0.0
CO2 (other)	7.6	7.6	7.6	0.0%	0.0%						7.6	7.6	7.6	0.0%	0.0%	0.0
CH4	155.1	126.0	108.2	-30.3%	-14.1%						155.1	126.0	108.2	-30.3%	-14.1%	17.8
N2O	3.7	3.7	3.7	0.0%	0.0%						3.7	3.7	3.7	0.0%	0.0%	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	166.4	137.3	119.5	-28.2%	-13.0%	0.0	0.0	0.0	-	-	166.4	137.3	119.5	-28.2%	-13.0%	17.8
All sectors																
CO2 (fuel related)	3068.1	3274.1	2923.5	-4.7%	-10.7%						3068.1	3274.1	2923.5	-4.7%	-10.7%	350.6
CO2 (other)	164.4	183.1	182.1	10.8%	-0.6%						164.4	183.1	182.1	10.8%	-0.6%	1.1
CH4	461.7	380.1	344.7	-25.3%	-9.3%						461.7	380.1	344.7	-25.3%	-9.3%	35.5
N2O	376.3	317.0	282.4	-24.9%	-10.9%						376.3	317.0	282.4	-24.9%	-10.9%	34.6
HFC	52.3	84.2	52.6	0.6%	-37.6%						52.3	84.2	52.6	0.6%	-37.6%	31.6
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	5.5	6.9	3.2	-41.2%	-53.4%						5.5	6.9	3.2	-41.2%	-53.4%	3.7
Total	4138.3	4271.0	3807.2	-8.0%	-10.9%						4138.3	4271.0	3807.2	-8.0%	-10.9%	463.8

EU (EU-wide implementation excluding ACEA agreement) industrial boilers allocated to industrial sectors

marginal cost: 31.62 Euro'99 per t of CO2 eq.

Industrial sectors

	Direct emissions (Mt CO2 eq.)					Indirect emissions (Mt CO2 eq.)					Direct and indirect emissions (Mt CO2 eq.)					Reduction
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
Iron and steel																
CO2 (fuel related)	172.6	133.9	118.0	-31.7%	-11.9%	56.6	41.9	36.5	-35.5%	-12.9%	229.2	175.8	154.4	-32.6%	-12.2%	16.0
CO2 (other)	23.4	24.3	24.3	4.0%	0.0%						23.4	24.3	24.3	4.0%	0.0%	0.0
CH4	0.2	0.2	0.2	0.0%	0.0%						0.2	0.2	0.2	0.0%	0.0%	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	196.2	158.4	142.4	-27.4%	-10.1%	56.6	41.9	36.5	-35.5%	-12.9%	252.7	200.3	178.9	-29.2%	-10.7%	16.0
Non-ferrous metals																
CO2 (fuel related)	15.2	12.5	11.9	-21.7%	-4.4%	41.3	19.9	16.5	-59.9%	-17.0%	56.5	32.4	28.5	-49.6%	-12.1%	0.5
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	7.7	6.5	1.0	-87.3%	-84.9%						7.7	6.5	1.0	-87.3%	-84.9%	5.5
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Sub-total	24.4	21.8	12.9	-47.1%	-40.9%	41.3	19.9	16.5	-59.9%	-17.0%	65.6	41.8	29.4	-55.1%	-29.5%	8.9
Chemicals																
CO2 (fuel related)	96.4	51.3	43.7	-54.7%	-14.8%	119.4	136.1	115.7	-3.1%	-15.0%	215.8	187.4	159.4	-26.1%	-14.9%	7.6
CO2 (other)	11.4	14.2	14.2	25.0%	0.0%						11.4	14.2	14.2	25.0%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	108.2	48.2	21.5	-80.1%	-55.4%						108.2	48.2	21.5	-80.1%	-55.4%	26.7
HFC	26.5	7.2	0.4	-98.6%	-95.0%						26.5	7.2	0.4	-98.6%	-95.0%	6.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	242.6	120.9	79.9	-67.1%	-33.9%	119.4	136.1	115.7	-3.1%	-15.0%	362.0	257.0	195.6	-46.0%	-23.9%	41.0
Building Materials																
CO2 (fuel related)	95.2	92.0	88.6	-6.9%	-3.6%	35.8	28.9	23.5	-34.4%	-18.7%	130.9	120.8	112.1	-14.4%	-7.2%	3.3
CO2 (other)	105.8	119.6	118.5	12.0%	-0.9%						105.8	119.6	118.5	12.0%	-0.9%	1.1
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	201.0	211.6	207.2	3.1%	-2.1%	35.8	28.9	23.5	-34.4%	-18.7%	236.8	240.4	230.6	-2.6%	-4.1%	4.4
Paper and Pulp																
CO2 (fuel related)	28.9	21.3	18.9	-34.6%	-11.1%	40.2	84.5	69.7	73.1%	-17.5%	69.1	105.7	88.6	28.1%	-16.2%	2.4
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	28.9	21.3	18.9	-34.6%	-11.1%	40.2	84.5	69.7	73.1%	-17.5%	69.1	105.7	88.6	28.1%	-16.2%	2.4
Food, drink and tobacco																
CO2 (fuel related)	45.5	30.9	26.0	-42.9%	-16.1%	43.6	72.5	62.3	42.9%	-14.2%	89.1	103.5	88.2	-1.0%	-14.7%	5.0
CO2 (other)	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
CH4	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
N2O	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
HFC	0.0	3.8	0.0	-	-100.0%						0.0	3.8	0.0	-	-100.0%	3.8
PFC	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	45.5	34.7	26.0	-42.9%	-25.2%	43.6	72.5	62.3	42.9%	-14.2%	89.1	107.3	88.2	-1.0%	-17.8%	8.8
Other industries																
CO2 (fuel related)	107.6	107.0	102.1	-5.1%	-4.6%	152.6	142.0	118.3	-22.5%	-16.7%	260.2	248.9	220.4	-15.3%	-11.5%	4.9
CO2 (other)	16.2	17.5	17.5	7.5%	0.0%						16.2	17.5	17.5	7.5%	0.0%	0.0
CH4	0.1	0.1	0.1	0.0%	0.0%						0.1	0.1	0.1	0.0%	0.0%	0.0
N2O	4.7	4.7	4.7	0.0%	0.0%						4.7	4.7	4.7	0.0%	0.0%	0.0
HFC	24.5	41.2	27.9	13.6%	-32.4%						24.5	41.2	27.9	13.6%	-32.4%	13.3
PFC	2.3	19.0	17.7	659.8%	-6.6%						2.3	19.0	17.7	659.8%	-6.6%	1.3
SF6	0.0	0.0	0.0	-	-						0.0	0.0	0.0	-	-	0.0
Sub-total	155.4	189.3	169.8	9.3%	-10.3%	152.6	142.0	118.3	-22.5%	-16.7%	308.0	331.3	288.1	-6.5%	-13.0%	19.5
Total industry																
CO2 (fuel related)	561.4	448.7	409.1	-27.1%	-8.8%	489.4	525.8	442.4	-9.6%	-15.9%	1050.8	974.5	851.5	-19.0%	-12.6%	39.6
CO2 (other)	156.8	175.6	174.5	11.3%	-0.6%						156.8	175.6	174.5	11.3%	-0.6%	1.1
CH4	0.4	0.4	0.4	0.0%	0.0%						0.4	0.4	0.4	0.0%	0.0%	0.0
N2O	112.8	52.8	26.1	-76.8%	-50.5%						112.8	52.8	26.1	-76.8%	-50.5%	26.7
HFC	51.1	52.2	28.2	-44.7%	-45.9%						51.1	52.2	28.2	-44.7%	-45.9%	24.0
PFC	10.0	25.5	18.7	86.6%	-26.5%						10.0	25.5	18.7	86.6%	-26.5%	6.8
SF6	1.5	2.9	0.0	-100.0%	-100.0%						1.5	2.9	0.0	-100.0%	-100.0%	2.9
Total industry	894.0	758.0	657.1	-26.5%	-13.3%	489.4	525.8	442.4	-9.6%	-15.9%	1383.3	1283.8	1099.4	-20.5%	-14.4%	100.9

EU (EU-wide implementation excluding ACEA agreement) industrial boilers allocated to industrial sectors

marginal cost: 31.62 Euro’99 per t of CO2 eq.

Transport sector (CO2)

	Direct emissions (Mt CO2 eq.)					**Indirect emissions (Mt CO2 eq.)**					**Direct and indirect emissions (Mt CO2 eq.)**					**Reduction**
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by transport mean																
road	623.5	812.8	791.0	26.9%	-2.7%						623.5	812.8	791.0	26.9%	-2.7%	21.9
train	9.1	1.7	1.5	-83.3%	-10.0%	25.4	35.0	28.4	12.2%	-18.8%	34.5	36.7	30.0	-13.1%	-18.4%	0.2
aviation	81.6	152.7	131.6	61.3%	-13.9%						81.6	152.7	131.6	61.3%	-13.9%	21.2
inl. navigation	20.6	26.8	26.1	27.1%	-2.6%						20.6	26.8	26.1	27.1%	-2.6%	0.7
by transport activity (base year: 1995)																
passenger	545.2	684.0	655.6	20.3%	-4.1%						545.2	684.0	655.6	20.3%	-4.1%	28.3
freight	254.4	310.1	294.6	15.8%	-5.0%						254.4	310.1	294.6	15.8%	-5.0%	15.6
Sub-total	734.8	994.1	950.2	29.3%	-4.4%	25.4	35.0	28.4	12.2%	-18.8%	760.2	1029.1	978.7	28.7%	-4.9%	43.9

EU (EU-wide implementation excluding ACEA agreement) industrial boilers allocated to industrial sectors

marginal cost: 31.62 Euro’99 per t of CO2 eq.

Energy supply (CO2)

	Direct emissions (Mt CO2 eq.)					**Indirect emissions (Mt CO2 eq.)**					**Direct and indirect emissions (Mt CO2 eq.)**					**Reduction**
Emission (Mt of CO2 equivalent)	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Emissions in 1990 or 1995*	*Emissions in 2010 under baseline conditions*	*Emissions in 2010 under Kyoto target conditions*	*% Change from 1990 or 1995*	*% Change from 2010 baseline*	*Direct Emission reduction from baseline levels (Mt CO2 eq.)*
by generator																
industrial generators	123.7	253.7	195.8	58.3%	-22.8%											57.8
other generators	0.0	27.9	22.3	-	-19.9%											5.5
utilities	835.8	772.3	636.3	-23.9%	-17.6%											136.0
boilers in	114.6	57.3	63.0	-45.0%	9.9%											-5.7
industry	0.0	0.0	0.0	-	-											0.0
refineries	73.8	44.3	51.9	-29.7%	17.1%											-7.6
district heating	40.8	13.0	11.1	-72.7%	-14.5%											1.9
fuel extraction and refining	57.5	55.9	53.1	-7.6%	-5.0%											2.8
Sub-total	1131.5	1167.0	970.6	-14.2%	-16.8%											196.4