European Commission

Directorate General Environment

EUROPEAN ENVIRONMENTAL PRIORITIES;
AN ENVIRONMENTAL AND ECONOMIC ASSESSMENT

Climate Change

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Contents

1. Introduction

According to the undertakings at the Kyoto Protocol in December 1997, the EU should reduce its greenhouse gas (GHGs) emissions in the 2008-12 period to a level that is 8% below their level 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.[1] The GHGs covered are CO_2, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride. For the three synthetic gases the protocol allows countries the option of using 1995 as base year. The Protocol also allows a number of flexibility mechanisms in the attainment of targets. These include carbon emissions savings generated from changes in land use, such as reforestation, emissions reductions obtained from carbon credits either from implementing projects among Annex B[2] countries (i.e. joint implementation) or through emissions savings from financing allowable projects in developing (non Annex B) countries by using the "clean developing mechanism". Finally the protocol gives the opportunity to trade greenhouse gas emission permits across all Annex B countries.

Another possibility would be to transfer the emission rights as part of investment project deals involving partners from different Annex B countries. In the Kyoto Protocol, this is called ”joint implementation”. Similarly Annex B countries may obtain emission rights through investment projects involving a partner from Annex B and a partner outside Annex B. This is called “clean development mechanism” in the protocol. All these mechanisms may well prove to provide important ways to reduce greenhouse gas emissions in an efficient and flexible manner.

A number of serious uncertainties remain regarding the application of the Kyoto Protocol and the role that the energy system of the EU will be called upon to play in meeting the Kyoto obligations. Firstly, the precise means through which the flexibility mechanisms will operate have not yet been fully agreed upon among the parties to the Protocol. Since these mechanisms will determine the amount of GHG emission reductions that EU and other Annex B countries will be able to achieve "externally," it is not possible at this stage to determine the target for reductions of GHG emissions from within the EU.

Secondly, there is still a great deal of uncertainty surrounding the likely developments in non-energy related CO_2 emissions. This is important because it will help determine the degree of emissions reduction that will need to be achieved through the energy system. As with energy related CO_2 emissions, there are a number of possible scenarios and projections for non-CO_2 GHGs that in 1990 amounted to 870 Mt CO_2. Developments in non-CO_2 GHGs are very significant for the determination of policy measures that are likely to be taken in order to meet the target set at Kyoto for total GHGs.

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[1] All quantities of GHGs in this chapter refer to 10^6 tons of CO_2 equivalent.

[2] Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States of America.

Thirdly, and partly because of the above, the specific policies and measures that will be adopted in order to reach the targets undertaken at Kyoto have not yet been announced and are the subject of debate at present. Clearly, if these policies and measures had been announced the projections for the energy system would be different from those of the baseline scenario. Under reasonable assumptions for the period to 2010 (the baseline scenario), it is unlikely that the EU will meet its Kyoto undertakings, at least through energy related CO_2 emissions. Instead of the 8% reduction in emissions by 2010, an 8% increase is projected for 2010 when compared to the level of CO_2 emissions in 1990. Depending on the outlook and policy measures for non-CO_2 greenhouse gases, such as CH4, it is clear that a number of additional policy initiatives will have to be undertaken for the abatement of energy related emissions.

The provisions of the Kyoto Protocol are applied in two alternative scenarios both of which would achieve the 8% GHG reduction target for the EU. The first alternative, a no-trade scenario, focuses on reduction of CO_2 emissions under the Burden Sharing Agreement of the EU through measures undertaken strictly within the territory of each member state. Thus, the Kyoto Protocol would be totally implemented separately by each country within the EU with no provision for GHG emissions trading either within the EU or internationally, or recognition of beneficial spillover effects from the management of other priority issues such as waste. Table 1-1 summarises the emission reduction targets for each EU member state according to the June 1998 Post-Kyoto Burden Sharing agreement.

Table 1- 1: The EU Burden Sharing agreement

	Emission reduction target (% change from 1990 levels)
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
Luxemburg	-28.0
Netherlands	-6.0
Portugal	27.0
Spain	15.0
Sweden	4.0
United Kingdom	-12.5
European Union	**-8.0**

Source: Council conclusions-June 1998 Post-Kyoto Burden Sharing figures

The second option, a full-trade scenario, accepts the flexibility of the Kyoto Protocol with respect to emissions trading of GHGs to develop the most economically efficient approach to meet the Kyoto target (also implicitly including Joint Implementation and Clean Development Mechanism). In this case, emission reductions for each EU member state are not according to the Burden Sharing Agreement, but are based on least-cost considerations and emission trading both within the EU and within the Annex B set of countries. Since a least-cost option prevails in the “Full Trade” scenario, the marginal abatement cost within the EU is aligned to the permit price within the international permit market. Based on POLES model calculations that have been coordinated with the model runs of the EU PRIMES for the same purpose as regards Kyoto compliance under a regime of pollution permits trading between Annex B countries, permit prices have been found to be uniform at €$_{97}$ 17.4/tCO_2 (or €$_{97}$ 63.7 per t of carbon) [3], leading Annex B to meet the Kyoto targets.[4] Within the context of the resulting full-trade energy scenario, the Kyoto targets are met also for the EU.

In the analysis, the non-CO2 GHGs have been treated separately and are therefore covered by a separate chapter.

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 this would be 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, that economic agents, i.e. producers and consumers of energy, 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 current policies and trends without including specific effort 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.

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[3] One ton of CO_2 emitted contains 12/44 tons of carbon. Therefore, if the marginal abatement cost is one Euro per ton of CO_2 then the corresponding value per ton of carbon is equal to 44/12 Euro.

[4] The POLES model is a global sectoral model of the world energy system. The development of the POLES model has been partially funded under the JOULE II and JOULE III programs of DG XII of the European Commission. Since 1997 the model is fully operational and can produce detailed long term (2030) world energy and CO_2 emission outlooks with demand, supply and price projections by main region. The model splits the world in 26 regions. The detailed results on emission trading can be found in “Final Publishable Report” of “Energy Technology Dynamics and Advanced Energy System Modelling” (TEEM) project, in the framework of Non Nuclear Energy Programme JOULE III, European Commission – DG-XII, Contract JOS3-CT97-0013, September 1999. Other results were published in “European Union utlook to 2020”, Special Issue November 1999, European Commission Energy DG. For the model design see the model reference manual: *"POLES 2.2. European Commission, DG XII, December 1996"*.

The analysis focuses on the differences between the results of each lower emissions 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. Such changes 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 a rich set of information revealing the priority of changes that are cost effective by sector and country, and their nature. This information can 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, in other words, the model-based marginal abatement cost curves, can be used as a basis for defining the sharing of the emission reduction effort by country and by sector.

2.1 Marginal Abatement Cost and Emission Reduction Targets

The PRIMES model simulates the overall market equilibrium of the energy sector. It computes the prices of energy products that lead to the balancing of demand and supply of each energy product in a period of time (usually a five-year period).

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.[5] This shadow variable, is the marginal abatement cost that is associated with the emission reduction constraint and represents the economic cost of avoiding the last unit of carbon that is required by the constraint. [6]

An alternative way to think of the link between an emission reduction target and its associated marginal abatement cost is to assume that the emission target is achieved through the creation of a hypothetical market in pollution permits in an auctioneering regime, i.e. in such a manner that producers and consumers of energy need to buy the right to emit CO_2. Evidently buying such permits being roughly proportional to the carbon content of the fossil energy fuels, leads consumers and producers of energy to perceive higher prices (or usage costs) of fossil fuels. The mechanism through which the energy system responds to the imposition of carbon constraints is that of changes in relative energy prices. These changes

[5] The PRIMES energy system model formulates energy market equilibrium according to the mixed-complementary mathematical methodology, which roughly corresponds to the Kuhn-Tucker conditions that are dual to a mathematical programming problem. Consequently, the imposition of a global constraint on emissions is mathematically strictly equivalent to the inclusion of a shadow variable, a shadow cost, which appropriately affects all economic costs, proportionally to their emissions. The mechanism through which the energy system responds to the imposition of carbon constraints is that of changes in relative energy prices. These changes reflect the carbon content of each fuel and provide incentives to the economic agents to reduce their "consumption" of carbon. Consequently, the resulting changes in relative prices would effectively reflect the carbon intensity of each fuel.

[6] One ton of CO_2 emitted contains 12/44 tons of carbon. Therefore, if the marginal abatement cost is one Euro per ton of carbon then the corresponding value per ton of CO_2 is equal to 12/44 Euro.

reflect the carbon content of each fuel and provide incentives to the economic agents to reduce their "consumption" of carbon. Consequently, the resulting changes in relative prices would effectively reflect the carbon intensity of each fuel. In such a market, the emission target is reflected in the number of permits that are marketed. The marginal abatement cost is then equivalent to the price of permits that the market would establish for any given emission reduction target. Both the permit price and the marginal abatement cost reflect the degree of difficulty that the system faces in reaching the target.

2.2 Marginal abatement costs and energy system costs

The starting point for measuring the avoidance of CO_2 emissions in any given time period is the level of emissions projected within the baseline scenario.

The economic interpretation of the costs for the economy arising from the marginal cost is complex. The imposition of a carbon emission constraint induces an external cost to the economy 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 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.

When quantifying a marginal abatement cost curve one must be careful to clarify whether the calculation relates to partial or general equilibrium conditions. By using an energy system model (as is the case of PRIMES), the calculation is at the level of partial equilibrium and usually considers the rest of the economy unchanged. At a general equilibrium level, system adjustments, other than those occurring in the energy system, might induce further loss of welfare.

Because of the emission constraint, the economic agents will bear additional costs (from baseline) in order to obtain the same level of services obtained by using energy. In other words, the energy system will require additional funding from the rest of the economy. It might be also the case that the economic agents reduce the use of energy (by substituting other services for the energy service) so as to partly alleviate the additional costs.

The additional costs for the economic agents arising from the higher costs in the provision of the energy service do not represent a direct leakage from the economic system. These funds are recycled within the economy in the form of additional purchases of goods and services, usually substituting domestically produced commodities for largely imported energy products. In general equilibrium terms, all these effects result in a re-allocation of resources and activities within the economy. It is expected, however, that the new allocation induce a net loss of welfare, since the emission constraint corresponds to an external cost for the economy. For each economic agent the effects are different and may be significant in some cases (e.g. energy intensive industries) or negligible (even more positive) for those agents that face an increased activity within the new allocation. However, the benefits from the reduction of CO_2 emissions are not included in such calculations.

3. Scenario Analysis[7] for CO_2

3.1 The Baseline Scenario

The definition of the baseline scenario is important because it constitutes the basis for assessing the policy scenarios and the ensuing policy targets (e.g. emission ceilings). For this purpose, the baseline scenario is conceived as the most likely development of the energy system in the future in the context of current knowledge, policy objectives and means.

The baseline scenario includes current trends and the effects of all policies in place and in the pipeline. For analytical reasons it excludes all additional actions and policies that aim at further reducing CO_2 emissions so as to comply with the Kyoto emission commitments. The baseline includes:

- Dynamic trends of technology progress improving the efficiency of the energy system, to the extend that current knowledge can predict,
- The effects from restructuring of markets effected through the liberalisation of electricity and gas market in Europe, and
- The restructuring of the sectoral pattern of economic growth of the European Union that shifts away from traditional energy intensive sectors and operates through high value added activities.

Energy prices are assumed to gradually increase from their presently low-level following a smooth ascending path. Table 3-1 shows the main assumptions for the energy prices at the border of the EU. Oil prices are assumed to recover by 2005 at their 1995 level and then grow smoothly. Natural gas prices increase at lower rates in the first half of the period but then grow slightly faster than oil as a result of pressures from the supply side. Coal prices remain practically stable in real terms. Energy taxation policies are assumed to remain unchanged from the current situation in the EU member states.

Table 3-1: Baseline Assumptions on Energy Prices

	Average boarder prices in the EU (€$_{97}$ per toe)				average % change per year		
	1995	**1998**	**2005**	**2010**	**1995-1998**	**1998-2005**	**2005-2010**
Crude oil	104.1	74.7	103.4	109.8	-10.5	4.8	1.2
Natural gas	83.7	74.7	92.6	101.5	-3.7	3.1	1.9
Coal	65.9	64.8	64.2	65.1	-0.5	-0.1	0.3

Table 2 summarises the macro-economic assumptions in the baseline scenario. Economic growth of the EU is projected to be significant (about 2.5% per year). The sectoral pattern of this growth is projected to change smoothly over time. The share of manufacturing in GDP

[7] These scenarios have not been run for Luxembourg. Consequently, all results relate to EU without Luxembourg. However, analysis made for Luxemburg indicates that CO_2 emissions in Luxembourg decrease by 16.5% in 2010 from 1990 levels (11 Mt CO_2) under baseline assumptions. The corresponding figures for the AP-full-trade and AP-no-trade scenarios (see below) are estimated at 19% and 26.6%, respectively.

decreases, while that of the services sector increases. Within the manufacturing sector, the contribution of energy intensive sectors further reduces. Population is increasing very slowly.

Table 3-2: Macroeconomic Assumptions for the EU in the baseline scenario

	Million €$_{97}$			% structure of GDP		% change per year
	1995	**2000**	**2010**	**1995**	**2010**	**2010-1995**
Gross Domestic Product	**7226**	**8226**	**10436**			**2.5**
Energy Intensive Manufacturing	431	476	580	6.0	5.8	2.0
Non Energy Intensive Manufacturing	1484	1656	2050	20.5	20.1	2.2
Services	4572	5277	6814	63.3	64.1	2.7
Population (mio persons)	**371.7**	**376.5**	**383.1**			**0.2**

Energy policies not directly related to Kyoto objectives are assumed to continue their development, and their effects are included in the baseline scenario:

- The liberalisation of electricity and gas markets starts operating and further develops in the beginning of the new century.
- The restructuring is enabled by mature gas-based power generation technologies that are efficient, involve low capital costs and are flexible regarding plant sizes, co-generation and independent power production.
- Energy policies that aim at promoting renewable energy (wind, small hydro, biomass and waste) are assumed to continue, involving subsidisation of capital cost and preferential electricity selling prices.
- On-going infrastructure projects in some member states concerning the introduction of natural gas are assumed to gain full maturity in the first half of the first decade of the projection period.
- Removal of all explicit or hidden subsidies to domestic coal and lignite.[8]
- Finally, stringent regulation for acid rain pollutants is also assumed to continue, in particular for large combustion plants.

However, the baseline only includes policies in place and in the pipeline as known by the end of 1997. So it does not include the EC-ACEA negotiated agreement. In 1998, a negotiated agreement was reached between the European Commission and the European automobile industry under the terms of which the industry is committed to reduce the average CO_2 emission figure for all new cars to 140 g/km by 2008[9]. 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). The agreement assumes that the behaviour of non-EU producers will be compatible with the above targets and that EU policies and fuel quality will not hamper the implementation of the negotiated agreement.

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[8] For example full abolishment of the "Kohlepfennig" policy in Germany.

[9]Much of the information on the agreement between the EU Commission and the European automobile industry is based on information available on the latter's web site as of the 18 of May of 1999.

As mentioned, the above agreement was not included in the baseline scenario. The reason for not including the EU-ACEA agreement has also to do with the desire to obtain comparative results from this study with the results obtained from PRIMES model under the Shared Analysis Project.[10] However, in the context of scenario works with PRIMES, sensitivity analysis was carried out to incorporate the effects of the EU-ACEA negotiated agreement (see Chapter 5.3.4).

It must be mentioned here that the constructed baseline scenario for the present study is almost identical (version of May 1999) to that defined under the Shared Analysis Project (September 1999). There are slight differences in the two scenarios due to slight changes in some assumptions.

The results of the baseline scenario show that despite the evidence of some saturation for some energy uses in the EU, energy demand is expected to continue to grow, even though at rates significantly smaller than in history. Thus, while significant economic growth can take place with only a small increase in energy use, there is no complete de-linking between energy and the economy. The results of the baseline projection show an increase of energy demand by 18.5% from 1990 to 2010. The baseline results show a significant improvement of the overall energy intensity. This is partly due to the sectoral restructuring and dematerialisation of economic growth of the EU, but also to the fact that new capital vintages (for industry, buildings and appliances) do incorporate technology progress corresponding to zero or negative costs of energy efficiency improvement.

Production of fossil primary energy within the EU, after peaking in the period 2000-2005, is expected to decline throughout to 2010. In the contrary, renewable energy sources of energy are likely to receive a significant boost as a result of policy and technology progress. Despite the evidence of some saturation for some energy uses in the EU, energy demand is expected to continue to grow even though at rates significantly smaller than in history. The growth rate in primary energy consumption is expected to be close to 1% over the period to 2010. Figure 3-1 shows the relative change of some key indicators of the energy system compared to their 1990 level arbitrarily set at 100.

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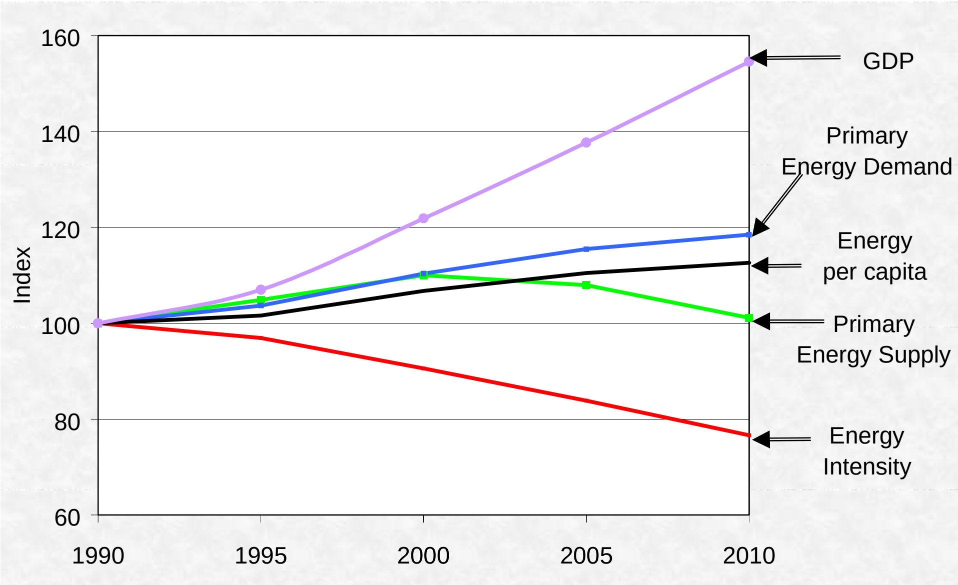
[10] See Capros P. et al. (1999) "European Union Energy Outlook to 2020", European Commission – Directorate General for Energy (DG-XVII), special issue of "Energy in Europe", catalogue number CS-24-99-130-EN-C, ISBN 92-828-7533-4.

Figure 3-1: EU primary energy indicators, 1990-2010



Source: PRIMES

The implied energy intensity improvement (expressed as primary energy demand per unit of GDP) is gradually expected to improve and to reach an annual rate of 1.3 % pa in 1990-2010 (see Table 3-3). Structural change in the demand side mainly explains this change. The role of energy technology is also important. The EU energy system remains dominated by fossil fuels over the next years and their share rises marginally from its level of just under 80% in 1995. Import dependency will increase from around 47.5% in 1990 to 55 % in 2010.

Table 3-3: Primary Energy Demand, Baseline scenario

	Mtoe					% Annual growth rates			% Shares			
	1990	1995	2000	2005	2010	1990-2000	2000-2010	1990-2010	1990	1995	2000	2010
Solid Fuels	301	237	204	203	180	-3.8	-1.3	-2.6	22.9	17.4	14.0	11.5
Liquid Fuels	543	574	604	636	654	1.1	0.8	0.9	41.3	42.1	41.6	42.1
Natural Gas	222	273	341	368	409	4.4	1.8	3.1	16.9	20.1	23.6	26.3
Nuclear	181	205	223	227	226	2.1	0.1	1.1	13.8	15.1	15.4	14.5
Electricity (trade outside EU)	2	1	1	2	2	-9.4	9.1	-0.6	0.2	0.1	0.1	0.1
Renewable En. Sources	64	71	77	81	86	1.9	1.1	1.5	4.9	5.2	5.3	5.5
Total	**1313**	**1362**	**1450**	**1517**	**1556**	**1.0**	**0.7**	**0.9**				
Energy intensity (toe/M€$_{97}$)	195	189	176	163	149	-1.0	-1.7	-1.3				
Energy per capita (toe/capita)	3.6	3.7	3.9	4.0	4.1	0.7	0.5	0.6				

Source: PRIMES

The use of solid fuels is expected to continue falling until 2010 both in absolute terms and as a proportion of total energy demand. Spurred by its very rapid penetration in new power generation plant and co-generation, gas is by far the fastest growing primary fuel. Its share in primary energy consumption is projected to increase further to 26% by 2010. The share of oil in primary consumption is projected to be relatively stable over the period to 2010 and its annual growth rate is projected to decelerate from 1% in the period to 2005 to 0.6 % during 2005-2010. Under baseline technology assumptions, novel energy forms, such as hydrogen and methanol, do not make significant inroads, primarily due to cost considerations.

Final energy demand is expected to grow marginally faster than primary energy (because of improved rates of conversion efficiency in power generation), rising by 1.1% pa over the projection period. As can be seen from Table 3-4 there are relatively modest changes in fuel shares over the next years

Table 3-4: Final Energy Demand by Sector and by Fuel, Baseline scenario

	Mtoe					% Annual growth rates			% Shares			
	1990	**1995**	**2000**	**2005**	**2010**	**1990-2000**	**2000-2010**	**1990-2010**	**1990**	**1995**	**2000**	**2010**
Total	**850**	**883**	**951**	**1005**	**1048**	**1.1**	**1.0**	**1.1**				
by sector												
Industry	255	244	256	268	279	0.0	0.9	0.4	30.0	27.7	26.9	26.6
Residential	234	242	257	264	268	1.0	0.4	0.7	27.5	27.4	27.1	25.5
Tertiary	109	123	139	150	158	2.4	1.3	1.9	12.8	13.9	14.6	15.0
Transports	253	275	299	323	344	1.7	1.4	1.6	29.7	31.1	31.5	32.8
by fuel												
Solid Fuels	71	43	36	32	27	-6.5	-2.9	-4.7	8.3	4.9	3.8	2.6
Liquid Fuels	378	404	436	457	477	1.4	0.9	1.2	44.5	45.7	45.9	45.5
Natural Gas	157	177	198	208	212	2.3	0.7	1.5	18.5	20.1	20.9	20.2
Steam	66	67	70	78	84	0.6	1.8	1.2	7.8	7.6	7.4	8.0
Electricity	156	169	188	209	226	1.9	1.8	1.8	18.4	19.2	19.8	21.5
Hydrogen	0	0	0	0	0	-	-	-	0.0	0.0	0.0	0.0
Methanol - Ethanol	0	0	0	0	0	-	-	-	0.0	0.0	0.0	0.0
Renewable En. Sources	22	23	22	21	22	-0.1	0.2	0.0	2.6	2.5	2.3	2.1
Biomass	*21*	*22*	*21*	*21*	*21*	*-0.1*	*0.0*	*0.0*	*97.8*	*97.4*	*97.8*	*96.3*
Other	*0*	*1*	*0*	*1*	*1*	*-0.3*	*5.7*	*2.7*	*2.2*	*2.6*	*2.2*	*3.7*

Source: PRIMES

Energy demand in the tertiary sector is the fastest growing segment of final demand reflecting the expected restructuring of the economy towards services. The modest growth in residential energy demand reflects the lack of growth in EU population and the small increase in the number of households. By 2010, transportation accounts for almost a third of EU final energy consumption, followed by industry and the residential sector, which account for around 26% of consumption each.

Oil becomes almost exclusively a fuel for transportation and petrochemicals. The increase in transportation energy demand is actually greater than the increase in the demand for liquid fuels over the 1990-2010 period, implying a decline in oil consumption in the other sectors.

Under baseline assumptions, the technology of electricity and steam generation improves leading to higher thermal efficiency, lower capital costs and greater market availability of new generation technologies. The assumed improvement, however, is not spectacular and no technological breakthrough occurs during the projection period in the baseline scenario.

The use of electricity is expected to expand by 1.9 % pa over the projection period and its growth is expected to be especially rapid in the tertiary sector. Steam demand is projected to grow by 1.5 % pa in the period to 2010. The industrial sector is projected to remain the dominant user of steam.

Table 3-5 demonstrates that total power capacity requirements for the EU increase by some 146 GW in the 1995-2010 period.[11]

[11] The detailed breakdown of power generation per type of technology was not available for 1990 in the PRIMES database.

Table 3-5: Power generation capacity by type of plant, Baseline scenario

	Installed GW				% Annual growth rates			Shares %		
	1995	2000	2005	2010	1995-2000	2000-2010	1995-2010	1995	2000	2010
Nuclear	131.9	136.2	135.3	134.0	0.7	-0.2	0.1	23.1	22.3	18.7
Coal and Lignite	179.7	166.2	143.2	101.1	-1.6	-4.8	-3.8	31.5	27.2	14.1
Open Cycle multi-Fired	65.7	67.7	61.5	50.6	0.6	-2.9	-1.7	11.5	11.1	7.1
Open Cycle of IPP	32.6	33.1	29.9	23.9	0.3	-3.2	-2.0	5.7	5.4	3.3
GTCC and small GT	46.3	84.0	154.6	259.9	12.6	12.0	12.2	8.1	13.7	36.3
Clean Coal and Lignite	0.5	0.5	0.5	5.5	0.0	28.4	18.1	0.1	0.1	0.8
Biomass-Waste of Utilities	3.9	4.4	4.1	4.7	2.5	0.5	1.2	0.7	0.7	0.7
Fuel Cells	0.0	0.0	0.0	0.0				0.0	0.0	0.0
Hydro-Renewables	109.3	119.3	127.9	136.2	1.8	1.3	1.5	19.2	19.5	19.0
Total Capacities	**570.0**	**611.2**	**656.9**	**715.9**	**1.4**	**1.6**	**1.5**			
Power generation efficiencies										
For total electricity & steam	0.53	0.54	0.57	0.62	0.6	1.2	1.0			
Normalised for electricity only	0.37	0.39	0.42	0.45	1.1	1.4	1.3			

Source: PRIMES

The use of traditional coal and oil plants declines very rapidly. These declines in capacity are more than made up from the dramatic increase in gas turbine combine cycle plants and small gas turbines. Their capacity increases by nearly 6 times over the projection period to reach 260 GW, or 36 % of the total installed capacity by 2010. Significant growth in generation by clean coal plants and biomass generation is also expected to occur over the next years, in particular towards the end of the projection period. However, these forms of power generation will still only account for less than 1.5 % of total generation capacity by 2010. Growth in hydroelectricity and other renewable forms of generation is projected to be modest but at 27 GW of new capacity, the increase in these capacities will make a significant contribution. The additions mostly concern wind power.

A significant improvement is expected to occur in the efficiency of power generation (see Table 3-5). The efficiency of the overall power and steam generation system is expected to increase by around 9 percentage points and to reach 62 % by 2010. The efficiency of generation of electricity excluding steam improves from 37 to 45 % between 1995 and 2010. This is the combined effect of the adoption of more efficient technologies (like GTCC) and of co-generation.

The rising share of fossil fuels will lead to an increase in the carbon intensity of the EU energy system. Together with the modest increase in energy demand, this will lead to an increase in CO_2 and other energy related emissions. CO_2 emissions are projected to increase annually by 0.4% in 1990-2010 (0.6% in 2000-2010, see Table 3-6).

Table 3-6: CO_2 emissions by sector, Baseline scenario

	Mt CO_2					% Annual growth rates			Shares %			
	1990	1995	2000	2005	2010	1990-2000	2000-2010	1990-2010	1990	1995	2000	2010
Total	**3068**	**3029**	**3131**	**3273**	**3311**	**0.2**	**0.6**	**0.4**	**100.0**	**100.0**	**100.0**	**100.0**
Industry	424	381	386	385	381	-0.9	-0.1	-0.5	13.8	12.6	12.3	11.5
Tertiary	190	200	217	220	218	1.3	0.1	0.7	6.2	6.6	6.9	6.6
Households	450	430	454	449	447	0.1	-0.2	0.0	14.7	14.2	14.5	13.5
Transports	735	800	869	936	994	1.7	1.4	1.5	24.0	26.4	27.8	30.0
Electricity-steam production	1211	1160	1147	1226	1219	-0.5	0.6	0.0	39.5	38.3	36.6	36.8
Energy branch	57	59	57	56	52	0.0	-1.0	-0.5	1.9	1.9	1.8	1.6
CO_2 emission index (1990=100)												
Total	**100.0**	**98.8**	**102.1**	**106.7**	**107.9**							
Industry	100.0	89.9	91.0	90.8	89.8							
Tertiary	100.0	105.0	114.3	116.1	114.9							
Households	100.0	95.5	100.7	99.8	99.2							
Transports	100.0	108.8	118.3	127.4	135.3							
Electricity-steam production	100.0	95.8	94.7	101.2	100.6							
Energy branch	100.0	103.6	100.3	98.0	91.0							

Source: PRIMES

In absolute terms, the increase in emissions originated from combustion of natural gas more than make up for the sharp decline in emissions that results from the decline in the use of solid fuels. Energy intensity improvements act in favour of moderating the rise of CO2 emissions. In the period to 2010, the sectors with the fastest increase in emissions are those where energy demand is expected to grow fastest, namely the tertiary and transportation sectors. However, in terms of their absolute contribution to the increase in emissions, it is the transportation sector, which accounts for nearly two thirds of the overall increase between 1995 and 2010.

3.2 Definition of scenarios

Two alternative scenarios have been defined as regards the achievement of the Kyoto emission reduction target for the EU (-8% in 2008 to 2012 from 1990 levels).

The first scenario, the AP-no-trade scenario, examines the achievement of the Kyoto target based on the Burden Sharing agreement between EU member states. Under the assumptions of this scenario, each country must achieve its own emission reduction target by reducing CO_2 emissions in the absence of flexibility mechanisms as regards trading. The emission reduction target is implemented at a global level for each member state and therefore, since a market model as PRIMES is used to quantify the case, it is allocated to the sectors (consumers and producers of energy) at least cost. I.e. the marginal abatement cost is equalized across the sectors of a single member state, a situation that could be interpreted as hypothetical emission trading within the member state under an auctioneering regime.

The second scenario, the AP-full-trade scenario, examines the achievement of the Kyoto target in the presence of flexibility mechanisms both as regards trading with all Annex B countries and the reduction of non-CO_2 greenhouse gasses. It must be noted that total emissions within Annex B countries remain unaffected and comply with the emission reduction target as set under the Kyoto protocol.

In other words, in the AP-full-trade scenario, 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 industrial realism or considerations. The permit price has been set at €$_{97}$ 17.4/tCO_2 based on results provided from the POLES model. The flexibility mechanisms involve trading among Annex B countries. The CDM and JI are not directly modelled in POLES but implicitly the model considers gains for the EU in terms of reducing the marginal abatememt cost and the emission target to be met through national EU measures. In accordance to that the marginal abatement cost for the EU energy system has also been set at €$_{97}$ 17.4/tCO_2, resulting in a reduction CO_2 emissions of only 0.4% in 2010 compared to 1990. The remainder of the emission reduction as agreed upon in the Kyoto Protocol is obtained outside the EU. This means that a quantity of 245 Mt of CO_2 is traded to the EU through pollution permits at a cost of €$_{97}$ 4.5 billion. For the non-CO_2 GHGs, the emission reductions are (for the whole of the EU) equal to the AP-no-trade scenario (see annex on non-CO2 GHGs).

3.3 The AP-no-trade Scenario

As already discussed, in the AP-no-trade scenario the EU member states are assumed to achieve a reduction of CO_2 emissions by 8% in 2010 compared to 1990 levels on the basis of the Burden Sharing agreement. Table 3-7 summarises the reduction achieved by each member state as well as the corresponding marginal abatement cost.[12] As can be seen from the table, the marginal efforts and costs differ substantially across member states when each country has to reduce emissions unilaterally according to the latest Burden Sharing agreement. While the average marginal abatement cost at the EU level is of €$_{97}$ 62.5/tCO_2avoided, Germany achieves its target with a cost of €$_{97}$ 27.8/tCO_2 while the corresponding figure for Netherlands reaches 166.8/tCO_2. In other words, if no flexible instruments are used, it is likely that, Belgium, Sweden and in particular the Netherlands will find it very expensive to reach the emission reductions as agreed in the Burden Sharing agreement concerning the Kyoto Protocol. On the other hand, France and Germany are likely to find it relatively cheap to reach the reduction targets.

[12] The Burden Sharing Agreement has been applied separately to CO_2 emissions and not to the whole range of GHGs. This explains the difference between the agreed under the Kyoto protocol emission reduction target (-8% from 1990 levels) and the resulting emission reduction target for CO_2 emissions (-8.3%). The results obtained are within tolerance limits for a numerical model. For example, in the case of Sweden the emission change computed by the model is +6.7% instead of +4% as agreed in the Burden Sharing Agreement. However, this difference corresponds to just 1 additional Mt of CO2 emitted compared to the Agreement.

Table 3-7: CO_2 emissions by EU member state, AP-no-trade scenario

	Mt CO_2			Marginal Abatement Cost	% change from 1990		% Shares in CO_2 emissions		
	1990	2010		2010	2010		1990	2010	
		Baseline	AP no-trade	AP no-trade	Baseline	AP no-trade		Baseline	AP no-trade
EU14	**3068**	**3311**	**2812**	**62.5**	**7.9**	**-8.3**	**100**	**100**	**100**
Austria	55	58	48	52.8	5.7	-12.7	1.8	1.8	1.7
Belgium	105	123	97	99.7	17.4	-7.1	3.4	3.7	3.5
Denmark	53	55	42	55.6	4.3	-20.8	1.7	1.7	1.5
Finland	51	72	51	54.6	40.8	0.1	1.7	2.2	1.8
France	352	393	355	32.0	11.6	0.6	11.5	11.9	12.6
Germany	952	839	755	27.8	-11.8	-20.6	31.0	25.3	26.9
Greece	71	109	89	63.6	54.3	25.3	2.3	3.3	3.2
Ireland	30	43	34	59.1	42.6	13.0	1.0	1.3	1.2
Italy	388	430	363	51.8	10.8	-6.3	12.6	13.0	12.9
The Netherlands	153	207	144	166.8	35.4	-5.7	5.0	6.3	5.1
Portugal	39	65	50	58.4	65.4	27.4	1.3	2.0	1.8
Spain	202	275	233	41.7	36.3	15.2	6.6	8.3	8.3
Sweden	50	69	53	67.4	38.4	6.7	1.6	2.1	1.9
United Kingdom	567	572	498	42.7	0.9	-12.2	18.5	17.3	17.7

Source: PRIMES

Other work with the same model and methodology has shown that the cost effectiveness gains, for the EU as a whole, from equalising the marginal abatement cost across all member states, i.e. under an emission permits trading regime across EU member states, are substantial. These gains, in terms of average EU marginal cost, are of the order of 40%. Of course, the marginal cost calculations carried out with an energy model provide only partial information on Burden Sharing. In reality, the EU burden sharing agreement has also taken into account several factors other than cost-effectiveness. For example, it has considered the history of emissions in member states, the prospects for economic cohesion within the EU and the flexibility of the economic system of each country to adjust under carbon emissions targets. It is, of course, likely that member states in accepting the Burden Sharing agreement had different expectations of their future emissions than those projected under the baseline assumptions in this study.

3.3.1 Impacts on primary energy demand

At the aggregate level of analysis, the economic system has two means of responding to the imposition of the carbon constraint while maintaining the same level of GDP. It can either reduce the level of energy used per unit of GDP (the energy intensity) or it can change the fuel mix in order to reduce the carbon intensity of its energy sub system. The division of the system's response between these two effects is an extremely important indication of where most of the flexibility in the system is to be found. A reduction in the carbon intensity of the energy system signifies that substitution opportunities among fuels are more cost effective than substitution of energy by other goods.

__Table 3-8: Primary energy demand, AP-no-trade scenario__

	Mtoe				% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP no-trade		Baseline	AP no-trade		Baseline	AP no-trade
Solid Fuels	301	180	101	-43.5	-40.4	-66.3	23	12	7
Liquid Fuels	543	654	590	-9.9	20.5	8.6	41	42	41
Natural Gas	222	409	412	0.9	84.1	85.8	17	26	29
Nuclear	181	226	223	-1.0	24.3	23.1	14	15	16
Electricity (trade outside EU)	2	2	2	-0.2	-11.5	-11.7	0	0	0
Renewable En. Sources	64	86	109	26.3	34.7	70.2	5	6	8
Total	**1313**	**1556**	**1437**	**-7.6**	**18.5**	**9.4**	**100**	**100**	**100**
Energy intensity (toe/M€$_{97}$)	189	149	138	-7.6	-20.9	-26.9			
Energy per capita (toe/cap)	3.66	4.06	3.75	-7.6	10.8	2.4			
Carbon Intensity (t of CO_2/toe)	2.22	2.13	1.96	-8.1	-4.3	-12.0			
Total CO_2 (Mt CO_2)	**3068**	**3311**	**2812**	**-15.1**	**7.9**	**-8.3**			

Source: PRIMES

These two effects can be seen in Table 3-8. It can be seen that, for the period to 2010, in the AP-no-trade scenario nearly half of the overall reduction in emissions is achieved through a reduction in energy consumption. Thus, for the level of adjustment difficulties implied by the scenario, it seems that at the margin it is as difficult for the system to reduce overall energy demand as it is to change the mix in primary fuels.

In terms of primary fuels, the effects shown in Table 3-8 capture both, the reduction in consumption that is due to the decline in total energy demand and the relative change in the demand for each fuel that the imposition of the constraint would generate. It can be seen that by far the most significant effect is that for solid fuels consumption for which both effects are negative. In other words, the demand for solid fuels, which are the most carbon intensive among all primary fuels, decline not only because of the overall fall in energy consumption but also because their use is replaced by less carbon intensive fuels. The reverse effect operates on gas and, especially, renewable energy forms both of which increase, when compared to their consumption level under baseline assumptions. The modest negative effect on liquid fuels is due mostly to a small reduction in overall demand rather than to substitution.

3.3.2 Impacts on final energy demand

In terms of changes in final consumption, the impacts of the AP-no-trade scenario are significantly different from those presented above on primary energy. Firstly, the difference between the reduction in final energy demand and the corresponding reduction in emissions is much less than was the case for primary energy demand. Thus, in 2010, the reduction in demand accounts for about two thirds of the overall reduction in emissions originating from adjustments in final energy. Effectively, substitution at the primary level is rather easier to achieve than at the level of final energy demand. To a large extent, this is due to the projected shift away from carbon intensive fuels within final energy even under baseline assumptions for reasons quite unrelated to any carbon constraints. As was seen in the discussion of the baseline scenario, many of the final energy sectors have been moving away from oil and solids, the most carbon intensive fuels, and in favour of electricity and gas. Thus, by 2010 there is effectively very limited scope for further changes in the fuel mix and this is likely to make it much more difficult for the EU to attain further reductions after the first commitment period (2008-2012) of the Kyoto Protocol.

Table 3-9: Final energy demand, AP-no-trade scenario

	Mtoe				% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP no-trade		Baseline	AP no-trade		Baseline	AP no-trade
Total	**850**	**1048**	**968**	**-7.7**	**23.3**	**13.8**	**100**	**100**	**100**
Industry	255	279	263	-5.5	9.2	3.3	30	27	27
Tertiary	109	158	133	-15.5	44.4	22.0	13	15	14
Households	234	268	251	-6.3	14.6	7.4	27	26	26
Transports	253	344	320	-7.0	36.3	26.8	30	33	33
Total CO_2 (Mt CO_2)	**1799**	**2040**	**1829**	**-10.3**	**13.4**	**1.7**	**100**	**100**	**100**
Industry	424	381	339	-10.9	-10.2	-20.0	24	19	19
Tertiary	190	218	166	-23.9	14.9	-12.5	11	11	9
Households	450	447	400	-10.4	-0.8	-11.1	25	22	22
Transports	735	994	924	-7.1	35.3	25.7	41	49	50

Source: PRIMES

In terms of the reaction of final energy demand sectors, Table 3-9 shows that the tertiary sector is the most sensitive to the imposition of the carbon constraint. In 2010 energy demand in tertiary declines by about two times the corresponding reduction of total final energy demand.

The most interesting aspect of the figures in Table 3-9 is the contrast between the sectors regarding the differential changes between energy demand and emission reductions. This effectively reflects the scope for fuel substitution within sectors. As expected, there is hardly any difference between the two changes in the transportation sector. This is because no new cost-effective fuels are expected to enter the transportation sector, in a significant way, in the near future.[13] Consequently, any reductions in the emissions of the sector are likely to be due to reductions in the energy demand of the sector rather than to any changes in the fuel mix. All other sectors experience significantly faster declines in carbon emissions than in energy demand suggesting a larger degree of opportunity for further changes in the fuel mix in favour of electricity and gas.

3.3.3 Impacts on power and steam generation

The analysis showed that changes at the level of final demand in 2010 (including fuel structure) account for about 40% of total reduction in emissions imposed by the carbon constraints under the AP-no-trade scenario. Clearly, larger reduction in emissions originates from the process of transformation of primary energy into final energy. More specifically, the power and steam generation system of the EU appears to be the sector that can adjust in the most cost-effective way to emission constraints. As can be seen from Table 3-10, the contribution by the energy sector, which includes activities like refining[14] is relatively modest.

[13] The use of low or zero carbon fuels in transportation implies the massive development of infrastructure for new fuel cycles, like hydrogen and methanol originating from biomass or fossil fuels with CO_2 sequestration.

[14] The effects on the power and steam generation activities of refineries are accounted for in the power sector.

Table 3-10: Power and steam generation, AP-no-trade scenario

	1990	2010 Baseline	2010 AP no-trade	% diff. in 2010	% change from 1990: 2010 Baseline	% change from 1990: 2010 AP no-trade	Shares, %: 1990	Shares, %: 2010 Baseline	Shares, %: 2010 AP no-trade
Electricity and steam output (TWh)	**3138**	**4255**	**4083**	**-4.0**	**35.6**	**30.1**	**100**	**100**	**100**
Fossil Fuels	2158	2981	2774	-7.0	38.1	28.5	69	70	68
Nuclear	720	891	882	-1.0	23.7	22.5	23	21	22
Hydro and Renewables	260	383	427	11.5	47.5	64.4	8	9	10
Total CO_2 (Mt CO_2)	**1268**	**1271**	**982**	**-22.7**	**0.2**	**-22.6**	**100**	**100**	**100**
Electricity and steam	1211	1219	934	-23.4	0.6	-22.9	96	96	95
Energy sector	57	52	48	-7.7	-9.0	-16.0	4	4	5
Fossil fuel inputs in electricity and steam generation (Mtoe)	**364**	**423**	**375**	**-11.5**	**16.4**	**3.0**	**100**	**100**	**100**
Solids	198	134	66	-51	-32.0	-66.7	54	32	18
Liquids	86	87	66	-24	1.2	-22.8	24	20	18
Gas	62	174	197	13	178.9	216.2	17	41	53
Biomass/Waste	18	28	45	61	57.7	153.3	5	7	12
Efficiency rates of Electricity and steam generation	0.51	0.61	0.64	5.2	18.6	24.7			

Source: PRIMES

It is partly because the high flexibility of the electricity and steam generation system that its output does not decline as sharply as that of other forms of final energy. As can be seen from Table 3-10, electricity and steam production declines by almost half the amount of reduction in total final energy demand. There are many reasons for this flexibility of the generation system.

Firstly, since nearly half of electricity generation takes place using carbon free primary fuels, such as hydro and nuclear, a 1% reduction in emissions in the system can take place with only half as much reduction in output. Only generation through fossil fuels needs to be reduced. Secondly, generation through carbon free fuels can actually increase with the exception of nuclear power for which it is not allowed except of on-going constructions. Thirdly, the system can respond by increasing its overall efficiency of generation that is based on fossil fuels. This can be achieved by adopting improvements in the technology used for any given fuel, through alternative combinations of technologies and fuels (such as the use of GTCC as opposed to conventional thermal coal plant) and through changes in the allocation of the available plants in the merit order of dispatching.

The operation of at least some of the above mechanisms can be seen in Table 3-10, where a sharp difference can be seen to occur between the decline in the system's output and fossil fuel inputs. The decline in inputs is close to 3 times the corresponding decline in electricity and steam output for 2010.

The flexibility of the power and steam generation sector to respond to carbon constraints is shown most dramatically by the changes achieved in emissions. On average, for every one per cent reduction in generation output there is a multiple decline in CO_2 emissions. Thus, in the AP-no-trade scenario, by reducing electricity and steam generation by just 4%, the generation system reduces its emissions by 23% and this accounts for two thirds of the overall system reduction in emissions in order to reach the carbon constraint. Since, as was seen above, around half of this reduction is achieved through improved efficiency and an increase in non-fossil fuels, nearly half of the overall reduction in emissions is achieved through changes in the generation fuel mix.

Compared with the developments in the baseline, a small decrease of co-generation of heat and power is observed in the AP-no-trade scenario.

3.4 The AP-full-trade Scenario

In the AP-full-trade scenario the EU member states will reduce emissions by 8% in such a way that some of the reductions are carried out in the European Union territory while others are carried outside its borders. For the latter the energy producers and users in the EU will pay a compensation through the emission trading or joint implementation mechanisms with other Annex B countries. In the comparison of compliance costs through measures in the EU territory the additional costs from purchasing permits are ignored.

In accordance to POLES and PRIMES coordinated model results for trading within Annex B countries, the permit price has been set at €$_{97}$ 17.4/tCO_2. The model results indicate that under this assumption the EU member states are projected to be net buyers[15] of emission permits amounting to 245 tons of CO2 (49% of the total reduction requirement as agreed in the Kyoto Protocol). Conversely the EU member states are estimated to undertake domestically 51% of the reduction requirements, achieving a reduction of CO_2 emissions by 0.4% in 2010 compared to 1990 levels. Practically this means that energy related CO_2 emissions in the EU are stabilised in 2010 to their level in 1990. Table 3-11 summarises the reduction achieved by each member state.

Table 3-11: CO_2 emissions by EU member state, AP-full-trade scenario

	Mt CO_2			Marginal Abatement Cost	% change from 1990		% Shares in CO_2 emissions		
	1990	2010		2010	2010		1990	2010	
		Baseline	AP full-trade	AP full-trade	Baseline	AP full-trade		Baseline	AP full-trade
EU14	**3068**	**3311**	**3057**	**17.4**	**7.9**	**-0.3**	**100**	**100**	**100**
Austria	55	58	54	17.4	5.7	-2.6	1.8	1.8	1.8
Belgium	105	123	117	17.4	17.4	11.3	3.4	3.7	3.8
Denmark	53	55	50	17.4	4.3	-5.4	1.7	1.7	1.6
Finland	51	72	61	17.4	40.8	19.0	1.7	2.2	2.0
France	352	393	370	17.4	11.6	5.1	11.5	11.9	12.1
Germany	952	839	772	17.4	-11.8	-18.8	31.0	25.3	25.3
Greece	71	109	96	17.4	54.3	35.4	2.3	3.3	3.1
Ireland	30	43	40	17.4	42.6	31.5	1.0	1.3	1.3
Italy	388	430	398	17.4	10.8	2.6	12.6	13.0	13.0
The Netherlands	153	207	192	17.4	35.4	25.3	5.0	6.3	6.3
Portugal	39	65	61	17.4	65.4	55.8	1.3	2.0	2.0
Spain	202	275	254	17.4	36.3	25.8	6.6	8.3	8.3
Sweden	50	69	63	17.4	38.4	25.8	1.6	2.1	2.1
United Kingdom	567	572	531	17.4	0.9	-6.4	18.5	17.3	17.4

Source: PRIMES

[15] Main sellers of permits are Russia and Ukraine.

3.4.1 Impacts on primary energy demand

In the AP-full-trade scenario, as was the case for the AP-no-trade scenario, the emission reduction target is achieved through an almost equal contribution of energy consumption reduction and of changes in primary fuels mix.

Table 3-12: Primary energy demand, AP-full-trade scenario

	Mtoe				% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP full-trade		Baseline	AP full-trade		Baseline	AP full-trade
Solid Fuels	301	180	130	-27.5	-40.4	-56.8	23	12	9
Liquid Fuels	543	654	626	-4.4	20.5	15.2	41	42	42
Natural Gas	222	409	422	3.3	84.1	90.2	17	26	28
Nuclear	181	226	223	-1.0	24.3	23.1	14	15	15
Electricity (trade outside EU)	2	2	2	2.1	-11.5	-9.6	0	0	0
Renewable En. Sources	64	86	94	8.7	34.7	46.5	5	6	6
Total	**1313**	**1556**	**1497**	**-3.8**	**18.5**	**13.9**	**100**	**100**	**100**
Energy intensity (toe/M€$_{97}$)	189	149	143	-3.8	-20.9	-23.9			
Energy per capita (toe/cap)	3.66	4.06	3.91	-3.8	10.8	6.6			
Carbon Intensity (t of CO_2/toe)	2.22	2.13	2.04	-4.0	-4.3	-8.1			
Total CO_2 (Mt CO_2)	**3068**	**3311**	**3057**	**-7.7**	**7.9**	**-0.3**			

Source: PRIMES

In terms of primary fuels, see Table 3-12, solid fuels bear the highest drop while gas and renewable energy forms increase when compared to their consumption level under baseline assumptions.

3.4.2 Impacts on final energy demand

In the AP-full-trade scenario, in 2010, the reduction in final demand is hardly smaller than the reduction in emissions originating from adjustments in final energy. In other words, given the changes in the fuel mix that are projected in the baseline, the role of energy intensity improvements in the demand side is significantly higher than that of carbon intensity improvements within the final demand sectors.

Table 3-13: Final energy demand, AP-full-trade scenario

	Mtoe				% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP full-trade		Baseline	AP full-trade		Baseline	AP full-trade
Total	**850**	**1048**	**1016**	**-3.1**	**23.3**	**19.4**	**100**	**100**	**100**
Industry	255	279	273	-2.1	9.2	6.9	30	27	27
Tertiary	109	158	145	-7.9	44.4	33.0	13	15	14
Households	234	268	262	-2.2	14.6	12.1	27	26	26
Transports	253	344	336	-2.4	36.3	33.1	30	33	33
Total CO_2 (Mt CO_2)	**1799**	**2040**	**1956**	**-4.1**	**13.4**	**8.7**	**100**	**100**	**100**
Industry	424	381	363	-4.7	-10.2	-14.5	24	19	19
Tertiary	190	218	195	-10.7	14.9	2.7	11	11	10
Households	450	447	428	-4.2	-0.8	-4.9	25	22	22
Transports	735	994	970	-2.4	35.3	32.1	41	49	50

Source: PRIMES

As can be seen from Table 3-13, the tertiary sector is again the most responsive to the introduction of the emission reduction target since in terms of final energy demand the reduction observed is almost four times the corresponding reduction in other sectors. More than 75% of emissions reduction in the tertiary sector is achieved through energy intensity improvements, while the corresponding contribution in industry and households is around 50%. This means that while industry and households find equally cost effective the improvement of technological equipment and the adjustments of fuel mix, the tertiary sector gives priority to the improvement in the use of energy and the efficiency of the building cells. The small responsiveness of the transport sector in the AP-full-trade scenario is noticeable.

3.4.3 Impacts on power and steam generation

In the AP-full-trade scenario, the changes in demand side in 2010 account for less than 35% of total reduction in emissions. The bulk of emission reduction comes from the power sector in the AP-full-trade scenario. The changes can be seen in Table 3-14.

Table 3-14: Power and steam generation, AP-full-trade scenario

					% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP full-trade		Baseline	AP full-trade		Baseline	AP full-trade
Electricity and steam output (TWh)	**3138**	**4255**	**4164**	**-2.1**	**35.6**	**32.7**	**100**	**100**	**100**
Fossil Fuels	2158	2981	2878	-3.5	38.1	33.3	69	70	69
Nuclear	720	891	882	-1.0	23.7	22.5	23	21	21
Hydro and Renewables	260	383	404	5.6	47.5	55.8	8	9	10
Total CO_2 (Mt CO_2)	**1268**	**1271**	**1101**	**-13.4**	**0.2**	**-13.2**	**100**	**100**	**100**
Electricity and steam	1211	1219	1051	-13.8	0.6	-13.3	96	96	95
Energy sector	57	52	50	-3.5	-9.0	-12.2	4	4	5
Fossil fuel inputs in electricity and steam generation (Mtoe)	**364**	**423**	**392**	**-7.4**	**16.4**	**7.8**	**100**	**100**	**100**
Solids	198	134	90	-33	-32.0	-54.6	54	32	23
Liquids	86	87	75	-13	1.2	-11.8	24	20	19
Gas	62	174	194	11	178.9	210.6	17	41	49
Biomass/Waste	18	28	33	17	57.7	84.1	5	7	8
Efficiency rates of Electricity and steam generation	0.51	0.61	0.63	4.3	18.6	23.7			

Source: PRIMES

While electricity and steam generation reduces by just over 2% (compared to a reduction of 3.8% for primary energy demand), the reduction of emissions in the sector reaches 13.5%. About 55% of this reduction is achieved through improvements in the average efficiency of plants (because of using more the plants with higher efficiency, like the GTCCs) and shifts towards the use of renewable energy forms. The remaining is achieved through changes in the fuel mix, mainly in favour of natural gas and to the detriment of solids.

4. Scenario Analysis for non-CO_2

4.1 The Baseline scenario

4.1.1 Methane

In line with EEA (1999), baseline emissions data are based on a study from AEA Technology (1998), in which six emission categories are distinguished:

1. Enteric Fermentation (EF)
2. Animal Manure Management (AM)
3. Landfill of Waste (LF)
4. Coal Mining (CM)
5. Oil and Gas (O&G)
6. Other

Emissions from LF in AEA Technology (1998) were taken from the Second National Communications. However, it turned out that these emissions were inconsistent with the amounts of organic and paper waste landfilled in PEEP 8 (Waste Management). Therefore, emissions from LF for the years 1990/1994 have been adjusted. Total methane emissions from LF in the EU15 have been taken from AEA Technology (1998), but the distribution between the countries are based on the amounts of organic/paper waste landfilled in the individual member states. It turned out that the adjusted emission distrubution among the countries is close to the methane emissions as reported by the IPCC. In table 4-1, methane emission for 1990 are presented by emission category and for each member state.

In table 4-2, Baseline methane emissions for 2010 are presented. Total emissions are 4.6% higher than reported by AEA Technology (1998). This is due to higher amounts of organic and paper waste landfilled in 2010 in PEEP 8 (Waste Management).

Table 4-1 Methane emissions in Ktonnes per year in 1990.

Country	EF	AM	LF	CM	O&G	Other	**Total**	**Mtonnes CO_2 Eq**
Austria	146	27	88	0	4	218	**483**	**10**
Belgium	198	176	166	15	39	37	**631**	**13**
Denmark	167	162	35	3	9	10	**386**	**8**
Finland	90	11	35	0	0	19	**155**	**3**
France	1430	168	756	206	126	330	**3016**	**64**
Germany	1430	614	865	1230	333	298	**4770**	**101**
Greece	142	23	373	43	0	132	**713**	**15**
Ireland	551	52	134	0	10	62	**809**	**17**
Italy	643	192	1765	15	304	947	**3866**	**82**
Luxembourg	16	2	3	0	2	1	**24**	**1**
Netherlands	402	103	241	0	179	44	**969**	**20**
Portugal	124	68	238	3	1	126	**560**	**12**
Spain	346	465	1002	613	74	213	**2713**	**57**
Sweden	188	12	43	0	0	39	**282**	**6**
UK	1005	125	1402	818	480	145	**3975**	**84**
EU-15	**6878**	**2200**	**7144**	**2946**	**1561**	**2621**	***23350***	***490***

Table 4-2 Baseline methane emissions in Kt per year in 2010.

Country	EF	AM	LF	CM	O&G	Other	**Total**	Mtonnes CO_2 eq.
Austria	147	29	101	0	5	166	**447**	**9**
Belgium	286	189	191	0	49	49	**764**	**16**
Denmark	133	176	48	6	8	7	**377**	**8**
Finland	60	8	42	0	3	17	**130**	**3**
France	1303	173	805	12	126	249	**2668**	**56**
Germany	1069	423	1044	519	322	239	**3616**	**76**
Greece	146	26	469	44	1	227	**913**	**19**
Ireland	653	65	189	0	14	82	**1003**	**21**
Italy	638	201	2020	1	384	912	**4155**	**88**
Luxembourg	24	3	5	0	2	1	**35**	**1**
Netherlands	362	89	302	0	179	35	**967**	**20**
Portugal	124	54	283	0	0	143	**604**	**13**
Spain	337	550	1179	381	141	298	**2885**	**61**
Sweden	202	12	52	0	3	26	**295**	**6**
UK	819	98	1833	108	489	127	**3474**	**73**
EU-15	**6303**	**2096**	**8562**	**1071**	**1726**	**2578**	***22336***	***469***

Source: AEA Technology (1998), adjusted for LandFills (LF).

Based on tables 4.1 and 4.2, the following can be stated about the emission changes under the Baseline scenario between 1990 and 2010:

- Overall, methane emissions decrease by 4,3% between 1990 and 2010. The largest emission reductions are achieved in the Coal Mining industry (-64%). In the same period, the largest source, i.e. LF covering 30% of all methane emissions in 1990, shows a substantial increase of 20% and therefore this emission source is responsible for 38% of all methane emissions in 2010.
- At member state level large countries like France, Germany and the United Kingdom show substantial reductions of methane emissions. On the other side large countries like Italy and Spain show relatively large increases in emissions.

4.1.2 Nitrous Oxide

In line with EEA (1999), baseline emissions are taken from ECOFYS (1998), in which seven emission sources are distinguished (see table 4-3). Due to rounding, total EU-15 emissions in table 4-3 are slightly higher than the sum of the emission-totals for each category.

Table 4-3 Emissions of N_2O in the EU-15 for seven emission categories in Ktonnes per year in 1990.

Source	1990	Mtonnes CO_2 eq.
Agriculture (AG)	420	130
Industrial processes (IP)	350	109
Fuel Combustion (FC)[1]	130	40
Transport (T)	40	12
Land use change and Forestry (LUF)	40	12
Waste Water Treatment (WWT)	10	3
Other sources	10	3
EU-15	**1009**	**313**

[1]Excluding Transport

Source: ECOFYS (1998)

ECOFYS does not present emissions for each category at the country level. Therefore, in table 4-4, only total nitrous oxide emissions for 1990 and 2010 are presented for each member state.

Table 4-4 Baseline nitrous oxide emissions in Ktonnes per year.

Country	1990	BL-2010	Change
Austria	12	8	-31%
Belgium	31	34	9%
Denmark	35	38	8%
Finland	17	19	15%
France	182	178	-2%
Germany	226	274	21%
Greece	13	18	34%
Ireland	27	24	-10%
Italy	166	156	-6%
Luxembourg	64	78	22%
Netherlands	1	1	0%
Portugal	14	14	1%
Spain	95	104	10%
Sweden	9	25	174%
United Kingdom	119	131	11%
EU-15	**1009**	**1103**	**9%**

Source: ECOFYS (1998)

Based on table 4-4, the following can be stated about emission changes in the baseline scenario between 1990 and 2010:

- Overall, the nitrous oxide emissions increase in the EU-15 with 9%;
- At member state level only in Austria, France, Ireland and Italy nitrous oxide emission decrease autonomously in the period 1990-2010. Overall, the emission change varies from –31% (Austria) to 174% (Sweden).

Additionally, it is stated in ECOFYS (1998) that the increases of emissions are largely due to Transport and Industrial Processes.

4.1.3 Halogenated gases

The halogenated gases only cover a small fraction of total GHG-emissions (1.5%). Nevertheless, in the future they might become more important because they serve as substitutes for ozone depleting substances. In line with EEA (1999), baseline emissions are taken from ECOFYS (1998), in which three groups of gases are distinguished in six emission categories (see table 4-5). Also, emission data at the member state level are not available. Emissions shown in the row ‘total’are used as a starting point in the remainder of this study.

Table 4-5 Baseline emissions of HFCs, PFCs and SF_6 in Ktonnes CO_2 equivalent per year in the EU-15.

Substance	Source	1995	2010
HFCs	HCFC-22 production	12-37	10
	Refrigeration	4.3	25
	Foam	0	24
	Other	Pm	5
PFCs	Aluminium production	9	5
	Other	Pm	Pm
SF_6	Electricity distribution	5	6
	Other	Pm	6
Total		**58**	**81**

Source: ECOFYS (1999)

4.1.4 Uncertainties in BL-emissions

In general, it can be stated that uncertainties in emissions of non CO_2 GHGs are large compared to CO_2. Within the basket of non CO_2 gases emissions of methane are most certain, followed by N_2O. As indicated earlier emissions of halogenated gasses are very uncertain for all countries (up to 100% and more). Based on UNFCCC (1997), uncertainties for CO_2, CH_4 and N_2O are estimated for some EU-15 countries in table 4-6. This table confirms the overall picture as sketched above.

Table 4-6 Uncertainty ranges in reported emissions (of 1995) of CO_2, CH_4, and N_2O for some EU15 countries in % or classified in H (High), M (Medium) and (L).

Country	CO_2	CH_4	N_2O
Belgium	2	30	50
Finland	H/M	M/L	M
Netherlands	2	25	50
Sweden	H/M	M	L
United Kingdom	5	20	M
EU-15	**H**	**M**	**L**

Source: UNFCCC [1997]

It can be concluded that uncertainties in emissions of non-CO_2 gases should be reduced substantially in order to be able to determine robust policy recommendations.

This should always be kept in mind before interpreting the results as shown in the remainder of this annex.

4.2 The AP No Trade scenario

It was decided to adopt a simple target in the APNT scenario of –8% for *all* GHGs, which is in accordance with the Kyoto protocol. Based on cost-considerations one could argue to reduce a larger amount of non CO_2 gases, but as indicated in paragraph 2.4, emissions of non-CO_2 gases are too uncertain to rely on them for achieving the obligation of the Kyoto Protocol.

4.2.1 Methane

To achieve a reduction of –8%, which means an additional reduction of 18 Mtonnes CO_2 equivalent in 2010 compared to BL-2010, the most cost-effective methane reduction measures presented in AEA Technology (1998), were applied (see table 4-7).

Table 4-7 Methane reduction measures in the APNT scenario and their reduction potential at the EU15 level, compared to BL-2010.

Source	Measure	Reduction (Mt CO_2 eq per year)	Costs ($€_{97}/tCO_2$ eq.)
O&G	Inspection and maintenance programme (pipelines)	0.92	-10.6
O&G	Inspection and maintenance programme (power generation)	0.21	-8.6
O&G	Inspection and maintenance programme (compressors)	0.84	-8.6
O&G	Recompression of gas during pipeline maintenance	0.23	-7.6
O&G	Compressors – no flushing at start up	0.12	-5.6
O&G	Compressors – Electrical start up in new installations.	0.12	-5.6
CM	Measures to recover and utilise mine gas	4.66	-3.2
O&G	Increase gas utilisation offshore	0.60	-2.8
EF	High genetic merit cows	1.39	0
O&G	Further increase gas utilisation offshore	0.60	0.3
LF	Improved landfill methane recovery	8.22	1.0
	TOTAL EU-15	**17.9**	**-1.7**

Source: AEA Technology (1998)

From table 4-7 it can be concluded that major reductions can be achieved in Coal Mining industry and by recovering methane from landfills. The full reduction potential of the latter is even much higher, but to achieve the target of –8%, there is no need to fully apply this measure.

Also, it should be noted that large emission reductions can be achieved by lowering the share of organic and paper waste in landfilling. This option is not considered here because it is too expensive compared to other CH_4-measures. Nevertheless, in the annex to PEEP 8, it is assumed major reductions in landfiling of organic and paper waste must be achieved to meet the AP targets for waste, resulting in a substantial *additional* CH_4 emission reductions of 65

Mtonnes CO_2 equivalent (!) which are ***not*** taken into account here. If these reductions become really true, then no policies would be needed at all for the non-CO_2 GHGs.

Applying the measures of table 4-7 at the member state level results in emission changes (compared to 1990) as shown in table 4-8.

Table 4-8 Methane reductions and abatement costs for the individual member states of the EU-15 in the APNT scenario

Country	Emissions in 2010	Emission change (compared to 1990)	Abatement costs ($M€_{97}$/year)
Austria	440	-8,8%	0,1
Belgium	752	19,3%	-0,7
Denmark	374	-3,3%	0,0
Finland	126	-18,6%	-0,2
France	2610	-13,4%	-0,9
Germany	3404	-28,7%	-11,3
Greece	891	25,1%	0,4
Ireland	990	22,4%	-0,2
Italy	4018	3,9%	-4,2
Luxembourg	34	41,3%	0,0
Netherlands	916	-5,5%	-2,0
Portugal	591	5,5%	0,2
Spain	2766	2,0%	-5,2
Sweden	291	3,1%	0,0
United Kingdom	3279	-17,5%	-6,6
EU-15	**21483**	**-8,0%**	**-30,5**

Based on table 4-8, the following can be concluded for the APNT scenario:

- Changes in emissions vary from –28,7% for Germany to 41,3% for Luxembourg;
- Overall methane abatement costs are negative, implying a win-win situation: emission reductions and financial benefits;
- Germany reduces most compared to the emissions of 1990 and realises the highest abatement benefits while Greece has abatement costs although its methane emissions increase substantially over the period 1990-2010.

In table 4-9 the EU-15 emissions for the sectors EF, AM, LF, Coal, O&G and Other are summarised for BL-1990, BL-2010 and APNT-2010.

Table 4-9 BL-1990, BL-2010 and NTPS-NT 2010 methane emissions.

Scenario	EF ($ktCH_4/a$)	AM ($ktCH_4/a$)	LF ($ktCH_4/a$)	CM ($ktCH_4/a$)	O&G ($ktCH_4/a$)	Other ($ktCH_4/a$)	**Total ($ktCH_4/a$)**
BL-1990	6878	2200	7144	2946	1561	2621	**23350**
BL-2010	6303	2096	8562	1071	1726	2578	**22336**
APNT- 2010	6237	2096	8170	849	1553	2578	**21483**
APNT (comp. to 1990)	-9,3%	-4,7%	14,4%	-71,2%	-0,5%	-1,6%	**-8,0%**

Based on table 4-9, the following can be concluded for methane emissions in the period 1990-2010 over the different sectors in the EU-15:

- Emission reductions are mainly achieved in the Coal Mining industry.
- Landfilling is the only category that shows an increase of emissions in both scenarios.
- For the other categories except Oil&Gas, most emission reductions are achieved autonomously (i.e. in the BaseLine).

4.2.2 Nitrous Oxide

To achieve a reduction of –8%, which means an additional reduction of 53 Mtonnes CO_2 equivalent in 2010 compared to BL-2010, the most cost-effective nitrous oxide reduction measures presented in ECOFYS (1998), were applied (see table 4-10).

Table 4-10 Nitrous oxide reduction measures in the APNT scenario and their reduction potential at the EU15 level, compared to BL-2010.

Source	Measure	Reduction ($Mt\ CO_2$ eq per year)	Costs (€$_{97}$/tCO_2 eq.)
AG	Improved use of fertilisers	2.59	-202
AG	Reduction of price support, set aside and Marginal Land Subsidy	3.62	0.0
W	Sewage treatment	0.79	0.0
IP	Catalytic reduction to N_2 and O_2 in nitric acid production.	25.6	0.3
IP	Catalytic reduction to N_2 and O_2 in adipic acid production.	20.7	0.3
	TOTAL EU-15	**53.3**	**-9.6**

Source: ECOFYS (1998)

It should be emphasised the full potential of the last measure in table 4-11 is much higher (65 Mtonnes). However, to meet the target of –8% there is no need to fully apply this measure.

Table 4-11 Nitrous oxide reductions and abatement costs for the individual member states of the EU-15 in the APNT scenario.

Country	Emissions in 2010	Emission change (compared to 1990)	Abatement costs ($M€_{97}$/year)
Austria	8	-34,9%	-4,9
Belgium	25	-18,4%	-15,3
Denmark	36	3,1%	-50,2
Finland	17	-2,4%	0,2
France	130	-28,6%	-75,8
Germany	238	5,2%	-127,6
Greece	17	30,8%	0,1
Ireland	23	-15,6%	-31,6
Italy	146	-12,3%	-95,6
Luxembourg	63	0,0%	0,0
Netherlands	1	-1,5%	-30,8
Portugal	12	-14,2%	-12,0
Spain	93	-2,0%	-66,5
Sweden	23	154,4%	-0,1
United Kingdom	99	-16,6%	-7,2
EU-15	**930**	**-8,0%**	**-509,6**

Based on table 4-11, the following can be concluded for nitrous oxide emission changes in the APNT scenario:

- The individual methane reduction targets vary from –34,9% for Austria to 154,4% for Sweden;
- Overall nitrous oxide abatement costs are negative, implying a win-win situation: emission reductions and economic benefits;

4.2.3 Halogenated gases

To achieve a reduction of –8%, an additional reduction of 28 Mtonnes CO_2 equivalent in 2010 compared to BL-2010 is needed. This is achieved by applying the most cost-effective methane reduction measures presented in ECOFYS (1999) were applied (see table 4-12).

From table 4-12 it can be concluded that the largest reductions can be achieved for HFCs. It should be emphasised that the maximum reduction potential of the last measure is 25 Mtonnes. However, to meet the target of –8% a reduction of 7.6 Mtonnes is enough.

Table 4-12 Emission reduction measures for HFCs, PFCs and SF_6 in the APNT scenario and their reduction potential at the EU15 level, compared to BL-2010.

Subst.	Source	Measure	Reduction (Mt CO_2 eq per year)	Costs (€$_{97}$/ tCO_2 eq.)
HFC	HCFC-22 Production	Incineration of flue gasses	9	0.4
SF_6	High and mid voltage switches	Leakage reduction modifications	5.4	1
SF_6	Windows	Leakage reduction	1.5	2
PFC	Aluminium production	Process modifications	4.3	5.6
HFC	Foams	Alternative blowing agents and insulation producs.	7.6	10
		TOTAL EU-15	**28**	

Source: ECOFYS (1999)

Emission reductions at the member state level are not available, but in annex ****** it is described how reduction costs are distributed among the economic sectors and the individual member states. In table 4-13, the result of this exercise is summarised.

Table 4-13 Country level HFC, PFC and SF_6 abatement costs in APNT in M€$_{97}$/year.

Country	HFC	PFC	SF_6	Total
Austria	2	0	0	**2**
Belgium	4	0	0	**4**
Denmark	1	0	0	**2**
Finland	1	0	0	**1**
France	14	4	2	**20**
Germany	26	7	2	**35**
Greece	0	2	0	**2**
Ireland	2	0	0	**2**
Italy	7	2	1	**11**
Luxembourg	0	0	0	**0**
Netherlands	4	3	0	**7**
Portugal	1	0	0	**1**
Spain	5	4	1	**10**
Sweden	2	1	0	**3**
United Kingdom	14	3	1	**18**
EU-15	**83**	**25**	**9**	***117***

Based on table 4-13, the following can be stated about the HFC, PFC and SF_6 abatement costs in the APNT scenario:

- Total annual abatement costs are 117 M€$_{97}$/year. Because emissions are reduced by 28 Mtonne CO_2-equivalent per year, this indicates a cost-effectivity of 4,2 €$_{97}$/tonne CO_2 equivalent;
- 71% of the abatement costs are related to HFC-reduction measures.

4.3 Interactions with other PEEPs

4.3.1 Methane

First of all, as also indicated in paragraph 4.2.1, major interactions exist with Waste Management (PEEP 8) because about one third of all methane emissions in Europe originate from Land Fills. Therefore, if landfilling is reduced substantially (as happens in the APNT scenarios), methane emissions are reduced as a side effect. In this annex we did not take into account this spill-over effect because it was decided not to depend on the difficult to achieve target with respect to Waste Management. Nevertheless, *if* the target is achieved additional methane emission reductions of 65 Mtonnes CO_2 equivalent could be achieved, although uncertainties are large. This is due to the fact that factors affecting methane emissions from landfills are difficult to quantify and vary from site to site.

With respect to measures in the category Animal Manure (AM), it is important that the animal scenario assumed by AEA Technology (1998), is comparable with the animal scenario in PEEP 5 (Acidification and Eutrophication). For 1990, the numbers (in million heads) are as follows:

	PEEP 2	**PEEP 5**
Dairy Cows	25	30.5
Non-dairy cattle	87.8	60.7
Sheep	98.1	108.8 (incl. Goats)
Pigs	113.9	115.7

The numbers of AEA Technology (1998) have been based on IPCC and EUROSTAT, and growth percentages up to 2010 are taken from Amman (1996). These percentages are only slightly different from the ones used in PEEP 5.

From the table above it can be concluded that the largest difference exist for Dairy Cows and Non-dairy cattle. Strictly, it would be needed to update the emission reduction potential of the AM-measures from AEA Technology (1998), but due to time constraints we could not make this update for this study, also because the animal-scenario was decided upon in a very late stage.

With respect to Coal Manifacturing (CM), it is important to compare the coal-scenario of AEA Technology (1998) with the outcomes of PRIMES (numbers in Mtoe) for the BL and the AP scenarios:

Scenario	1990	2000	2010
AEA Technology (1998)	210	111	79
BL (Shared Analysis)	210	110	85
AP NT	210	107	63
AP FT	210	108	68

Obviously, differences occur mainly in the period after 2000. However, since CM-measures to reduce methane are very cheap (and sometimes show negative costs down to –3 $€_{97}/tCO_2$ eq.) and are considered as a whole in the PEEP-study, these differences will hardly affect the outcomes with respect to costs and emission reductions.

With respect to Oil and Gas (O&G), differences between the AEA Technology scenario and PRIMES results are significant. However, most O&G related measures have not been applied in the PEEP scenarios because they are too expensive. The only measures that matter are related to maintenance programmes and two technical measures with respect to compressors (see table 3.1). Since the total reduction potential of these measures is limited and because the emission reduction as a result from maintenance programmes with respect to pipelines are rather independent from the amount of gas produced, the error that is introduced due to different gas and oil scenarios is small.

4.3.2 Nitrous oxide

Fisrt of all, the scenario with respect to fertilisers in the ECOFYS-study (1998) and the PEEP-study are about the same. Only for the Netherlands, there is a significant difference. In the ECOFYS-study, two measures are distinguished for agriculture.

The cheapest measure, Improved Used Fertiliser, does not have a spill-over effect to other PEEPs (unless it would mean that less fertilisers are going to be used, but this is not reported by ECOFYS).

For the second measure, Reduction of price support, set aside and Marginal Land Subsidy, it is not easy to determine to what extent the reduction as reported by ECOFYS (1998) can be achieved in reality and what spill-over effects can be expected for PEEP 7 (Water Quality) and PEEP 4 (Bio-diversity). Additional research would be needed to quantify these effects correctly.

The measure with respect to Waste water (W) is related the formation of N_2 in stead of N_2O during sewage treatment. Further research is needed to determine whether the effectivity of this measure as reported in table 4-10 is consistent with the sewage treatment scenario in PEEP 7.

Major reductions of N_2O can be achieved in the production of Acid Production, which is used in the production of fertilisers. As indicated, the fertiliser-scenario of ECOFYS (1998) is consistent with the fertliser scenario in this study and therefore this measure will be consistent also.

And finally, large reductions can be achieved in the production of Adipic acid which is a raw material for many synthetics. No spill-over effects are expected because the other PEEPs do not consider this sector explicitly.

4.4 The AP Full Trade scenario

No APFT-scenario has been determined for non CO_2 GHGs explicitly, but it has been estimated what emission reductions would be achieved if all emission reduction measures are applied which are cheaper than 17.4 €$_{97}$/tCO_2 (=63.7 €$_{97}$/tC) . This value coincides with the permit price (or carbon value) in the full trade scenario for CO_2 (see the annex on CO_2). In table 4-14, it is summarised what additional emission reductions could be expected for CH_4 and N_2O at the EU-15 level. Halogenated gases are left out, because no additional measures can be applied.

Table 4-14 Additional emission reductions in 2010, compared to APNT in Mt CO_2 equivalent for N_2O and CH_4 if all measures are applied up to 17.4 €$_{97}$/tCO_2 equivalent.

Source	Measure	Reduction CH_4	Reduction N_2O	Costs (€$_{97}$/tCO_2 eq.)
IP	Catalytic reduction to N_2 and O_2 in adipic acid production.		44.4	0.3
LF	Methane recovery and use for electricity generation	19.2		1.0
AM	Anaerobic digestion of pigs manure in temperate climates	5.0		1.5
O&G	Use of gas turbines instead of reciprocating engines	0.1		2.7
AM	Anaerobic digestion of dairy cattle manure in temperate climates	0.5		2.8
AM	Anaerobic digestion of non-dairy cattle in temperate climates	1.3		3.7
AM	Anaerobic digestion of pigs manure in cool climates	2.2		9.0
AM	Anaerobic digestion of dairy cattle manure in cool climates.	0.7		17
	TOTAL EU-15	**29.0**	**44.4**	

It should be emphasised the landfill related measure in the table above, is consistent with the AP scenario in PEEP 8. And again, as explained in paragraph 4.2.1, reduction of methane emissions from landfills through the reduction of landfilling of bio-degradable waste has *not* been taken into account, although its potential is very high (65 Mtonnes CO_2 eq.).

From table 4-14, it can be concluded that:

- Substantial additional reductions (1.9% of all CO_2 eq. emissions in 1990, non-energy sectors excluded) can be achieved if all measures would be implemented, which are cheaper than 17.4 €$_{97}$/tCO_2 equivalent. This suggests lower CO_2 emission reductions might be needed if emission trading was extended to CH_4 and N_2O. However, to include CH_4 and N_2O in a trading regime, it would be necessary to reduce uncertainties in both emissions and cost curves to levels which are comparable to uncertainties related to CO_2.
- additional CH_4 emission reductions are mainly related to LandFill and Anaerobic digestion of pigs manure (in both climates).
- N_2O emission reductions are completely achieved due the full implementation of only one cheap measure in the chemical industry.

5. Implications for Policy

5.1 Methodological remarks

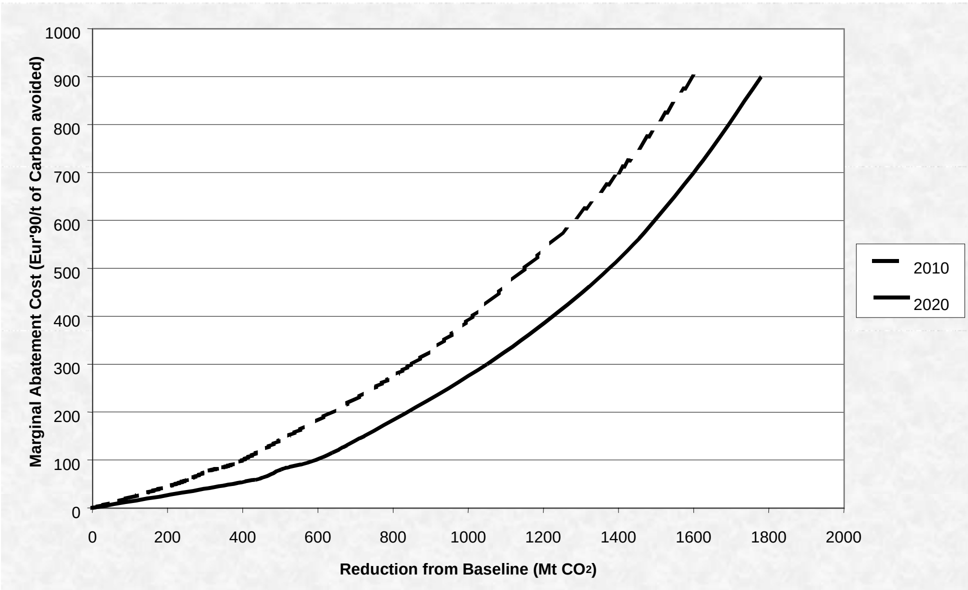
Imposing an emission reduction constraint at the overall system level implies that all consumers and producers of energy undergo changes, for example in their behaviour, choice of fuels and technologies. The menu of possible changes at the level of an individual consumer or producer includes actions that have different costs. The market system relates consumers and producers to each other and finally leads all consumers and producers to select those actions that at the margin have equal costs across the whole economy. Evidently, the level of such an equalised marginal cost of individual actions depends on the level of the emission reduction constraint.

A model like PRIMES, being a market-oriented partial equilibrium model, mimics such an adjustment process. PRIMES includes, at the level of consumer or producer behaviour, a menu of possible actions, some of them being of behavioural nature and some of them explicitly referring to technologies and fuel mix choices. The formulation is such that there is a continuum of possible actions at the level of each consumer and producer of energy. Consequently, the model shows that after imposing a carbon constraint all consumers and producers undertake many actions simultaneously. The changes with respect to a baseline situation are used as an indicator of the opportunity of actions at sectoral level when considering the influence of all inter-relationships among sectors in market equilibrium.[16]

Other analysis with PRIMES model has shown that there is a tendency for the degree of difficulty of reducing emission, as represented by the level of marginal abatement cost, to increase non-linearly as the required level of emission reduction increases (see Figure 5-1).

[16] Bottom-up approaches and linear programming models employ discrete menus of actions. Their methodology is by definition such that only one action is taken-up at the margin. Therefore they can provide an arrangement of actions along ascending costs. Although in reality actions are discrete at the very individual level , at the aggregate level of a sector the actions are not discrete due to high variety of individuals composing the sector. In a model considering aggregation of the sectors (like any model) it is more pragmatic to consider a continuum of possible actions. This is the case in PRIMES.

Figure 5-1:Marginal abatement cost and CO_2 emissions avoided compared to baseline 2010, 2020



Source: PRIMES

The issue of non-linear costs in incremental reductions in CO_2 emissions has been discussed in Capros and Mantzos (1999)[17] in great detail and for a great range of marginal abatement costs. It was concluded that there is a tendency for marginal abatement costs to increase non-linearly as the emissions target becomes more severe (see Figure 5-1). In other words, beyond a certain level of emissions reduction, for each additional ton of carbon reduction the cost increases disproportionately. It was also observed that for the range of emission reductions likely to be required for reaching the Kyoto target the degree of difficulty for the EU energy system remains within manageable levels.

5.2 Overview of Country Analysis

Table 5-1 presents, for each country, the improvement in terms of energy intensity and of carbon intensity for electricity and steam generation under the two scenarios in 2010 when compared to baseline assumptions. The table also shows the percentage contribution of the power and steam generation system to emissions reduction for each country in 2010.

[17]P. Capros, L. Mantzos: “Energy System Implications of Reducing CO2 Emissions: Analysis for EU Sectors and Member states by using the PRIMES Ver.2 Energy System Model”, Final report from ICCS/NTUA for DGXI of the European Commission, March 1999.

Table 5-1: Impacts on energy and carbon intensity by country in 2010

	Energy intensity (toe/M€97)			Carbon intensity in Elec/Steam (tCO_2/MWh)			% Share of Elec/Steam in Emission Change	
	Baseline	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade
	2010	% change in 2010		2010	% change in 2010			
AU	118.7	-3.5	-5.5	0.17	-14.3	-27.2	56.1	46.0
BE	201.1	-2.8	-11.5	0.20	-6.3	-24.4	28.5	27.6
DK	104.6	-5.6	-11.9	0.29	-11.5	-33.0	86.0	81.5
FI	176.1	-5.7	-11.1	0.26	-24.4	-41.7	86.6	80.5
FR	150.8	-1.9	-3.3	0.09	-10.5	-17.9	30.6	31.3
GE	138.8	-4.6	-5.6	0.38	-9.8	-12.2	69.5	62.1
GR	236.0	-7.5	-14.0	0.65	-17.0	-15.1	87.4	73.2
IR	129.8	-4.2	-10.6	0.41	-10.6	-29.0	71.8	68.6
IT	112.4	-4.2	-8.1	0.34	-13.7	-25.8	76.9	70.7
NL	186.8	-3.9	-21.9	0.30	-11.9	-25.2	65.3	43.3
PO	215.5	-2.8	-9.4	0.35	-7.2	-36.9	74.8	80.2
SP	153.2	-3.2	-5.5	0.31	-13.8	-27.0	72.8	69.4
SV	166.6	-3.1	-7.9	0.08	-16.9	-39.8	65.4	58.3
UK	169.7	-4.3	-7.9	0.32	-9.9	-13.9	60.6	46.7
EU14	**149.1**	**-3.8**	**-7.6**	**0.28**	**-12.3**	**-20.8**	**66.2**	**57.0**

Source: PRIMES

There are big differences among EU countries. For example, in the AP-full-trade scenario, 2010 emissions are nearly 19% below their level in 1990 in Germany and 6.5% in the UK while they are higher than their 1990 level by more than 30% in Greece and Portugal (see Table 5-2). These differences reflect to a large extent the different dynamics in each country's energy system and the prospects of industrial restructuring. The carbon intensity of the power generation system also plays a key role in the ease with which a country can adjust to the imposition of a carbon constraint.

Table 5-2: CO_2 emissions by EU member state, comparison of scenarios

	Baseline			No Trade			Full Trade		
	Mt CO_2		% change	Mt CO_2	% change in 2010		Mt CO_2	% change in 2010	
	1990	2010	1990-2010	2010	from 1990	from baseline	2010	from 1990	from baseline
Austria	55	58	6	48	-13	-17	54	-3	-8
Belgium	105	123	17	97	-7	-21	117	11	-5
Denmark	53	55	4	42	-21	-24	50	-5	-9
Finland	51	72	41	51	0	-29	61	19	-15
France	352	393	12	355	1	-10	370	5	-6
Germany	952	839	-12	755	-21	-10	772	-19	-8
Greece	71	109	54	89	25	-19	96	35	-12
Ireland	30	43	43	34	13	-21	40	31	-8
Italy	388	430	11	363	-6	-15	398	3	-7
The Netherlands	153	207	35	144	-6	-30	192	25	-7
Portugal	39	65	65	50	27	-23	61	56	-6
Spain	202	275	36	233	15	-15	254	26	-8
Sweden	50	69	38	53	7	-23	63	26	-9
United Kingdom	567	572	1	498	-12	-13	531	-6	-7
EU14	**3068**	**3311**	**8**	**2812**	**-8**	**-15**	**3057**	**0**	**-8**

Source: PRIMES

There is a tendency for countries with high energy intensities and high carbon intensities in their power generation system to contribute more to the required emission reduction than their share in baseline emissions in 2010 would warrant. For example France, which relies to a very large extent on nuclear power for electricity generation, contributes only 7.7%, in the AP-full-trade scenario, and 9%, in the AP-no trade scenario, to the EU reduction while its share in 2010 emissions is close to 12%. Greece, on the other hand, contributes 4% and 5.3% to the EU reduction, significantly more than its 3% share in 2010 emissions.

Under the AP-full-trade scenario, there is a significant correspondence between the shares of the different countries in terms their emissions in 2010 and the amount of emissions that they manage to avoid. This result is due to the relatively high degree of homogeneity of EU countries regarding the prospects of industry and technological developments under the EU Single Market. However, in the AP-no-trade scenario, the different effort required by each country under the Burden Sharing agreement results in significant distortions as regards the percentage contribution to emissions reduction and the emissions of the countries. The Netherlands, in which relatively high effort is required to reach the target of the Burden Sharing agreement, contributes by more than 12% in emission reduction while under baseline conditions its share in terms of emissions does not exceed 6.5%. On the contrary, Germany whose share of emissions under baseline conditions is more than 25% contributes in this case to emissions reduction by less than 17%. In general, the closer the marginal abatement cost of a country to the EU average, the higher the correspondence between emissions and contribution to emissions reduction.

Table 5-3 provides summary information on the efforts undertaken by the energy demand sector to reduce emissions. Reduction of emissions is achieved through structural and behavioural changes as well as through energy efficiency improvement in the demand-side. In general the reduction effort in the demand side is significantly higher under the AP-no-trade scenario. The shares of tertiary and industry in total emission reduction in the demand side are higher in the AP-full-trade, indicating the existence of lower cost opportunities in these sectors. Households and transports relatively increase their efforts under AP-no-trade.

Under the AP-full-trade scenario, there is a, rather, uniform drop of energy demand across EU member states ranging from 2.1% for Italy to 3.8% for UK (3.1% on average) compared to baseline for 2010. As regards changes by sector, the results show significant differences between the member states, whereas there is a rather even distribution of emissions reduction in the demand side for EU as a whole (around 28% coming from tertiary and from transports, industry and households accounting for 22% each).

Under the AP-no-trade scenario, the differences between the different member states are magnified due to the imposition of the Burden Sharing agreement. Netherlands have to achieve a reduction of final energy demand of 24% compared to baseline indicating a significant improvement of energy intensity in the demand side, whereas the corresponding figure for France and Germany is around 5% only.

Table 5-3: Changes in the demand side in 2010

	AP-full-trade						AP-no-trade					
	% dif. from baseline in 2010		% contribution to emission reduction				% dif. from baseline in 2010		% contribution to emission reduction			
	Final energy demand	CO_2 emissions	Industry	Tertiary	Households	Transports	Final energy demand	CO_2 emissions	Industry	Tertiary	Households	Transports
AU	-2.7	-4.8	28.5	0.5	38.1	32.9	-7.1	-13.3	25.3	0.4	37.8	36.5
BE	-3.0	-4.9	44.9	21.4	18.6	15.1	-13.7	-19.7	36.4	17.5	22.5	23.6
DK	-3.6	-2.8	11.0	30.9	5.4	52.8	-8.8	-9.4	8.0	21.0	15.4	55.6
FI	-2.4	-4.4	36.0	13.4	26.3	24.4	-7.0	-12.0	35.3	12.1	26.2	26.4
FR	-2.8	-4.9	20.3	31.8	23.2	24.7	-4.9	-8.2	17.8	28.2	25.5	28.5
GE	-3.7	-4.2	17.4	26.7	28.8	27.1	-5.1	-6.6	15.9	29.9	28.5	25.6
GR	-3.2	-3.1	11.5	11.8	20.6	56.1	-10.1	-10.3	10.3	13.0	20.1	56.5
IR	-3.3	-3.7	5.9	35.6	33.2	25.2	-9.6	-11.1	6.8	32.9	32.0	28.3
IT	-2.1	-2.7	30.1	24.5	16.6	28.8	-5.8	-7.2	22.3	21.7	19.4	36.6
NL	-3.4	-4.3	20.3	28.9	16.5	34.2	-24.1	-28.5	18.7	23.6	19.5	38.2
PO	-2.2	-2.6	26.0	16.6	17.5	39.9	-6.6	-8.3	17.8	15.6	16.3	50.3
SP	-2.6	-3.4	21.7	28.8	11.8	37.7	-5.6	-7.6	19.1	27.5	11.4	42.0
SV	-2.4	-4.6	35.0	29.3	13.3	22.4	-7.5	-14.0	30.7	23.2	13.9	32.2
UK	-3.8	-4.6	16.2	34.1	21.2	28.5	-8.7	-11.3	14.5	30.3	20.6	34.7
EU14	**-3.1**	**-4.1**	**21.5**	**27.8**	**22.2**	**28.5**	**-7.7**	**-10.3**	**19.6**	**24.8**	**22.1**	**33.5**

Source: PRIMES

Tables 5-4 and 5-5 summarise the changes that occur in electricity and steam generation under the AP-full-trade and AP-no-trade scenarios for each EU member state. The decrease of electricity demand (except for France where the introduction of emission reduction targets leads to increase of demand for electricity), combined with significant changes in fuel mix, leads to higher decrease of CO_2 emissions. However, the results differ across EU member states reflecting the different structures of power generation. The shares of carbon free sources in a country largely explain these differences. Further increasing the shares of renewable energies depends on the magnitude of the emission reduction constraint, which under the AP-no-trade scenario is large for some member states, like Belgium and the Netherlands.

Table 5-4: Changes in electricity generation in 2010

	Baseline			AP-full-trade				AP-no-trade			
	Electricity output (TWh)	Thermal plants	Hydro and renewables	Electricity Output	CO_2 emissions (incl. Steam prod.)	Thermal plants	Hydro and renewables	Electricity Output	CO_2 emissions (incl. Steam prod.)	Thermal plants	Hydro and renewables
		% of production		% dif. from baseline in 2010		% of production		% dif. from baseline in 2010		% of production	
AU	66	39.8	60.2	-2.9	-15.4	35.7	64.3	-4.6	-28.1	33.7	66.3
BE	100	48.2	3.3	-1.0	-6.3	46.7	4.6	-2.8	-24.6	41.6	9.3
DK	44	83.5	16.5	-5.7	-15.5	80.4	19.6	-8.6	-38.0	74.0	26.0
FI	90	58.1	17.1	-1.3	-25.2	56.8	18.0	-4.1	-43.7	53.6	20.5
FR	591	14.1	13.0	0.7	-9.6	14.9	12.6	0.8	-16.6	14.2	13.4
GE	599	64.4	7.6	-5.0	-13.1	62.4	9.2	-3.8	-14.8	63.4	9.1
GR	71	90.0	10.0	-6.4	-21.0	88.7	11.3	-16.3	-27.1	85.9	14.1
IR	34	93.1	6.9	-3.9	-13.6	88.8	11.2	-9.3	-34.6	86.4	13.6
IT	335	84.7	15.3	-1.9	-14.9	82.7	17.3	-5.1	-28.7	82.6	17.4
NL	128	98.2	1.8	-3.4	-12.7	97.0	3.0	-19.2	-34.1	89.8	6.2
PO	63	78.7	21.3	-3.2	-9.6	78.0	22.0	-8.0	-40.9	74.9	25.1
SP	249	62.2	14.6	-1.9	-14.9	60.6	15.7	-3.2	-28.4	60.0	16.1
SV	164	18.2	44.2	-2.4	-18.5	16.7	44.7	-4.7	-41.4	13.8	47.5
UK	483	77.1	2.1	-2.9	-12.1	76.3	2.6	-3.6	-16.8	75.6	3.0
EU14	**3018**	**57.8**	**12.7**	**-2.5**	**-13.8**	**56.3**	**13.7**	**-4.2**	**-23.4**	**54.7**	**14.8**

Source: PRIMES

Countries with high carbon intensity in power and steam generation under baseline conditions can achieve high emission reduction through shifts towards less carbon intensive fuels such as natural gas (see for example the cases of Finland, Germany, Spain and others). On the contrary, countries with low carbon intensity, such as the Netherlands where natural gas is the dominant fuel under baseline conditions, face much greater difficulties to reduce CO_2

emissions from power and steam generation. While in the case of Finland the reduction of CO_2 emissions is almost ten times the reduction of electricity demand in the case of the AP-no-trade scenario, the corresponding figure for Netherlands is only two times the reduction of demand.

Table 5-5: Shares of fossil fuels in thermal electricity production in 2010

	Baseline				AP-full-trade				AP-no-trade			
	Solids	Liquids	Gas	Biomass	Solids	Liquids	Gas	Biomass	Solids	Liquids	Gas	Biomass
AU	13.0	4.5	76.7	5.8	5.4	3.4	87.6	3.6	3.7	2.5	67.9	25.9
BE	6.8	1.6	90.8	0.8	5.0	1.8	92.3	0.9	0.0	1.4	92.6	6.0
DK	43.7	6.3	41.9	8.1	36.3	3.8	51.9	8.1	0.0	23.8	70.2	6.0
FI	54.7	0.1	32.2	13.0	31.3	0.1	54.0	14.7	15.9	0.1	63.0	21.1
FR	13.2	8.1	75.8	2.9	7.8	5.9	82.9	3.4	6.1	6.4	80.9	6.6
GE	61.4	1.3	34.6	2.6	50.5	1.2	45.3	2.9	46.5	1.1	47.0	5.4
GR	52.8	14.4	32.6	0.3	36.3	16.6	45.7	1.4	42.0	17.7	37.3	3.1
IR	22.9	5.1	70.1	1.9	20.0	3.3	72.9	3.8	8.8	2.9	79.4	9.0
IT	11.0	14.3	73.1	1.6	5.7	9.5	82.6	2.2	0.2	2.4	93.7	3.7
NL	14.5	0.5	82.5	2.5	4.3	0.6	91.4	3.7	0.0	0.6	94.1	5.3
PO	29.0	8.4	59.8	2.9	23.9	8.4	64.7	2.9	0.0	8.6	80.6	10.8
SP	35.0	5.4	51.5	8.1	22.7	5.7	60.0	11.7	16.3	5.2	53.5	25.0
SV	8.3	19.5	53.2	19.1	8.7	24.3	48.6	18.3	1.3	29.4	43.3	26.0
UK	19.1	3.5	76.4	1.0	12.2	3.6	82.3	1.9	9.8	4.0	83.0	3.3
EU14	**30.5**	**5.7**	**60.6**	**3.2**	**21.5**	**4.9**	**69.5**	**4.1**	**16.8**	**4.2**	**71.4**	**7.7**

Source: PRIMES

5.3 Overview of Sectoral Analysis

As shown in other studies with PRIMES[18] the allocation of the emission reduction effort to the energy demand and supply sectors changes with the level of emission reduction target.

The scenarios analysed in the context of Kyoto commitments are such that in most cases the bulk of the reduction in carbon intensity of the EU energy system is effected through the electricity and steam generation system. For the period to 2010, nearly 57% of the overall reduction in emissions is achieved through adjustments in the power and steam generation sector in the AP-no-trade scenario, this share becoming even higher (65%) in the AP-full-trade scenario. Table 5-6 illustrates the contribution of the different sectors in the achievement of the emission reduction target under the two scenarios. The Table below also shows that the emission reduction effort in the demand sectors is considerably higher under the AP-no-trade scenario. As the low cost possibilities in the power and steam generation sector tend to be exhausted already under the AP-full-trade scenario, the targets under AP-no-trade call upon demand-side actions to effect the reduction.

[18] See P. Capros and L. Mantzos “Energy System Implications of Reducing CO_2 Emissions”, Report to European Commission DG-XI, 23 April 1999.

Table 5-6: Change of CO_2 emissions by sector in 2010

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-10.2	-14.5	-20.0	7.1	8.3	11.5	11.9	12.1
Tertiary	14.9	2.7	-12.5	9.2	10.5	6.6	6.4	5.9
Households	-0.8	-4.9	-11.1	7.3	9.3	13.5	14.0	14.2
Transports	35.3	32.1	25.7	9.4	14.2	30.0	31.7	32.8
Electricity-steam production	0.6	-13.3	-22.9	66.2	57.0	36.8	34.4	33.2
Energy branch	-9.0	-12.2	-16.0	0.7	0.8	1.6	1.6	1.7
Total	**7.9**	**-0.3**	**-8.3**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

The analysis of changes induced by the emission targets indicates a certain priority of measures that policy needs to adopt. In the next chapters, concerning sectoral analysis, the presentation of measures starts from the AP-no-trade scenario under which a reduction of CO_2 emissions by 8% is based on the Burden Sharing agreement. This scenario exerts larger implications on the energy system and hence it is more relevant for concluding on priority setting about measures. The AP-full-trade scenario involves moderate changes that can be considered as just incremental changes from baseline. In terms of priority setting, the analysis for this scenario examines whether the measures identified have to be implemented (to a full extend or not) to stabilise emissions.

5.3.1 Power and Steam Generation

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. The necessary structural changes span a variety of issues. They range from low cost changes in fuel mix (e.g. in polyvalent plants) up to considerable reorientation of investment choices and the premature under-utilisation of conventional plants.

A significant effect comes from lower demand for electricity and steam due to measures adopted in the demand side (including better housekeeping, energy efficiency improvement of equipment and others). In both scenarios, demand for electricity and steam decreases. The substitution effects in favour of electricity in the demand side are always found to be lower than the direct electricity-saving effects. The power and steam system facing lowered demand, and consequently reshaped load, influences the investment schedules, the use of plants and the possible deployment of smaller-scale technologies particularly used by smaller generators. The model represents this mechanism through varying economies of scale by size of generator and type of plant.

In 2010, CO_2 emissions reduction in power and steam generation reaches 23.5% in the AP-no-trade scenario and 14% in the AP-full-trade scenario (from 1990 levels). Part of the reduction achieved (estimated at about 15% of emission reduction in the power sector in both scenarios) is the result of measures adopted in the demand side that lead to the reduction of electricity and steam demand.

In power and steam generation, a list of measures that contribute to emissions reduction includes the following:

1. At least 40% of electricity generation has to be based on the use of natural gas (mainly through GTCC plants), that is more than 5 percentage points beyond the baseline. There

is no need for additional capacity but just shifts in the utilisation of plants. In absolute terms, production from natural gas should increase by 73 TWh under the AP-no-trade scenario and 95 TWh under the AP-full-trade scenario. Higher production in the latter scenario is due to higher demand for electricity. This relate to the expectations about the availability and future prices of natural gas for large generation (see point below).

2. The role of natural gas is also important as regards both power and steam production. Policy incentives (including security of supply strategies for gas supply to Europe, development of infrastructure and monitoring of gas to gas competition within the newly liberalised gas market in Europe) should lead to preserving cheap gas supply, in particular to generators regardless their size and availability of provision. The share of gas in steam production, including the substantial part of cogeneration, can be also facilitated through policy measures acting at the level of power market regulator, aiming at protecting small generators that mostly use cogeneration. The share of gas in steam in production should increase in 2010 up to around 60% (+10 percentage points compared to the AP-full-trade scenario) from 44% in the baseline. Sensitivity analysis showed that the role of natural gas is crucial in the period to 2010. If supply of natural gas to the European Union were less cost-effective than expected under the baseline scenario, the cost of emission reduction in Europe would be significantly higher (see also discussion on uncertainties).

3. Measures in power generation should aim at decreasing the production of electricity from coal and lignite from 17.5% in the baseline scenario down to 9% in the AP-no-trade scenario. Similarly, steam production from coal and lignite should be decreased down to 5% of total (15% in baseline). The decrease can be moderated under the AP-full-trade scenario. The corresponding figures are 12% and 10% of electricity and steam production respectively. Such measures could include: removal of any explicit or hidden subsidisation of domestic coal and lignite; strict application of the revised large combustion plant directive because this, aiming at reducing local pollution, entails high costs for coal and lignite plants (therefore indirect effects in favour of reducing CO2 emissions are obtained); global non fossil fuel obligations at the level of the regulator and TSO of the liberalised power market.

4. The share of biomass and waste in electricity production is projected to double to reach 4% under the AP-no-trade scenario. Additional investments of about 4 GW in biomass-waste plants are required for this purpose. The share of biomass and waste in steam production should increase to around 20% in both scenarios from 15% in baseline. A series of measures can facilitate penetration of biomass and waste for power and steam generation. These might include: subsidisation of investment; removal of institutional barriers at local municipality level; non fossil fuel obligations at the level of regulator and TSO; integration of energy related biomass policy into the common agricultural policy.

5. Although demand for electricity decreases, production from nuclear plants has to remain rather stable. Consequently, the share of nuclear energy increases slightly from 29.5% in the baseline to 30.5% of electricity production in the AP-no-trade scenario (30% for the AP-full-trade). Support of research and development in favour of nuclear security, nuclear decommissioning technologies and new nuclear technologies must continue, especially because of the longer run issues.

6. Production of electricity from renewable energy forms approaches 15% in the AP-no-trade scenario (14% for the AP-full-trade scenario) from 12.5% under baseline conditions. The bulk of the increase calls upon wind energy by investing about 14 GW in

new wind plants, under the AP-no-trade scenario, leading to an increase of production from wind energy by 48 TWh. The corresponding figures for the AP-full-trade scenario are smaller (10 GW and 27 TWh). This development more than counterbalances the decrease of large hydro production (about 5 TWh in both scenarios), which is due to lower demand. A series of measures supporting renewables are incorporated in the baseline. Besides preserving their actual implementation, there is need for supplementary measures. The range of possible measures is large, including: subsidisation of investment; development of infrastructure (wind parks adequately connected to the grid which should be reinforced); green certificates; feed-tariff measures; non fossil fuel obligations at the level of regulator and TSO.

7. Co-generation of electricity and steam highly develops under baseline conditions. It is important to keep their share constant in the emission reduction scenarios, despite the drop of demand (about 15% of electricity and 45% of steam production). The analysis has shown that there are mechanisms acting against further development of co-generation in the emission reduction scenarios examined. Although engineering analysis on a project-by-project basis shows that co-generation is beneficial for efficiency (hence emissions), the results from system analysis show that when imposing a carbon constraint the system might prefer further expanding base-load GTCC plants, which are very efficient, rather than expanding co-generation. The latter is less efficient than GTCC in electric terms, because it has to follow middle load as it is driven by steam uses and still uses fossil fuels that emit carbon. As mentioned before, measures in the domain of supply of natural gas and measures to protect small generators in the electricity liberalised markets will help to preserve high development of cogeneration.

The combination of the above measures leads to an increase of overall thermal efficiency by 1.5 percentage points in both scenarios (from 45% in baseline to around 46.5%). The effect of the above measures on carbon intensity is more pronounced. This improves by 21% in the AP-no-trade scenario and by 12% in the AP-full-trade scenario.

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 for renewables (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.

Considerable policy issues emerge for the sector when analysing the long term. Analysis with PRIMES has shown that the strategic choices for the period beyond 2015 for power generation may have considerable implications.

5.3.2 Services and households

In the demand-side tertiary is the most responsive sector to emission reduction. The reduction of emissions in tertiary reaches 24% in the AP-no-trade and 11% in the AP-full-trade scenario compared to baseline for 2010. The response of households to the emission reduction targets is less important, ranging from 10% to 4% respectively.

This is an interesting finding since the structure of energy demand in the service sectors is, in some respects, quite similar to that of the household sector. The most important similarity is that the bulk of energy consumption takes place in buildings (like office blocks, hospitals, schools etc) and for the same reasons as in households, namely heating, cooling, cooking, lighting and the use of appliances. The technologies determining energy efficiency in these sectors are effectively the same. However, the major difference, that is mainly responsible for their different behaviour, is related to the size of equipment, especially for heating and cooling purposes. 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 the household sector. In addition, decisions to invest in energy efficiency are taken by firms in the tertiary sector and by individual people 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.

Although differing in magnitude, the measures that contribute to a reduction of CO_2 emissions are similar in both sectors.

1. The improvement of the thermal integrity of buildings in both sectors is of utmost importance. Since it is expensive to improve insulation and glazing in existing buildings, it is expected that the bulk of the effort as regards thermal integrity is likely to be achieved through higher standards for new building constructions. The dynamics are very slow regarding renewal of buildings. Strict standards for new buildings will delay in showing results at the average level. The model results for the average level of efficiency of buildings confirm this slow improvement: in average thermal integrity improves by 2.6% in services and 2% in households compared to baseline in 2010 for the AP-no-trade scenario.

2. Better housekeeping, including variation of standards of comfort (e.g. turning the thermostats down (up) a few degrees during cooler (warmer) weather) and the application of power management for lighting and electric appliances are also important measures for services and households. For the average consumer such behavioural effects are found to lead to an additional decrease of energy needs under the AP-no-trade scenario (AP-full-trade scenario), by about 3% (1.2%) in the tertiary and 1.9% (0.7%) in households.

3. The scope for efficiency gains in the domain of electric appliances is large. The model results show an impressive improvement of the average electric appliance in tertiary by more than 40% in the AP-no-trade and 35% in the AP-full-trade scenario compared to baseline in 2010. This measure includes the introduction of high efficiency standards for lighting in tertiary buildings. The improvement of electric appliances used in the households sector is less impressive, also because of the higher value that households attribute to capital costs. The efficiency improvement of electric appliances for home use is impressive under baseline conditions (25% in 2010 from 1990) and the additional improvement under emission reduction targets is rather small.

4. Efficiency in space heating equipment in tertiary also improves by about 12% in the AP-no-trade and 5% in the AP-full trade scenario compared to baseline. The corresponding figures for households are of less significance (2% and 0.5% respectively). Electric heating equipment (including heat pumps) is the key driver for the achievement of these efficiency improvements. About 36% of space heating needs in services is to be satisfied by electric heating equipment under the AP-no-trade scenario (30% for the AP-full-trade scenario) from 25% in baseline in 2010 (18% in 1995).

5. Improved equipment is adopted in other uses, as well, like for air conditioning, the use of boilers and water heating. The average efficiency improvements are rather small: 5-6% for the AP-no-trade scenario and 2-3% for the AP-full-trade scenario.

5.3.3 Industrial sectors

In industry, although energy and associated equipment are important production factors, the share of purchased energy in total cost of manufacturing is small, ranging from 1% to 12% depending on how energy intensive the sector is. Sectors producing high value added generally have low cost shares for purchased energy. In Europe, the sectors that bear large energy cost represent a small share in total value added and this share is stable or decreasing over time.

In energy intensive sectors, the bulk of energy consumed is associated to the production process. The longevity of process specific equipment used in those industries highly restrains the flexibility of industry in reducing emissions. Energy efficiency improvement in these processes is embodied in capital investment, the schedule of which largely determines the change of average efficiency. Given growth prospects in these sectors are rather limited and often under-utilisation of existing capacities is observed in Europe, new capital investment is also expected to be limited and slow. Under these circumstances, the energy intensive industry needs high cost-related incentives to re-invest in processing or prematurely change technology.

Changes in fossil fuel mix in direct energy uses do not have an important role in emission reduction. This is because natural gas is extensively used under baseline conditions and high carbon-content fossil fuels are mostly used in specific processes.

There exist, however, low cost opportunities for emission reduction, which are presented in the analysis below.

Industry reduces its emissions by 11% in the AP-no-trade and by 5% in the AP-full-trade scenario, compared to baseline for 2010. Energy intensive sectors reduce emissions more than other sectors.

The **iron and steel sector,** which accounts for more than 30% of CO_2 emissions in industry achieves a reduction of 18% and 8% under the two scenarios examined.

1. Under the emission reduction constraints, the iron and steel sector will attempt changing the composition of its production, by giving more emphasis on higher quality steels that produce more value added and use less energy per unit of value added. Such structural changes are estimated to result to a reduction of material use (including energy needs) by 3.5% in the AP-no-trade and 1.5% in the AP-full-trade scenario compared to baseline.

2. Restructuring in favour of electric arc processing is projected to accelerate in the presence of emission reduction targets. The share of electric arc processing is likely to exceed 53% (of steel production) in the AP-no-trade (50% in the AP-full-trade) scenario compared to 46.5% under baseline conditions.

3. The above structural changes also imply changes in equipment efficiency. In terms of average energy efficiency, the improvement is rather limited (around 2.5 and 1% for the two scenarios).

4. The emission reduction targets seem to be small to trigger significant technological change of the processing. The penetration of advanced techniques is rather limited. These include:

    - Direct smelting and direct reduction that allow for a decrease of the use of coke in blast furnaces and reduces the need for ore preparation (sinter making).

    - Casting and rolling operations improve in energy terms by adopting hot connection techniques and mainly near-net-shape casting that replace continuous slab casting and hot rolling.

    - Several techniques, among others scrap pre-heating, contribute in making the electric arc processes more efficient.

The **non-ferrous metals industry** accounts for a very small part of emissions in industry (3.5% in baseline for 2010). The reduction of emissions reaches 7% in the AP-no-trade and 3% in the AP-full-trade scenario with reference to baseline in 2010. Significant part of these reductions can be achieved though better housekeeping, better auditing and control systems. Under the AP-no-trade scenario, the improvement is mostly effected through the cross-cutting technologies (discussed later). The sector of non-ferrous metals is highly depending on electricity. Energy uses are principally confined in a few very specific processes and technologies. In case of modest emission reduction targets (as in the case of AP), the non-ferrous sector reacts very little, in terms of technological and structural changes. Emission reduction mainly comes from the power generation side. The improvement of energy efficiency comes from a variety of rather incremental improvements, mostly in kilns and furnaces.

The **chemical sector** also accounts for a small part of emissions in industry (5.5% in baseline for 2010). It exhibits the highest reaction among all industrial sectors under the AP-no-trade scenario. The reduction achieved compared to baseline for 2010 reaches 23% (8% in the AP-full-trade scenario). The changes effected including the following:

1. The higher penetration of heat pumps in heat processing in the chemical sector leads to an improvement of efficiency of the energy use by about 25% compared to baseline in the AP-no-trade scenario (4% in the AP-full-trade scenario). Heat pumps allow for economies in the use of heat and cooling and greatly save electricity. The share of heat pumps in the chemical industry has to increase from a small percentage in the baseline (around 3% in 2010), into 20% in the AP-no-trade scenario (5.5% in the AP-full-trade scenario).

2. A shift towards the use of process related electric equipment is also important. Mechanical treatment, using electricity, may substitute for steam-based processing in the production of chemical products. The share of electric processing has to increase to around 30% in the AP-no-trade scenario from 28.5% in baseline. Efficiency of process related electric equipment improves by up to 3.5% in the AP-no-trade scenario.

3. A key factor for the improvement of specific energy consumption in all energy-intensive processes in the sector is the introduction of pinch analytical techniques, which optimise heat recovery in thermal processes and allow for energy savings. This leads to an improvement of thermal processing equipment efficiency of 4% and 1% in average for the two scenarios.

Building materials reduce their emissions by about 6% in the AP-no-trade scenario (2.5% for the AP-full-trade) compared to baseline for 2010. The sector accounts for 25% of emissions under baseline conditions. The adjustment of the non-metallic minerals industry is rather limited, in particular regarding basic processing. This is due to fact that the sector is capital intensive and to the longevity of existing equipment.

1. There are possibilities for incremental improvement of the overall processes, including better housekeeping and control. Such measures lead to a decrease of energy needs by 2.5% in the AP-no-trade scenario (1% for the AP-full-trade) compared to baseline.

2. Shifts towards less carbon intensive fuels, mainly natural gas, are possible. The share of solids in the sector decrease from baseline levels (17% in 2010) down to 14% in the AP-no-trade scenario (15% in the AP-full-trade). Fuel substitution mainly occurs for kilns. Advanced kiln technologies are gradually adopted involving improved furnace design and waste/heat recovery.

3. In general, shifts in favour of electric processing (rather than heat) for some of the sector's products (e.g. glass making) enable overall efficiency improvement. In addition, advanced electrical-technologies for mechanical treatments, mixing, grinding and milling allow, also, for efficiency gains and saving of electricity.

Paper and pulp industries account for a very small part of emissions in industry (3.2% in baseline for 2010) and reduce their emissions by 5.5% in the AP-no-trade scenario (2% in the AP-full-trade). The main changes are effected through heat and electricity savings enabled by heat management techniques and electrical-technologies respectively. The role of the latter is important, allowing for significant savings in mechanical treatment and refining. The main measures that are likely to be undertaken are the following:

1. The introduction of impulse drying that reduces energy requirements of evaporating drying by removing more water in the pressing section leading to high heat savings (theoretically up to one third). An average gain of about 3% in paper drying for the AP-no-trade scenario (1% for the AP-full-trade) is observed (compared to baseline for 2010).

2. The introduction of advanced techniques in pulping involves better management of steam input leading to an improvement of equipment efficiency. The average improvement is of about 3% and 1% for the two scenarios.

3. The use of sensors in paper refining, which allow for better process management, avoidance of reprocessing and greater use of recycled fibre, is one example of techniques

leading to specific energy savings. The average corresponding improvement is of about 5% in the AP-no-trade scenario (2% in the AP-full-trade).

The **other industrial sectors** produce equipment goods (for transports, for households, machinery, etc.), food, beverages and tobacco, textiles and other goods (e.g. wood products, rubber, construction, etc.). These sectors generally are low energy-intensive. The energy uses in specific product processing are very limited. For example, specific processes are coating and foundries in the equipment goods industry. Use of steam is significant in food processing, while low enthalpy heat uses (e.g. for drying and separation) are part of the production process in many sectors. Most of the technologies are of crosscutting nature, including motor drives, compressors, heating and cooling, etc. Under baseline conditions, other industrial sectors account for about 30% of CO_2 emissions in industry. Within the range of the scenarios examined, the low-energy industrial sectors undergo rather little adjustment. They reduce their emissions by 6% in the AP-no-trade and by 2% in the AP-full-trade scenario. The bulk of this reduction comes from the introduction of heat pumps.

1. The share of heat pumps has to increase from around 3% for baseline in 2010 to reach 13% in the AP-no-trade scenario (5% in the AP-full-trade). This will lead to an improvement of the equipment efficiency of low enthalpy heat uses by about 10% and 2.5% for the two scenarios respectively.

2. Better housekeeping, better auditing and control systems play a less significant role and lead to a reduction of energy needs by about 1% in the AP-no-trade scenario.

Energy-using technologies that are not product or process specific are widely used in industry. They include equipment types such as motor drives, air compressors, lighting, space heating and some standardised furnaces. The discussion below attempts a summary of the findings per equipment category in order to show the scope for improving industrial standards.

Industrial heat pumps play a considerable role in the AP-no-trade scenario as discussed at the level of each industrial sector. Their penetration is significant leading to improvement of energy efficiency in low enthalpy heat uses, in drying/separation and in particular in chemical industry and in food processing.

Technologically advanced **industrial furnaces** are increasingly adopted in the AP-no-trade scenario. The average efficiency gains lead to an average improvement of efficiency of about 2.5% compared to baseline in 2010. The progress is significant both for furnaces using fossil fuels and electric furnaces.

Industrial Motor Drives and Compressors include a wide range of equipment types. The model does not classify their use by size and does not make consideration of the variety of application conditions. The overall improvement of motor drives, in terms of specific efficiency, is rather limited in both scenarios, up to 1% compared to baseline in 2010. The potential is bigger, being theoretically 20% at the margin. Compressors improve in the AP-no-trade scenario in average by 3% (1% for the AP-full-trade scenario with a potential of around 22% at the margin).

Industrial lighting is generally highly optimised in the baseline scenario. Additional improvement in the AP-no-trade scenario reaches 7% while in the AP-full trade it is at around 2.5%.

The analysis for **industrial space heating** and the energy saving gains are combined with similar changes in other low enthalpy heat uses. Technologies that are more efficient and heat pumps enable those gains. In average, the savings are of the order of 3.5% under the AP-no-trade scenario compared to baseline scenario in 2010.

The PRIMES model includes possibility of changing the degree **material recycling** as a result of relative costs and emission constraints. Material recycling is possible for glass, paper and aluminium. The baseline scenario shows large economic scope for increasing material recycling in Europe, independently of GHG emission constraints. Having exhausted under baseline conditions the low cost options in this domain reduces the cost-effectiveness of additional recycling from baseline. Sensitivity analysis has shown that higher degree of material recycling have to be adopted at relatively high emission reduction targets, beyond those considered in the AP cases.

5.3.4 Transports

The transportation sector is actually very important for energy and emissions in Europe, accounting for about 50% of CO_2 emissions in the demand side in 2010 (41% in 1990). 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. In view of the current prices of transportation fuels, in which the part of taxes can reach up to 80%, further use of market instruments to reduce energy consumption would require exceptionally high increases in taxation[19]. Thus, 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 of such a policy emphasis is the CAFE standards adopted by the US following the first oil crisis.

There is very little doubt on the substantial technical potential for improvements in the efficiency of driving. Cars that use much less than 5lt/100km are already available in the market. However, with rising standards of living there is a tendency for even larger and more comfortable cars. It is because of this that, according to the automobile industry, the target initially proposed by the EU Commission for the next decade (efficiency of 5lt/100km, or 120g of CO_2 per km), while technically feasible would only be possible through the downsizing of the car fleet and could have a significant negative impact on the global competitiveness of the EU industry.

In 1998, a negotiated agreement was reached between the European Commission and the European automobile industry under the terms of which the industry is committed to reduce the average CO_2 emission figure for all new cars to 140 g/km by 2008[20]. 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

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

[20] Much of the information on the agreement between the EU Commission and the European automobile industry is based on information available on the latter's web site as of the 18 of May of 1999.

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). The agreement assumes that the behaviour of non-EU producers will be compatible with the above targets and that EU policies and fuel quality will not hamper the implementation of the negotiated agreement. The above agreement was not included in the baseline and the examined AP scenarios.

However, in the context of other works with PRIMES, sensitivity analysis was carried out to incorporate the effects of the negotiated agreement involving the European Commission and European, Japanese and Korean car manufacturers (shortly called EU-ACEA agreement). This analysis assumed that vehicle emissions are reduced to 170g/km in 2003, 140 in 2008, 120 in 2012 and 100 by 2020. Reductions have been assumed to take place linearly in the intervening years and involve no costs neither for the consumer nor the manufacturer. The results of the implementation of this agreement are quite significant both for emissions and for the demand for oil products within the EU. Under baseline conditions, by 2010, the impact of the negotiated 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.

The AP scenarios do not include the effects of the EU-ACEA agreement. Under the AP-no-trade scenario, the transports sector accounts for 14% of emissions reduction (9.5% in the AP-full-trade). The sector reduces emissions by 7% and 2.5% compared to baseline for the two scenarios respectively.

The most noticeable changes in the transport sector concern trains and aircraft. The measures that will lead to the decrease of emissions in transports sector are the following:

- It seems that there is scope for efficiency improvement of air transports. In the AP-no-trade scenario the rate of improvement reaches 23.5%, which is additional to the significant improvement (33% from 1995) projected under baseline conditions. The corresponding figure for the AP-full-trade scenario is 6%. Except of the technical improvement of the air fleet additional priority should be given on the optimisation of the use of the air fleet.

- Significant gains can be also obtained in train transports. Under AP-no-trade scenario efficiency is improved (in addition to the baseline) by 13% as regards passenger transport and by about 16% as regards goods transports (3.5% and 9% for the AP-full-trade scenario). Better management (further use of information technology etc) and motivations for the higher use of trains in the off-peak hours (resulting in higher load factors) to the detriment of other transport modes such as private cars may, also, play an important role.

- The results omitting the negotiated agreement show modest possibilities for improvement in road transports. Other analysis made with PRIMES model has shown that severe emission reduction constraints are necessary to generate significant technology change in private cars. This also concerns fuels cells and electric cars that do not penetrate significantly in the period to 2010. The main reason for this is that both electricity and fuel cells are still expected to be reliant on gas supplies, either directly or through methanol. Hence, under carbon constraints cars that rely on these forms of energy do not gain a significant advantage over more conventional cars.

- Significant effort should be concentrated on changing the behaviour of consumers as regards mobility. Consumers undertake travel for a number of reasons. For example, part of passenger travel is almost "obligatory" for most consumers, including travel to and from work, shopping etc. Similarly there are many kinds of more or less "discretionary" travel, including leisure and social travelling. In the AP-no-trade scenario consumers are projected to decrease their mobility by only 1% or 150 km per capita per year. The corresponding figure for the AP-full-trade scenario is 0.3% (50 km per capita per year). Bigger behavioural changes regarding mobility, car size, car use (e.g. number of passengers per car and trip), etc. may have considerable implications on emission reduction. Experience has shown that policy implementation is rather difficult in these areas.

5.4 Key measures for emissions reduction

The analysis above clearly indicates that the contribution of the different sectors to emissions reduction is quite uneven. This is because the cost-effectiveness of measures differs substantially across sectors.

The bulk of the effort for reducing CO_2 emissions should be concentrated to the power and steam generation system. The measures that need to be promoted include the better dispatching of natural gas fired plants (operating to the detriment of coal fired plants) and the increased use of renewable energy forms (mainly wind energy). Six key measures are identified:

1. Supply side policies to preserve gas prices and availability (infrastructure, gas to gas competition, security of supply)

2. Non fossil fuel obligation at the level of electricity market regulator and TSO

3. Removal of all explicit or hidden subsidies to domestic coal and lignite and transparency on fuel costs (to effectively obtain the removal of subsidies)

4. Supply-side measures in favour of renewables (infrastructure, removal of barriers regarding land use, agriculture, waste management, etc.)

5. Continuation and reinforcement of subsidisation for renewables, including the establishment of green certificates

6. Dispatching priority for renewables and co-generation of heat and power.

The tertiary sector can also play an important role to emissions reduction. The following key measures are identified:

1. Introduction of stricter standards in electric appliances and space heating/cooling equipment can play a significant role in emissions reduction

2. Incentives in favour of higher use of heat pumps.

3. Continuation and reinforcement of energy conservation measures seeking better housekeeping.

4. Stricter building codes for new construction to improve buildings thermal integrity.

The same measures can contribute to emissions reduction in households. However, their role is rather limited compared to the tertiary sector.

The effort in industry should be concentrated to the energy intensive sectors:

1. Structural changes towards less energy intensive process, for example electric arc processing in iron and steel, should be promoted.

2. Incentives should be given towards the use of heat pumps in all industrial sectors.

3. Also, recycling of materials has to be supported.

4. Continuation and reinforcement of energy conservation measures seeking better housekeeping

The transports sector is quite insensitive to the introduction of emission reduction targets. This is especially the case for private cars. In that sense, measures should be undertaken as regards better management (higher load factors, further use of information technology etc) of massive transport means such as aviation and train transports. The support of policy must be mainly oriented to manufacturers of vehicles, allowing them to introduce new car designs under competitive terms. The implication of the EU-ACEA negotiated agreement on car transports is very important. Minimum excise taxation on kerosene for aviation can also contribute to emission reduction (given the significant potential for improvement in air transports and the energy intensive character of aviation compared to other transport means).

An additional action that could lead to emissions reduction so as to comply to Kyoto emission reduction targets includes a taxation reform for minimum excise taxation on fuels to reflect carbon contents in relation to an equal reduction of social security contributions of employees. Of course trading of CO_2 emission permits within Annex B countries makes the achievement of the Kyoto Protocol much easier and cheaper for EU member states[21]. However, going “alone” (i.e. without trading among Annex B) can produce positive spillover effects to other environmental areas. Finally, specific measures for non-CO_2 GHGs to maximise their contribution to total emission reduction can be important for the relaxation of the effort required to achieve the emission reduction target of the EU.

6. Economic implications

The imposition of emission reduction targets results in an increase in energy system costs. The additional costs implied by a CO_2 emission reduction target is conveyed to the energy system through the marginal abatement cost incurred by the system in avoiding the last ton of CO_2 that is necessary in order to meet the reduction target.

[21] This statement ignores the costs from purchasing permits from outside the EU. However even if included the net gains from Annex B trading are still considerable.

Regarding the application of the PRIMES energy model and for analytical reasons, the AP-no-trade and AP-full-trade scenarios have been designed so that they exclude changes in economic structure and in particular to the sectoral value added and GDP. They do allow, however, for some changes within individual industrial sectors that are due to changes in the preferred technologies, process of production and material recycling.

The marginal abatement costs for the EU associated with the emission reduction targets examined, range from €$_{97}$ 17.4/tCO_2 avoided in the AP-full-trade scenario to €$_{97}$ 62.5/tCO_2 avoided in average in the AP-no-trade scenario. However, due to the nature of the AP-no-trade scenario (achievement of the emission reduction target on the basis of the Burden Sharing agreement) large discrepancies between counties are observed. Whereas for Germany a marginal abatement cost of €$_{97}$ 27.8/tCO_2 is required for the achievement of the target, the corresponding value for Netherlands reaches €$_{97}$ 166.8/tCO_2 (see Table below).

Table 6-1: Costs and share of emission reduction by country

	Marginal Abatement Cost (€$_{97}$/tCO_2)		Welfare loss (% of GDP)		% Share in Emission Reduction	
	AP full- trade	**AP no- trade**	**AP full- trade**	**AP no- trade**	**AP full- trade**	**AP no- trade**
AU	17.4	52.8	0.02	0.10	1.8	2.0
BE	17.4	99.7	0.02	0.40	2.5	5.1
DK	17.4	55.6	0.02	0.17	2.0	2.6
FI	17.4	54.6	0.05	0.22	4.4	4.2
FR	17.4	32.0	0.01	0.03	9.0	7.7
GE	17.4	27.8	0.02	0.04	26.4	16.8
GR	17.4	63.6	0.08	0.27	5.3	4.1
IR	17.4	59.1	0.02	0.19	1.3	1.8
IT	17.4	51.8	0.02	0.09	12.5	13.3
NL	17.4	166.8	0.03	0.94	6.1	12.6
PO	17.4	58.4	0.03	0.36	1.5	3.0
SP	17.4	41.7	0.02	0.10	8.4	8.5
SV	17.4	67.4	0.02	0.14	2.5	3.2
UK	17.4	42.7	0.02	0.09	16.3	15.0
EU14	**17.4**	**62.5**	**0.02**	**0.13**	**100**	**100**

Source: PRIMES

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 economy 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 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 targets, as estimated with the energy system model PRIMES, under the two scenarios for the EU in 2010 is between 2.0 and 13.5 billion €$_{97}$ per year, depending on the degree of emission permit trading within the EU and with Annex B countries. This cost represents a range of 0.02 to 0.13% of GDP, annually. 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. Within each country the analysis with the PRIMES model assumes that a least-cost allocation of the emission reduction target to the various demand and supply sectors is possible. Any deviation from a least cost allocation, for example because of policy implementation failure, could entail higher compliance costs. Sensitivity analysis with PRIMES also showed that emission permit trading within the EU member-states involving at least the power generation sector, refineries and heavy energy intensive industries could greatly help to approximate a least cost allocation within the EU.

At a general equilibrium level, system adjustments, other than those occurring in the energy system, might induce further loss or, in some cases, gains. The GDP losses under general economic equilibrium, as estimated with the use of GEM-E3 model, are higher than those estimated under partial equilibrium. In the no-trade case, the total additional welfare costs in the EU are about 0.23% of GDP in 2010 in case of no emission permit trading. If a full trade mechanism is implemented the costs are considerable lower: 0.11% of GDP.

The above GDP losses correspond to costs incurred because of measures undertaken in the territory of the EU. They do not include the costs from purchasing emission permits from outside the EU (from Annex B countries) as in the case of AP full trade scenario. Emission permits for 245 Mt of CO_2 at a permit price of €$_{97}$ 17.4/tCO_2 need to be purchased by EU member states under the full trade scenario s as to comply with the Kyoto commitment. The corresponding transfer payment of 4.3 billion €$_{97}$ per year from the EU to abroad will have further indirect macroeconomic consequences that are not evaluated. For example, countries that will earn this amount will demand for imported commodities that will be partly supplied by the European Union.

The table below summarises the findings about GDP losses and includes the costs of purchasing permits under the partial (PRIMES) and general (GEM-E3) equilibrium approaches.

	AP-No Trade	*AP-Full Trade*		
GDP loss in €$_{97}$ billion for 2010		*Costs in the EU*	*Costs outside the EU*	*Total cost*
Partial equilibrium	13.5	2.0	4.3	6.3
General equilibrium	24.0	11.5	4.3	15.8

The Table shows that, in the context of partial equilibrium, full trading more than halves welfare losses as compared to the no trade case. The effect is less pronounced when the general equilibrium approach is retained. Welfare losses from full trading are about 35% less compared to those of the no trade case.

The energy system cost of CO_2 emission reduction differs substantially across the EU member states. Table 6.1 shows that also the marginal abatement costs substantially differ by country in the case of AP-no-trading. As explained before, this is because there are large differences among member states in the structure of power and steam generation, in the fuel mix and technology choices and in base year emissions. In addition, the introduction of country specific targets in the case of the AP-no-trade scenario leads to further differentiation of welfare losses for each country clearly illustrating the easy or the difficulty by which the country specific target is achieved. It is important to note that these estimates are based on the PRIMES model, which only models the energy system of the EU economy.

The total energy system cost for the EU increases from baseline levels as a result of the imposition of the carbon constraints by between €$_{97}$ 32 and 92 billion per year for the two scenarios, including all costs due to carbon emission constraints. This increase in energy system costs reflects the increase in the sector's investment requirements, increased tariffs etc. It is by no means a pure economic cost since most of the additional funds will be recycled within the overall economy. The distributional effects would be more significant (see section on macroeconomic implications on sectors and countries as studied with the general economic equilibrium model GEM-E3).

One of the main factors limiting the energy system costs in the scenarios examined is the relatively low cost of switching between gas and coal in the electricity and steam generation sector, which accounts for the bulk of the reduction in emissions in both scenarios. Also, once the marginal abatement cost exceeds a certain level and the adoption of more energy efficient technologies becomes marginally cost effective, their market penetration develops a strong momentum, leading to the decline in the additional capital charges involved in the use of the new technology. In other words, the more a new technology is used the greater the reduction in its costs. In all sectors, the additional costs from paying for carbon emissions are largely offset by cost savings due to the adoption of improved technologies.

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 varying by sector.

In energy-intensive industrial sectors the increase in the average cost of sectoral output (industrial product) ranges from 4% (AP-full-trade scenario) to 11% (AP-no-trade scenario) in 2010, compared to baseline. The same increase in the output cost of non-energy intensive sectors ranges from 0.1% to 1.5%. In particular, the increase in the cost of energy for industry is higher, ranging from 12% to 32% in energy intensive sectors, and from 10% to 26% in non-energy intensive ones.

The energy cost for the service sectors increases from 3.5% (AP-full-trade scenario) to 14% (AP-no-trade scenario), however implying a small increase in total cost of the sector. Spending by households on energy fuel purchases and energy-using equipment increases by roughly 5% (AP-full-trade scenario) to 12% (AP-no-trade scenario). The energy costs in the transports sector also rise, ranging from 5% (AP-full-trade scenario) to 11% (AP-no-trade scenario). However, the cost of transportation increases less, ranging from 0.9% to 2% for passengers and from 1.5% to 3.5% for freight.

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 from 9% (AP-full-trade scenario) to 23.5% (AP-no-trade scenario), compared to baseline. The investment expenditures for power and steam generation also rise to maximum of 5%. Cost of investment per KWh (electricity and steam) produced in 2010 reaches $€_{97}$ 88 million under the AP-no-trade scenario compared to $€_{97}$ 80 million of in baseline and $€_{97}$ 82 million in the AP-full-trade scenario. Electricity tariffs increase from 7.5 to 20 % compared to baseline in 2010 (it must be mentioned here that under baseline conditions and in the context of electricity markets liberalisation electricity tariffs decreased by 10-14% from 1990 levels).

The total cost incurred by the average EU household for all kinds of energy services and related equipment increases from 3% to 6%. In absolute terms, this is equivalent to 50 - 127 $€_{97}$ 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.

From a policy perspective it is challenging to establish mechanisms that would lead to a least-cost allocation of emission reduction effort between the sectors and the EU member-states. Analysis with the PRIMES model showed that if a stepwise approach is followed to gradually establish an emission permit trading system, then it would be important to respect some priorities. If starting from the EU burden sharing agreement one wants to get close to a least-cost allocation, then it is more efficient to start from involving the power generation sector into a permit trading system. The interesting result is that the permit price that it would result from this partial trading would be close enough to the permit price that would prevail in a perfect intra-EU trading system. This result allows the argument that getting the utilities in trading is fair because it does not entail a significant deviation from the optimum. Companies in other sectors not being yet involved in trading would then have interest in joining the trading club, since they would gain from dealing with permit prices that would be generally lower than taxes or levies raised specifically for them. The same logic applies when considering the involvement of the EU member-states in the trading mechanisms. If for example Germany and the Benelux create a trading club then they will face a permit price that will be close enough to the perfect market price. This is an incentive for those countries to start doing trade provided that the other countries try alone to comply with their commitments. These countries, seeing those gains obtained from partial trading they will also seek joining the trading club. Therefore a stepwise trade creation is feasible provided that the trading starts in priority with those participants that will gain more than others when trading. In sectoral terms this is the case of power generation and regarding the countries, this is the case of Germany and the Benelux countries.

The following table summarises these findings. The results are based on a series of sensitivity analysis runs with the model starting from a case that includes the effects of the negotiated agreement of the EC with the car manufacturers.

Results of PRIMES Emission permit trading Cases		Gains in terms of total compliance cost as compared to the Burden Sharing case (in %)	Marginal Abatement Cost or Permit Price in Euro'97 per ton of CO_2: for the traders	Marginal Abatement Cost or Permit Price in Euro'97 per ton of CO_2: In average
	No trade, each sector and country separately	-126%	NA	123
	No trade, each country separately (EU burden sharing agreement)	**0%**	NA	53
Sectoral Trading	Elec+steam trading in EU7	9%	51	48
Sectoral Trading	Elec+steam trading in EU8	18%	31	45
Sectoral Trading	Elec+steam trading in EU14	21%	32	44
Sectoral Trading	Elec+steam+en.intensive trading, EU7	14%	55	48
Sectoral Trading	Elec+steam+en.intensive trading, EU8	21%	32	43
Sectoral Trading	Elec+steam+en.intensive trading, EU14	24%	33	43
Country trading	Full trading, Germany and Benelux	25%	34	40
Country trading	Full trading, EU7	26%	46	38
Country trading	Full trading, EU8	30%	32	33
Country trading	Full trading, EU14	34%	32	32
Country trading	Annex B Full trading	49%	17	17

EU14: all EU countries (excluding Luxemburg)

EU7: Belgium, Denmark, Finland, France, the Netherlands, Sweden and UK

EU8: EU7 and Germany

7. Uncertainties

The larger uncertainties have to be associated to the baseline scenario. The evolution of energy demand under baseline assumptions involves considerable improvement of energy efficiency reflecting current trends of technology and accelerated capital turnover associated to high economic growth. The corresponding assumptions led to an overall improvement of energy intensity by more than 20% in the 1995-2010 period. There are factors that could cancel such an improvement, for example false perception of future energy prices and barriers to the adoption of the best available energy techniques. Such factors could lead to high energy demand growth that would further imply significantly higher emissions compliance costs than those evaluated in the previous section.

The baseline scenario includes the effects from the liberalisation of the gas and electricity markets. The scenario assumes gas prices and economic conditions that act favourably to the adoption of efficient gas-fired technologies under the new competitive framework. However, there could be market and policy failures that could lead electricity companies to decide using old coal/lignite plants and postpone investment and high dispatching of gas units. Similarly, renewable energy forms, co-generation and nuclear could be under pressure in the new competitive markets. Consequently, the liberalisation of the energy markets could, at least temporarily, have adverse effects on the environment if market power was excessive or if current policies failed to reflect long-term tendencies to the actual market. Under such circumstances, the baseline would deviate from the CO_2 target and higher than estimated costs would be necessary in order to achieve the PEEP2 targets.

There are uncertainties about the evolution of world energy prices. Higher oil and gas prices have small effects on demand, as this is rather inelastic. However, high gas prices would entail significant impacts on fuel mix and technology choice in the power generation sector. The use of solid fuels would increase, leading to higher emissions and hence higher compliance costs. The effects from the power sector are found considerably higher than the positive effects (in favour of environment) from energy demand

The outlook for nuclear power is one of the key uncertainties as regards the future evolution of the EU energy system. However, analysis has shown that nuclear power can play a very significant role in reducing emissions beyond 2010. Regarding nuclear energy few changes can be envisaged for a horizon as short as 2010.

The role of transportation is critical for the future increase in oil import dependency and significant for the future growth in emissions. Assuming the recent negotiated agreement between the EU and the auto manufacturers association, it was shown that 2010 oil demand is reduced by 28 Mtoe (or more than half a million barrels per day) in the EU. This reduction is equivalent to more than 4% of EU oil demand, while CO_2 emissions in the EU would decline by 2.5% when compared to the baseline in 2010. This result indicates that the implementation of the negotiated agreement would lead to a decrease of the effort required for the achievement of the emission reduction targets. However, there is still large uncertainty as regards the required evolution of transport technologies in the horizon to 2010 so as to satisfy the undertakings of the negotiated agreement.

8. Conclusions

Under baseline assumptions for the period to 2010, it is unlikely that the EU will meet its Kyoto undertakings, at least through energy related CO_2 emissions. Instead of the 8% reduction in emissions by 2010 an 8% increase is projected for 2010 when compared to the level of CO_2 emissions in 1990.

In the context of the study the impacts of two scenarios on EU energy and emissions were analysed. The impacts that were discussed under the “AP-full-trade” scenario were based on what would be cost effective irrespectively of any national or industrial political considerations and in the presence of trading of emissions across Annex B countries while the “AP-no-trade” examined the implementation of the Burden Sharing Agreement.

In both scenarios the electricity and steam generation sector has a predominant role in meeting future reductions in emissions. Within this sector the change in fuel mix between gas and coal is the most important effect although the contribution from renewables and nuclear power is also significant. The tertiary and, to a lesser extend, household sectors seem to have possibilities for emission reduction both through adopting more efficient electric appliances and through better housekeeping and improving buildings. In industry the degree of flexibility available for emissions reduction is rather limited. Restructuring of industrial processes (e.g. more electric arc processing, more recycling of materials, etc.) and introduction of heat-pumps are the main means through which emissions reduction can be achieved. The most noticeable changes in the transport sector concern trains and aircraft. The effects in the road sector mainly concern behavioural changes. However, if new car designs would enter into the market under competitive terms, large benefits would be obtained for emissions and compliance costs. To this respect further exploring and complementing the recent ACES-EC agreement is of great importance.

The total welfare loss of reaching the emission targets under the two scenarios for the EU in 2010 is between 0.02 and 0.13 of one percentage point of GDP. The energy system cost of CO_2 emission reduction differs substantially across the EU member states. The cost effectiveness gains for the EU as a whole from equalising the marginal abatement cost across all member states are substantial. The gains in terms of average EU marginal cost are of the order of 40%. The introduction of country specific targets in the case of the AP-no-trade scenario leads to further differentiation of welfare losses for each country clearly illustrating the easy or the difficulty by which the country specific target is achieved. It is important to note that these estimates are based on the PRIMES model, which only models the energy system of the EU economy. Thus, the net additional welfare gains or losses for the rest of the economy have not been evaluated (see section on macroeconomic implications studied with GEM-E3).

Although uncertainties subsist regarding the baseline scenario and the costs of reducing emissions of non-CO2 GHG, the currently available studies show that priority must be given to implmenting several low cost options for these gasses. This will alleviate the overall compliance costs to Kyoto.

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APPENDIX: Change of CO_2 emissions by country and sector in 2010

The following tables summarise, for each member state and the EU as a whole, the projection of emissions in the baseline scenario as well as the contribution of the different sectors to the achievement of the CO_2 emissions reduction target under the AP-full-trade and AP-no-trade scenario.

Table 1: European Union

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-10.2	-14.5	-20.0	7.1	8.3	11.5	11.9	12.1
Tertiary	14.9	2.7	-12.5	9.2	10.5	6.6	6.4	5.9
Households	-0.8	-4.9	-11.1	7.3	9.3	13.5	14.0	14.2
Transports	35.3	32.1	25.7	9.4	14.2	30.0	31.7	32.8
Electricity-steam production	0.6	-13.3	-22.9	66.2	57.0	36.8	34.4	33.2
Energy branch	-9.0	-12.2	-16.0	0.7	0.8	1.6	1.6	1.7
Total	**7.9**	**-0.3**	**-8.3**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 2: Austria

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-3.7	-9.5	-17.9	12.4	13.6	16.1	16.4	16.6
Tertiary	-54.6	-70.3	-83.2	0.2	0.2	0.1	0.0	0.0
Households	-1.4	-7.6	-18.3	16.6	20.3	20.7	21.0	20.8
Transports	27.4	23.1	14.4	14.3	19.6	33.6	35.2	36.5
Electricity-steam production	0.2	-15.2	-27.9	56.1	46.0	28.6	26.2	24.9
Energy branch	-46.9	-48.1	-50.1	0.3	0.4	1.1	1.1	1.2
Total	**5.7**	**-2.6**	**-12.7**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 3: Belgium

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-3.7	-9.5	-17.9	12.4	13.6	16.1	16.4	16.6
Tertiary	-54.6	-70.3	-83.2	0.2	0.2	0.1	0.0	0.0
Households	-1.4	-7.6	-18.3	16.6	20.3	20.7	21.0	20.8
Transports	27.4	23.1	14.4	14.3	19.6	33.6	35.2	36.5
Electricity-steam production	0.2	-15.2	-27.9	56.1	46.0	28.6	26.2	24.9
Energy branch	-46.9	-48.1	-50.1	0.3	0.4	1.1	1.1	1.2
Total	**5.7**	**-2.6**	**-12.7**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 4: Denmark

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	0.0	-2.2	-5.5	1.5	1.5	6.5	7.0	8.1
Tertiary	-45.0	-51.8	-60.8	4.3	3.9	3.3	3.2	3.1
Households	9.9	9.2	2.7	0.7	2.8	10.4	11.4	12.8
Transports	11.1	8.3	0.9	7.4	10.3	27.0	29.0	32.3
Electricity-steam production	6.0	-10.5	-34.3	86.0	81.5	51.6	48.1	42.1
Energy branch	27.4	26.8	28.0	0.1	0.0	1.1	1.3	1.5
Total	**4.3**	**-5.4**	**-20.8**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 5: Finland

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	23.7	17.9	8.1	4.8	6.9	15.8	17.8	19.4
Tertiary	-29.7	-39.3	-53.4	1.8	2.4	2.0	2.1	1.9
Households	-2.2	-8.3	-18.9	3.5	5.1	8.7	9.6	10.1
Transports	17.0	14.1	8.4	3.3	5.1	20.3	23.4	26.4
Electricity-steam production	82.4	36.5	2.7	86.6	80.5	53.2	47.1	42.1
Energy branch	-	-	-	0.0	0.0	0.0	0.0	0.0
Total	**40.8**	**19.0**	**0.1**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 6: France

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-7.1	-12.5	-15.0	13.6	11.9	13.7	13.7	13.9
Tertiary	37.3	16.5	6.2	21.4	18.8	8.2	7.4	7.0
Households	1.1	-3.9	-8.1	15.6	17.0	18.3	18.4	18.4
Transports	28.3	25.2	22.3	16.6	19.0	39.8	41.3	42.1
Electricity-steam production	1.2	-8.5	-15.6	30.6	31.3	18.5	17.8	17.1
Energy branch	0.2	-8.8	-12.2	2.3	1.9	1.5	1.4	1.5
Total	**11.6**	**5.1**	**0.6**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 7: Germany

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-35.7	-38.5	-39.7	5.2	6.0	9.6	10.0	10.1
Tertiary	-36.9	-43.5	-48.5	8.0	11.2	6.1	6.0	5.6
Households	-0.6	-5.1	-7.6	8.7	10.7	15.4	15.9	15.9
Transports	27.4	24.2	22.7	8.1	9.6	25.7	27.2	27.5
Electricity-steam production	-17.8	-28.6	-29.9	69.5	62.1	42.2	39.8	39.9
Energy branch	-42.0	-44.1	-44.9	0.5	0.5	1.0	1.1	1.1
Total	**-11.8**	**-18.8**	**-20.6**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 8: Greece

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	58.9	56.4	51.7	1.4	2.7	11.3	12.7	13.3
Tertiary	55.9	49.0	31.0	1.5	3.5	4.1	4.4	4.2
Households	32.7	26.0	11.2	2.6	5.3	6.2	6.7	6.4
Transports	71.5	66.0	53.5	7.0	15.0	27.0	29.8	29.7
Electricity-steam production	48.9	17.6	8.5	87.4	73.2	50.8	45.7	45.6
Energy branch	12.4	10.3	3.8	0.1	0.3	0.6	0.7	0.7
Total	**54.3**	**35.4**	**25.3**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 9: Ireland

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-1.9	-3.3	-6.7	1.7	2.1	9.2	9.8	11.1
Tertiary	173.4	157.6	130.0	10.0	10.4	13.6	13.9	14.4
Households	-21.6	-26.4	-35.3	9.4	10.0	12.0	12.2	12.5
Transports	77.6	73.6	64.0	7.1	8.9	24.1	25.5	28.1
Electricity-steam production	53.6	32.8	0.4	71.8	68.6	41.1	38.5	33.9
Energy branch	-77.2	-78.4	-80.6	0.0	0.0	0.0	0.0	0.1
Total	**42.6**	**31.5**	**13.0**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 10: Italy

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-19.1	-22.7	-26.2	6.7	6.3	11.1	11.4	12.0
Tertiary	67.7	48.5	22.4	5.5	6.2	3.5	3.4	3.0
Households	-4.1	-5.8	-9.4	3.7	5.5	15.4	16.3	17.2
Transports	36.6	34.5	29.5	6.4	10.4	30.9	32.8	34.6
Electricity-steam production	11.2	-5.4	-20.7	76.9	70.7	38.1	35.0	32.1
Energy branch	-35.2	-38.8	-43.8	0.8	0.9	1.0	1.0	1.1
Total	**10.8**	**2.6**	**-6.3**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 11: The Netherlands

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	25.7	19.4	-12.7	7.0	10.5	10.4	10.7	10.4
Tertiary	40.0	31.9	-3.6	9.9	13.2	12.9	13.1	12.7
Households	20.6	16.0	-15.1	5.7	10.9	11.2	11.6	11.3
Transports	73.1	67.0	28.5	11.7	21.3	25.1	26.1	26.7
Electricity-steam production	25.4	9.5	-17.4	65.3	43.3	38.5	36.3	36.4
Energy branch	2.2	0.5	-11.3	0.5	0.9	2.0	2.2	2.5
Total	**35.4**	**25.3**	**-5.7**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 12: Portugal

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	61.3	57.0	52.0	6.3	3.4	13.7	14.2	16.8
Tertiary	65.0	56.8	41.0	4.0	3.0	4.7	4.8	5.3
Households	70.8	61.0	42.1	4.3	3.2	4.3	4.3	4.7
Transports	78.8	75.5	65.8	9.7	9.7	30.5	31.8	36.8
Electricity-steam production	55.4	40.5	-8.1	74.8	80.2	45.0	43.2	34.6
Energy branch	220.0	211.1	197.4	0.8	0.5	1.6	1.7	2.0
Total	**65.4**	**55.8**	**27.4**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 13: Spain

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	10.1	6.3	2.6	5.8	5.7	13.0	13.6	14.3
Tertiary	91.3	71.4	48.3	7.6	8.2	5.6	5.5	5.2
Households	8.9	3.8	-2.3	3.1	3.4	5.1	5.3	5.4
Transports	54.7	51.4	46.5	10.0	12.6	36.9	39.2	41.4
Electricity-steam production	32.2	12.6	-5.3	72.8	69.4	37.7	34.8	31.9
Energy branch	4.0	0.3	-3.2	0.7	0.7	1.6	1.7	1.8
Total	**36.3**	**25.8**	**15.2**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 14: Sweden

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	37.6	29.4	15.8	11.8	12.5	18.0	18.7	19.7
Tertiary	-35.9	-47.1	-62.7	9.9	9.4	5.2	4.7	3.9
Households	-9.2	-15.1	-27.7	4.5	5.6	6.3	6.5	6.5
Transports	23.5	21.2	13.4	7.5	13.1	36.8	39.7	43.8
Electricity-steam production	147.4	101.6	44.9	65.4	58.3	32.2	28.9	24.5
Energy branch	12.4	6.2	-7.1	0.9	1.1	1.4	1.5	1.5
Total	**38.4**	**25.8**	**6.7**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES

Table 15: United Kingdom

	% Change 2010-1990			% Share in Emission Reduction		% Share in 2010 Emissions		
	Baseline	AP full- trade	AP no- trade	AP full- trade	AP no- trade	Baseline	AP full- trade	AP no- trade
Industry	-7.0	-11.5	-16.9	6.2	7.6	9.3	9.6	9.6
Tertiary	82.6	59.4	32.4	13.2	15.9	7.5	7.1	6.3
Households	-8.5	-12.4	-17.7	8.2	10.8	14.1	14.5	14.6
Transports	27.5	24.0	17.2	11.0	18.2	29.5	30.9	31.2
Electricity-steam production	-16.9	-26.9	-30.8	60.6	46.7	36.4	34.5	34.8
Energy branch	21.9	20.0	17.6	0.7	0.9	3.2	3.3	3.5
Total	**0.9**	**-6.4**	**-12.2**	**100.0**	**100.0**	**100**	**100**	**100**

Source: PRIMES