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Technical Report on Climate Change in Europe: an integrated economic and environmental asssessment

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This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission.

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Abstract

The economic assessment of priorities for a European environmental policy plan focuses on twelve identified Prominent European Environmental Problems such as climate change, chemical risks and biodiversity. The study, commissioned by the European Commission (DG Environment) to a European consortium led by RIVM, provides a basis for priority setting for European environmental policy planning in support of the sixth Environmental Action Programme as follow-up of the current fifth Environmental Action Plan called 'Towards Sustainability'. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion, social incidence and sustainability. The study incorporates information on targets, scenario results, and policy options and measures including their costs and benefits.

Main findings of the study are the following. Current trends show that if all existing policies are fully implemented and enforced, the European Union will be successful in reducing pressures on the environment. However, damage to human health and ecosystems can be substantially reduced with accelerated policies. The implementation costs of these additional policies will not exceed the environmental benefits and the impact on the economy is manageable. This requires future policies to focus on least-cost solutions and follow an integrated approach. Nevertheless, these policies will not be adequate for achieving all policy objectives. Remaining major problems are the excess load of nitrogen in the ecosystem, exceedance of air quality guidelines (especially particulate matter), noise nuisance and biodiversity loss.

This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment*. The areas discussed in the main report are fully documented in the various *Technical reports*. A background report is presented for each environmental issue giving an outline of the problem and its relationship to economic sectors and other issues; the benefits and the cost-benefit analysis; and the policy responses. Additional reports outline the benefits methodology, the EU enlargement issue and the macro-economic consequences of the scenarios.

Technical Report on Climate Change

This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission. This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment*.
Reports in this series have been subject to limited peer review.

The report consists of three parts:

Section 1:
Environmental assessment

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Section 2:
Benefit assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

Section 3:
Policy assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

References
All references made in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology. The references made in the section on environmental assessment follows at the end of section 1.

Contents

1. Environmental assessment

1.1 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.

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

[1] All quantities of GHGs in this chapter refer to million 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, The Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, United States of America.

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 1.1.1 summarises the emission reduction targets for each EU member state according to the June 1998 Post-Kyoto Burden Sharing agreement.

Table 1.1. 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
Luxembourg	-28.0
The 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 co-ordinated 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.

[3] One ton of CO_2 emitted contains 12/44 tons of carbon. Therefore, if the marginal abatement cost is € 1.00 per ton of CO_2 then the corresponding value per ton of carbon is equal to € 44/12 = € 3.67.
[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'*.

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

1.2 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.

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.

1.2.1 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]

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[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 € 1.00 per ton of CO_2 then the corresponding value per ton of carbon is equal to € 44/12 = € 3.67.

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 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.

1.2.2 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.

1.3 Scenario Analysis[7] for CO_2

1.3.1 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 1.3.1 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 1.3.1: 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 1.3.2 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 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.

[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.

Table 1.3.2 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 186 g/km. An intermediate target was set for 2003 up to 170 g/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 120 g/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.

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 1.5).

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.

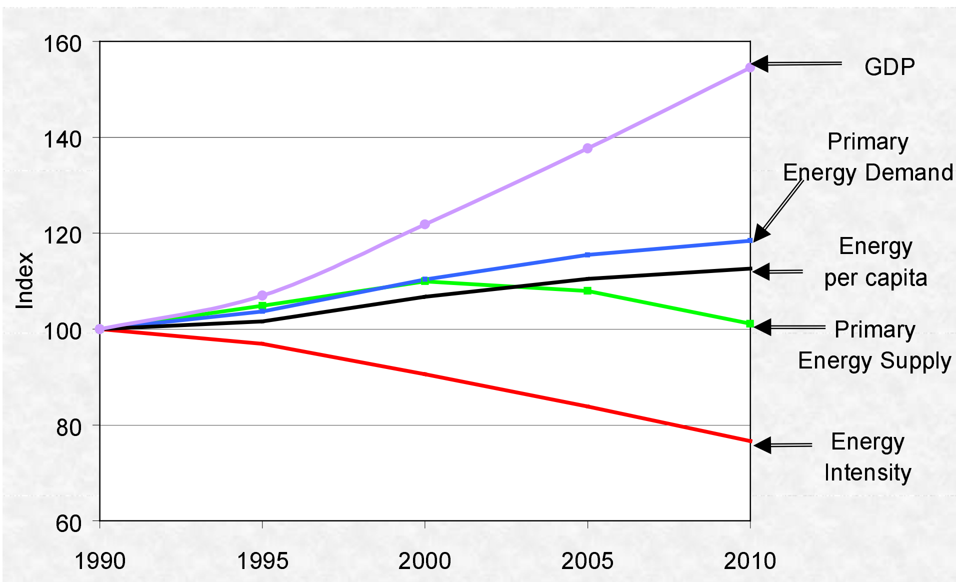
[8] For example full abolishment of the 'Kohlepfennig' policy in Germany.

[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.

[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.

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 1.3.1 shows the relative change of some key indicators of the energy system compared to their 1990 level arbitrarily set at 100.



Source: PRIMES

Figure 1.3.1 EU primary energy indicators, 1990-2010

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 1.3.3). 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 1.3.3 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 1.3.4 there are relatively modest changes in fuel shares over the next years

Table 1.3.4 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 1.3.5 demonstrates that total power capacity requirements for the EU increase by some 146 GW in the 1995-2010 period.[11]

Table 1.3.5 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 1.3.5). 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 1.3.6).

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

Table 1.3.6 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 CO_2 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.

1.3.2 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 equalised 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 per 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 abatement 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 per 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 Section 1.4).

1.3.3 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 1.3.7 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 per tCO_2avoided, Germany achieves its target with a cost of €$_{97}$ 27.8 per tCO_2 while the corresponding figure for The Netherlands reaches € 166.8 per 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.

Table 1.3.7 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.

[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 CO_2 emitted compared to the Agreement.

1.3.3.1 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 1.3.8 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 1.3.8. 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 1.3.8 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.

1.3.3.2 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 1.3.9 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 1.3.9 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 1.3.9 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.

1.3.3.3 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 1.3.10, 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 1.3.10 Power and steam generation, AP-no-trade scenario

					% change from 1990		Shares, %		
	1990	2010		% diff. in 2010	2010		1990	2010	
		Baseline	AP no-trade		Baseline	AP no-trade		Baseline	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 1.3.10, 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 1.3.10, 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.

1.3.4 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 co-ordinated model results for trading within Annex B countries, the permit price has been set at €$_{97}$ 17.4 per 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 CO_2 (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 1.3.11 summarises the reduction achieved by each member state.

Table 1.3.11 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

1.3.4.1 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.

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

Table 1.3.12 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 1.3.12, solid fuels bear the highest drop while gas and renewable energy forms increase when compared to their consumption level under baseline assumptions.

1.3.4.2 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 1.3.13 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 1.3.13, 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.

1.3.4.3 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 1.3.14.

Table 1.3.14 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.

1.4 Scenario Analysis for non-CO_2

1.4.1 The Baseline scenario

1.4.1.1 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 according to the analysis in the Technical Report on 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 distribution among the countries is close to the methane emissions as reported by the IPCC. In Table 1.4.1, methane emission for 1990 are presented by emission category and for each member state.

In Table 1.4.2, 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 the Technical Report on Waste Management.

Table 1.4.1 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**
The 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 1.4.2 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**
The 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 1.4.1 and 1.4.2, 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.

1.4.1.2 Nitrous Oxide

In line with EEA (1999), baseline emissions are taken from ECOFYS (1998), in which seven emission sources are distinguished (see Table 1.4.3). Due to rounding, total EU-15 emissions in Table 1.4.3 are slightly higher than the sum of the emission-totals for each category.

Table 1.4.3Emissions 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 1.4.4, only total nitrous oxide emissions for 1990 and 2010 are presented for each member state.

Table 1.4.4 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%
The 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 1.4.4, 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.

1.4.1.3 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 1.4.5). 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 1.4.5 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)

1.4.2 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 1.4.6. This Table confirms the overall picture as sketched above.

Table 1.4.6 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
The 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 Technical Report.

1.4.3 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.

1.4.3.1 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 1.4.7).

Table 1.4.7 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 (€$_{97}$ per 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 1.4.7 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, the Technical Report on Waste Management assumed major reductions in landfiling of organic and paper waste to 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 1.4.7 at the member state level results in emission changes (compared to 1990) as shown in Table 1.4.8.

Table 1.4.8 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€$_{97}$ per 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
The 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 1.4.8, 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 1.4.9 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 1.4.9 Annual methane emissions (ktonne CH4 per year) for the BL-1990, BL-2010 and AP-NT 2010 scenario.

Scenario	EF	AM	LF	CM	O&G	Other	**Total**
BL-1990	6878	2200	7144	2946	1561	2621	**23350**
BL-2010	6303	2096	8562	1071	1726	2578	**22336**
AP-NT- 2010	6237	2096	8170	849	1553	2578	**21483**
AP-NT comp. to 1990	-9.3%	-4.7%	14.4%	-71.2%	-0.5%	-1.6%	**-8.0%**

Based on Table 1.4.9, 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).

1.4.3.2 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 1.4.10).

Table 1.4.10 Nitrous oxide reduction measures in the AP-NT scenario and their reduction potential at the EU15 level, compared to BL-2010.

Source	Measure	Reduction (Mt CO_2 eq per year)	Costs (€$_{97}$ $_{per}$ 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 1.4.11 is much higher (65 Mtonnes). However, to meet the target of –8% there is no need to fully apply this measure.

Table 1.4.11 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€$_{97}$ per 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
The 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 1.4.11, 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;

1.4.3.3 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 1.4.12).

From Table 1.4.12 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 1.4.12 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 (€$_{97}$ per 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 products.	7.6	10
		TOTAL EU-15	**28**	**4.0**

Source: ECOFYS (1999)

Emission reductions at the member state level are not available, but in *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface* it is described how reduction costs are distributed among the economic sectors and the individual member states. In Table 1.4.13, the result of this exercise is summarised.

Table1.4.13 Country level HFC, PFC and SF_6 abatement costs in APNT in M€$_{97}$ per 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**
The 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 1.4.13, the following can be stated about the HFC, PFC and SF_6 abatement costs in the APNT scenario:

- Total annual abatement costs are €$_{97}$ 117 million per year. Because emissions are reduced by 28 Mtonne CO_2-equivalent per year, this indicates a cost-effectivity of €$_{97}$ 4.2 per tonne CO_2 equivalent;
- 71% of the abatement costs are related to HFC-reduction measures.

1.4.4 Interactions with other Environmental Problems

1.4.4.1 Methane

First of all, major interactions exist with Waste Management 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 Technical Report 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 the context of Acidification and Eutrophication. For 1990, the numbers (in million heads) are as follows:

	Climate Change	**Acidification and Eutrophication**
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 the context of Acidification and Eutrophication.

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 (minus) €$_{97}$ 3 per tCO_2 eq.) and are considered as a whole in this 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 scenarios analysed 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 1.4.14). 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.

1.4.4.2 Nitrous oxide

First of all, the scenario with respect to fertilisers in the ECOFYS-study (1998) and this 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 spillover effect to other environmental problems (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 Water Quality and Bio-diversity. Additional research would be needed to quantify these effects correctly.
The measure with respect to Waste water (W) is related to 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 1.4.10 is consistent with the sewage treatment scenario in the context of Water Quality.
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 fertiliser 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 spillover effects are expected because this sector is not considered explicitly in the context of the other environmental problems.

1.4.5 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 €$_{97}$ 17.4 per tCO_2 (=€$_{97}$ 63.7 per tC). This value coincides with the permit price (or carbon value) in the full trade scenario for CO_2 (see section 1.3). In Table 1.4.14, 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 1.4.14 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 €$_{97}$ 17.4 per tCO_2 equivalent.

Source	Measure	Reduction CH_4	Reduction N_2O	Costs (€$_{97}$ per 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**	**1.1**

It should be emphasised the landfill related measure in the Table above, is consistent with the AP scenario in the context of waste management. And again, 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 1.4.14, 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 €$_{97}$ 17.4 per 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.

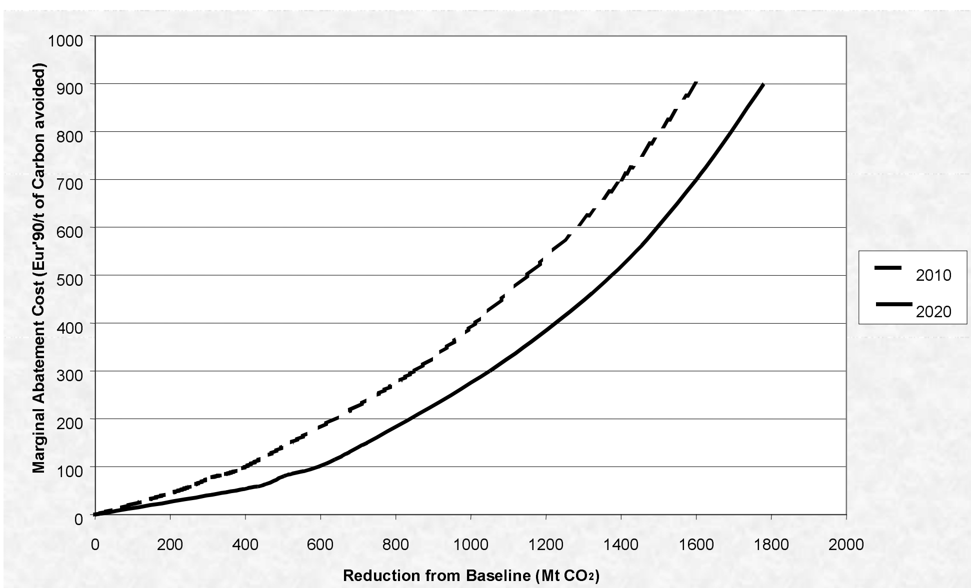
1.5 Implications for Policy

1.5.1 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 1.5.1).



Source: PRIMES

Figure 1.5.1: Marginal abatement cost and CO_2 emissions avoided compared to baseline 2010, 2020

[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.

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.

1.5.2 Overview of Country Analysis

Table 1.5.1 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.

Table 1.5.1 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 1.5.2). 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.

[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 1.5.2 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 1.5.3 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. The 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 1.5.3 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 1.5.4 and 1.5.5 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 1.5.4 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 The Netherlands is only two times the reduction of demand.

Table1.5.5 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

1.5.3 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 1.5.6 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.

Table 1.5.6 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

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

this scenario examines whether the measures identified have to be implemented (to a full extend or not) to stabilise emissions.

1.5.3.1 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.

1.5.3.2 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.

1.5.3.3 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.

1.5.3.4 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

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

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 5 lt/100 km 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 5 lt per 100 km, or 120 g 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 186 g/km. An intermediate target was set for 2003 up to 170 g/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 120 g/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 170 g/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

[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.

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.

1.5.3.5 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 Sates[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.

1.5.3.6 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.

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 per tCO_2 avoided in the AP-full-trade scenario to $€_{97}$ 62.5 per 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 per tCO_2 is required for the achievement of the target, the corresponding value for The Netherlands reaches $€_{97}$ 166.8 per tCO_2 (see Table below).

[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.

Table 1.5.7 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 per 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 €$_{97}$ 4.3 billion 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.

Table 1.5.8 GDP losses in 2010

GDP loss in €$_{97}$ billion for 2010	AP-No Trade	AP-Full Trade		
		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 1.5.8 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 €$_{97}$ 50 to €$_{97}$ 127 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.

Table 1.5.9 Results of sensitivity analysis of emission trading systems with the Primes model

Results of PRIMES		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	
Emission permit trading Cases			for the traders	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
	Elec+steam trading in EU8	18%	31	45
	Elec+steam trading in EU14	21%	32	44
	Elec+steam+en.intensive trading, EU7	14%	55	48
	Elec+steam+en.intensive trading, EU8	21%	32	43
	Elec+steam+en.intensive trading, EU14	24%	33	43
Country trading	Full trading, Germany and Benelux	25%	34	40
	Full trading, EU7	26%	46	38
	Full trading, EU8	30%	32	33
	Full trading, EU14	34%	32	32
	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

1.5.4 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 targets for climate change.

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.

1.5.5 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 implementing 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 A.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 A.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 A.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 A.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 A.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 A.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 A.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

TableA.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 A.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 A.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 A.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 A.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 A.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 A.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 A.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

2. Benefit assessment

2.1 Public opinion

Eurobarometer (1995) cites 'global pollution' as the third most important environmental problem with 40% of respondents citing it as a serious issue. This compares to a second place ranking in 1992.

2.2 Expert opinion

GEP et al. (1997) rank the climate change problem second when overall world expert opinion is accounted for (23.7% ranking it as serious). European opinion is actually stronger than the world average on climate change with scores of 34% (N Europe, first rank) and 28% (S Europe, second rank).

2.3 Benefit estimation

Table 2.1.1 reports the primary benefit estimates of the NT and FT AP scenarios. The methodology is described below.

Table 2.1.1 Summary AP scenario benefit estimates in 2010 only: € billion

	mid	low - high
NT: primary benefit only	3.7	1.2 - 8.5
FT: primary benefit only	3.7	1.2 - 8.5
NT: primary and secondary benefits	20.5	-
FT: primary and secondary benefits	13.4	-

Suitable indicators and valuation estimates for future research in this area are as follows:

- Change in the rate of warming per decade due to EU compliance with EU Protocol;
- Population at different risk levels (e.g. sea level rise).

Methodology: climate change damage models

This section focuses on the climate change damage models for the main greenhouse gases, CO_2, CH_4 and N_2O. Studies of the monetised value of damage done from global warming are now quite extensive. Pearce et al. (1996) review a number of studies and these are summarised in Table 2.1.2. As a consequence of the scientific focus, the studies tend to be based on the $2xCO_2$ scenario. The most studied aspects are the impacts on agriculture and the costs of sea level rise, with some studies on forestry. Several studies provide a first order assessment of the total global warming damage using a simple enumerative approach, i.e. the total damage is the sum of individual damage categories. Such a partial equilibrium approach means the estimates do not include the feedback effects (e.g. a change in agricultural yields will induce changes on the food, tobacco or textile industry). All of the economic assessments undertaken to date are incomplete as they exclude some impacts which are potentially important, including low-risk, high-consequence events which are problematic to quantify and value. Despite such short-comings, professional judgement suggests that global warming impacts are recommended for monetary evaluation.

Table 2.1.2 gives estimates of the marginal damage costs from global warming (carbon only), otherwise known as the marginal benefits from optimal control of global warming. Note that all values relate to US $ (1990).

Table 2.1.2 *Marginal damage costs from global warming: Carbon only ($1990)*

Study/ estimate	*1991-2000*	*2001-2010*	*2011-2020*	*2021-2030*
Nordhaus 1991	<----------------7.3------------------->			
Nordhaus 1994 p=0.03, best guess p=0.03, expected value	5.3 12.0	6.8 18.0	8.6 26.5	10.0 -
Fankhauser 1995 with p=0,0.005,0.03 with p=0 with p=0.03	 **20.3** 48.8 5.5	 **22.8** - -	 **25.3** - -	 **27.8** 62.9 8.3
Cline 1993 s=0	5.8- 124	7.6- 154	9.8- 186	11.8-221
Peck and Teisberg 1992, p=0.03	10 - 12	12 - 14	14 - 18	18 - 22
Maddison 1994	5.9 - 6.1	8.1 - 8.4	11.1 - 11.5	14.7 - 15.2
Eyre et al, 1997* s = 0 s = 1 s = 3 s = 5 s = 10	 142 73 23 9 2	 149 72 20 7 1		

**Note*: Eyre et al. estimates are for 1995-2004 and 2005-2014 and the estimates here exclude equity weighting.

Table 2.1.2 shows the considerable sensitivity of estimates to discount rates. The discount rates given in Table 2.1.2 for Fankhauser's estimates relate to the pure time preference rate component, p, only. According to Fankhauser (1995) his social cost estimates based on the distribution of values for p are equivalent to a 'best guess' value of 0.5% for p. To this must be added a value for the elasticity of the marginal utility of income multiplied by the expected growth rate. Fankhauser and Eyre et al. take the elasticity to be about unity, so that the only variable is the expected long-term economic growth rate of income per capita. Rabl (1996) suggests this is 1.6-1.8% pa, so that the discount rate would be 2.2 to 2.3%. Accordingly, we select the values in Eyre etc of 0-3% and ignore others that they report (up to s=10%). For comparison with Fankhauser we use s=3%. No value for s=2% is recorded in Eyre et al but interpolation suggests a value of $38 tC at 1990 values or $47 in 1997 prices.

The relevant damage estimates are *marginal damage*, i.e. the damage done by increasing greenhouse gas emissions now by a small amount. Computing marginal damage is not, however, straightforward (for an outline interpretation, see guide to economic models of climate change, based on Fankhauser (1995), given at the end of the benefits section). The relevant concept is the present value of damage done from an increase in emissions, allowing for the fact that greenhouse gases are cumulative pollutants, i.e. a unit increase in emissions now resides in the atmosphere for a long period of time. Thus,

$$PV(D) = \Sigma \partial D_t / \partial E.(1+s)^{-t}, \quad t = 1...T$$

Where PV is present value, D is damage, E is emissions, s is the discount rate, t is time, and T is time horizon. The complexities involve:

- relating emissions to concentrations;
- relating concentrations to radiative forcing and warming;
- relating warming to damage (since the ratio of damages per tonne of gas is not the same as global warming potentials - see the guide to climate change models at the end of this chapter);
- selecting the discount rate.

Two forms of estimate are produced in the literature: (i) estimates of actual damage arising at the point in time when $2xCO_2$ occurs and arising from a small increase in emissions now, and (ii) a 'shadow price' defined as the level of tax required to keep emissions on an optimal trajectory as estimated by the modeller. Because the estimates relate to damage or benefit at the time when $2xCO_2$ occurs, they are then discounted back to the present (see formula above) so that the choice of discount rate matters. Indeed, it is the discount rate that largely accounts for the difference in estimates.

Empirical estimates for global warming

Table 2.1.2 gives a summary of existing empirical estimates for global warming damage. The effect of different discount rates is shown by the values of 'p', the utility discount rate. This rate discounts future utility and it is usual to add this rate to the rate for discounting future income (consumption). Controversy surrounds the value of 'p' since some authors regard utility discounting as illicit, i.e. they set p=0.

While the studies vary, Fankhauser's model has considerable attractions because of its use of the discount rate as a random variable. This is shown here in the row with p=0, 0.005, 0.03, i.e. with a probability distribution assumed for p taking values of 0%, 0.5% and 3%. Recent work by Mendelsohn and Neumann (1997) suggests *net benefits* for impacts on the market sector in the USA, and Mendelsohn (1996) has also suggested that this conclusion may hold true for the world as a whole. This is not the position taken here. Also ignored is the effect of equity weighting on the estimates. For this debate see Fankhauser et al. (1997).

Finally, we require values for the other greenhouse gases. The usual procedure is to use global warming potential (GWP) as a mechanism for expressing all greenhouse gases as carbon-equivalents. However, as Fankhauser (1995) and others have pointed out, GWPs are *not* the appropriate multiplier if the focus is on damage. For GWPs to be the correct adjustment, damage would have to be linearly related to radiative forcing. But the two are not linearly related since damage depends on other factors as well, such as the previous level of radiative forcing and the level of warming that has already taken place. Fankhauser (1995) estimates the marginal damages for the main greenhouse gases as shown in Table 2.1.3. Table 2.1.3 presents mid marginal damage values, with range from 5^{th} to 95^{th} percentile given in brackets. All values are expressed in US $1997 prices.

Recent work by Eyre et al. (1997) suggests very similar values to Fankhauser for N_2O and CH_4 but higher values for carbon, once the analysis is put on a similar footing. It is not clear why the values differ for one of the greenhouses gases but not for the others.

Table 2.1.3 *Marginal damage values for the main greenhouse gases: 1997$/tonne*

Greenhouse Gas	Marginal Damage Values in different Year spans			
	Estimate 1991-2000	*2001-2010*	*2011-2020*	*2021-2030*
CO_2 as C: mean ($tC)				
Fankhauser	**25.0** (7.6-55.6)	**28.0** (9.1-65.1)	**31.1** (10.2-71.8)	**34.2** (11.3-79.0)
Eyre et al	47	45		
CH_4				
Fankhauser	**132.8** (59.0-252.1)	**158.7** (71.3-306.3)	**187.0** (84.9-360.4)	**216.5** (97.2-420.7)
Eyre et al	123	145		
N_2O as N: mean ($tN)				
Fankhauser	**3561** (990-8921)	**4156** (1172-10284)	**4798** (1380-11908)	**5521** (1571-13679)
Eyre et al	4674	4600		

Note: 1990-1997 $ price escalation of 3% pa assumed, i.e. multiplication factor of 1.23.
Source: Fankhauser (1995) and Eyre et al. (1997).

Secondary benefits

Table 2.1.2 and Table 2.1.3 record *damages* or *benefits as avoided damages*. However, when evaluating warming control policies it is the case that those policies will secure other benefits. Thus, control of CO_2 is likely to involve policies, which will also reduce conventional pollutants such as particulates, nitrogen and sulphur[22]. If the measures relate to traffic control then there may be benefits from accident reduction, reduced noise etc. Thus the *benefits of policy measures* are very likely to exceed the avoided damage. This is the *secondary benefits* or *ancillary benefits* issue. Table 2.1.4 summarises estimates of secondary benefits. It is important to note that the estimates are not strictly comparable. Some relate to benefits from associated air pollution reduction only, others to additional benefits such as reduced congestion. They also relate to different abatement measures. The spread of values is therefore predictably wide since the estimates will be context-specific. It seems unlikely, however, that secondary benefits will be much less than the central value for primary benefits, i.e. $20 tC, which would mean that benefits from CO_2 control are not likely to be less than $40 tC. This rule of thumb is not readily transferred to the other greenhouse gases, however, since control of methane and nitrous oxide is unlikely to be associated with spillover effects on such a scale as carbon, the latter being more pervasive to the economy.

[22] There are also negative secondary benefits of climate change related measures, such as small increases in emissions of NH_3.

Table 2.1.4 Secondary benefits of global warming control: $ tonne / C

Study	*Country*	*Secondary Benefits $ per tC controlled*
Alfsen et al, 1992	Norway	272-373
Alfsen, 1995	Norway	24-452
	EU	21 +
Barker, 1993	UK	125-282
	USA	332
	Norway	254-386
Scheraga and Leary, 1994	USA:Carbon tax	2- 20
	USA:BTU tax	3 - 28
Pearce, 1992	UK	195+
	Norway	412
Burtraw and Toman, 1997	USA various policies	3- 79

Source. Adapted from Ekins (1996) and Burtraw and Toman (1997)

Two approaches are taken to estimate the secondary benefits of climate control. The first method is based on the current literature. It assumes overall values to be used for *damages* are those given in Table 2.1.3, whilst for *benefits* 'twice' the values for carbon in Table 2.1.3 are used, but to err on the conservative side and assume zero secondary benefits for methane and nitrous oxide.

The second method used for estimating secondary benefits uses the following procedure:

i) estimate positive secondary benefits to acidification from SO_x and NO_x emissions reductions and negative secondary benefits to acidification from NH_3 emissions increase due, i.e. the changes in emissions are valued with unit pollutant damage values established for acidification (see Technical Report on acidification);
ii) estimate secondary benefits to tropospheric ozone, i.e. NO_x emissions reduction due to climate control are valued with average NO_x damage values established for tropospheric ozone (see Technical Report on tropospheric ozone),
iii) estimate secondary benefits to urban stress, due to primary PM_{10} and secondary aerosols reduction from climate change related measures. Benefits to urban stress are measured as avoided cases of premature mortality and morbidity incidences, valued with the relevant (VOSL-age adjusted, VOLY) and values for morbidity effects. The secondary benefits due to measure that reduce secondary aerosols, however, are provided as an indication of their size only. This is because these values are already subsumed in the secondary benefits to acidification (see (i))[23].
iv) sum the secondary benefit estimates.

Evaluating the AP scenarios

Table 2.1.5 gives the results of applying the shadow values in Table 2.1.3 to the different scenarios for climate change. It gives the total environmental damage per country due to the three main greenhouse gases for the different scenarios. I.e. the emissions data are converted to tonnes of C[24], N[25] and CH_4 and then multiplied by the corresponding values in Table 2.3. The damage values are reported in € at 1997 prices.

[23] The SO_x and NO_x emissions data used in this study are reasonably consistent with the data used in AEA Technology (1999) study. This suggests the secondary benefit estimates to acidification could be justified.
[24] To convert CO_2 to C, multiply by 12/44
[25] To convert N_2O to N, multiply by 14/44

Table 2.1.5 Total damage to world due to EU15 emissions of GHGs: € million (1997)

Country	1990	Baseline 2010	NT-AP 2010	FT-AP* 2010
Austria	399	462	394	432
Belgium	734	974	789	920
Denmark	397	468	376	430
Finland	343	527	383	450
France	2650	3220	2910	3010
Germany	6500	6480	5840	5970
Greece	521	885	742	792
Ireland	302	457	394	432
Italy	2950	3650	3180	3420
Luxembourg	131	156	131	136
The Netherlands	1030	1530	1100	1420
Portugal	315	536	433	507
Spain	1620	2380	2060	2200
Sweden	341	537	426	490
UK	3990	4490	3930	4160
EU-15	**22200**	**26800**	**23100**	***24700***

* Total damage for FT-AP is the sum of FT-AP for carbon and NT-AP for CH_4 and N. Note that the damage figure for FT presented in Table 2.1.5 overestimates the damage to the world because the avoided damage from emissions reduction outside the EU15 from trading are excluded.

The AP scenario for climate change aims to achieve the European Union's obligations under the Kyoto Protocol, i.e. an 8% reduction in greenhouse gas emissions by 2008-2012 relative to 1990 as a base year. The two variants 'No Trade' and 'Full Trade' represent different approaches to achieving this target. The 'No Trade' variant assumes emissions trading, does not take place other than within the national borders of each Member State. The 'Full Trade' variant assumes emissions trading takes place between Annex B countries.

The estimates of environmental damage reported in Table 2.1.5 are calculated by using the emissions data for EU15 only. By definition, the 'Full Trade' scenario achieves the Kyoto target but some 235mtCO_2 reductions are secured outside the EU such that global emissions reduction is the same in both the 'No Trade' and 'Full Trade' scenario. This means the damage to the world in 2010 under the AP scenario is: € 23.1 billion. Table 2.1.6 reports the changes in total damage to the world due to EU15 emissions of the main greenhouse gases across the three scenarios.

Table 2.1.6 Change in damage to world due to EU15 emissions of CO_2, CH_4 and N_2O, a comparison of scenarios. € million (1997)

Country	2010 Baseline less 1990	2010 NT-AP less 1990	2010 NT-AP less 2010 Baseline
Austria	+64	-4	-68
Belgium	+240	+55	-185
Denmark	+71	-21	-92
Finland	+184	+40	-144
France	+574	+256	-318
Germany	-23	-662	-640
Greece	+364	+221	-143
Ireland	+155	+92	-63
Italy	+703	+230	-473
Luxembourg	+25	+0.3	-25
The Netherlands	+500	+68	-432
Portugal	+221	+118	-103
Spain	+753	+437	-316
Sweden	+196	+85	-112
UK	+498	-61	-559
EU 15	**+4525**	**+852**	**-3670**
% change	20.3% increase	3.8% increase	13.7% decrease

Note: numbers differ to Table 2.1.5 due to rounding. For clarity, FT-AP scenario is omitted from Table 2.1.6.

The most dramatic implication of Table 2.1.6 is that, relative to the start year of 1990, the AP scenarios secure an aggregate damage level associated with 2010 emissions that barely differs from the damage level associated with 1990 emissions. The reasons for this are (a) the baseline scenario involves substantial increases in emissions due to economic growth and population change, with the AP scenario more than offsetting the increase in terms of tonnes of individual greenhouse gases, and (b) the shadow price of gases rises through time so that individual unit emissions in the future have a higher unit damage value due to income and population growth world-wide. Table 2.1.6, column 3 shows that certain countries have NT-AP scenario increases in emissions damages relative to 1990, notably Spain, but also including Italy, Greece, France, Sweden and Portugal.

Benefits of NT-AP and FT-AP scenarios

Table 2.1.7 reports the mid primary and secondary benefit estimates for the two variants of the AP scenario, 'No Trade' and 'Full Trade'. Where possible, lower and upper ranges are given in brackets.

Table 2.1.7 Primary and secondary benefits of the AP scenario: € billion (1997)

AP variant	Primary benefit	Secondary benefit				
		General	To acidification	To trop. ozone	To urban stress	
					Pri PM_{10}	Sec aerosol
No Trade	3.7 (1.2 - 8.5)	3.4	13.1 (3.4 - 50.4)	2.8	4.6 (16.4)	*9.8 (35.3)*
Full Trade	3.7 (1.2 - 8.5)	1.7	16.9 (1.9 - 28.0)	1.5	4.6 (16.4)	*9.8 (35.3)*

Pri = primary, sec = secondary.
Note: General secondary benefit estimates are based on the 'twice' carbon approach.
Secondary benefits to acidification, tropospheric ozone and urban stress are found by valuing the secondary emissions reduction by relevant average damage values. All values assume premature mortality is valued with VOSL. For details see Technical Report on acidification, tropospheric ozone and urban stress. Secondary benefits to urban stress refer to the AP scenario. The secondary benefits from reduced secondary aerosols are given as an indication of their size only, that is, these values are not included in the

total secondary benefits of climate change, because they are already included in the secondary benefits to acidification.

It is important to recall that the two variants of the AP scenario, 'No Trade' and 'Full Trade' both achieve the same global greenhouse gas emissions reduction target. Thus, due to the global nature of greenhouse gas pollutants, the primary benefits to the world (or avoided primary damages), of the 'No Trade' and 'Full Trade' variants are the same. By subtracting the 2010 damages of the NT variant from the Baseline, the primary benefit to the world of the AP scenario is given at some € 3.7 billion with a range of € 1.2 - 8.5 billion.

However, the 'No Trade' and 'Full Trade' variants of the AP scenario will differ in the level of secondary benefits to the EU15. Unlike the 'Full Trade' variant, the 'No Trade' variant relies entirely on EU15 emissions control in order to achieve the greenhouse gas emissions reduction target, which suggests higher secondary benefits to EU15 under the 'No Trade' variant. As expected, the secondary benefits to acidification and tropospheric ozone, of the 'No Trade' variant are greater than the 'Full Trade' variant, at some € 15.9 billion (from € billion 13.1 + 2.8) compared to € 8.8 billion (from € billion 7.3 + 1.5) for the 'Full Trade' variant.

Assuming premature mortality is valued with VOLY, secondary benefit estimates to acidification for the NT variant fall to € 8.5 billion with a range of € 2.2 to 32.7 billion, whilst for the FT variant they become € 4.7 billion with a range of € 1.2 to 32.7 billion. Likewise, assuming VOLY, the secondary benefits to tropospheric ozone for the NT variant are € 0.4 billion and for the FT variant € 0.2 billion. Secondary benefits to urban stress in the AP scenario, due to reductions in primary PM_{10} are, € 2.6 (12.0) billion, whilst the secondary benefits due to reductions in secondary aerosols are € 5.7 (25.7) billion, recall that these values are reported as an indication of their size only.

Sensitivity analysis

Table 2.1.8 sets out the results of the sensitivity analysis, where the key assumptions are changed and the effects of these changes are reported. Table 2.1.8 gives the primary and separately the secondary benefit estimates for the different scenarios in 2010 only.

Table 2.1.8 Key assumptions and the estimated results of changing these assumptions

Key Assumption in main report	Current value € billion	Revised assumption	Revised value € billion
Primary benefit in 2010 only			
Primary benefit Unit damage values: Fankhauser (1995) No Trade (NT) Full Trade (FT)	 3.7 (1.2 - 8.5) 3.7 (1.2 - 8.5)	Primary benefit Unit damage values: Eyre (1997) NT FT	 5.7 5.7
Secondary benefit (SB) in 2010 only			
SB to <u>acidification only</u>: VOSL NT FT	 13.1 (3.4 - 50.3) 7.3 (1.9 - 28.1)	SB to <u>acidification only</u>: VOLY NT FT	 8.5 (2.2 - 32.7) 4.7 (1.2 - 18.2)
SB to <u>tropospheric ozone</u>: VOSL NT FT	 2.8 1.5	SB to <u>tropospheric ozone</u>: VOLY NT FT	 0.4 0.2
SB to <u>particulate matter</u> : VOSL, Maddison (1997) and Pearce et al (1996) Primary PM_{10} Secondary aerosols*	 4.55 *9.77*	SB to <u>particulate matter</u>: VOSL, Primary PM_{10} Secondary aerosols	 16.4 *35.3*
SB to <u>particulate matter</u>: VOLY: Maddison (1997) and Pearce et al (1996) Primary PM_{10} Secondary aerosols	 2.63 *5.66*	SB to <u>particulate matter</u>: VOLY: AEA Technology (1999) Primary PM_{10} Secondary aerosols	 12.0 25.7
Total Secondary benefits (in 2010 only)			
SB to acidification, tropospheric ozone and particulate matter: VOSL NT FT	 20.5 13.4	SB to acidification, tropospheric ozone and particulate matter: VOLY NT FT	 11.5 7.5
SB to acidification, tropospheric ozone and particulate matter: VOSL NT FT	 20.5 13.4	SB (to all other) 'Twice' carbon unit damage values: Fankhauser (1995) NT FT	 3.4 (1.1 - 7.8) 1.7 (0.6 - 4.0)
		SB (to all other environmental problems) 'Twice' carbon unit damage values: Eyre (1997) NT FT	 5.39 2.73

* Note that secondary benefits due to reductions in particulate matter, secondary aerosols are presented merely to indicate their size. They are not included in the total secondary benefits from climate change control measures, this is because they are already subsumed in the secondary benefit estimates due to reductions in acidification, see Section *Secondary Benefits*.

Below, we consider the uncertainty and bias associated with the primary and secondary benefit estimates.

Primary benefits

The extent of uncertainty for the primary benefit estimates is large. The main areas of uncertainty are climatological i.e. the expected changes in global mean temperature and changes in temperature dependent factors such as sea level, precipitation, evaporation etc. The uncertainty continues in the estimation of the impacts to ecosystems, agricultural yields and human health. However, the reliability of the Fankhauser (1995) marginal damage values is measured by using the 90% confidence interval, this provides low and high marginal damage values around the mid value. The results given in Table 2.1.8 show that AP scenario primary benefit estimates for climate change can be estimated to within a factor of roughly 2. Overall, the primary benefit estimates can be interpreted as a rough assessment of the order of magnitude only. As a cross-check for the reliability of these unit damage values, the benefit estimates are also calculated using the mean marginal damage values taken from Eyre (1997).

The primary benefit estimates may be biased downwards due to the omission of avoided damage to other sectors dependent on climate, such as tourism, transport, construction and insurance. But they may be overstated due to the omission of adaptation strategies (Mendelsohn and Neuman, 1999).

Secondary benefits

A key issue relating to the estimation of secondary benefits for climate change control is the approach to emissions valuation. We make use of two methods. The first approach takes emissions reduction of carbon and values them at 'twice' marginal damage values for carbon, whilst assuming secondary benefits due to CH_4 and N_2O are zero. The second takes the secondary pollutant emissions reduction (i.e. NO_x, SO_x,NH_3 and PM_{10}) associated with climate change control and values them with relevant unit pollutant damage values derived for acidification and tropospheric ozone. For urban stress, numbers of premature mortality cases and ill health incidences are estimated and valued with VOSL (adjusted for age) / VOLY and values per morbidity effect.

Below we identify the main areas of uncertainty and determine the expected direction of bias associated with the different approaches to secondary benefit estimation.

Secondary benefit estimates to acidification: The main areas of uncertainty associated with the secondary benefit estimates to acidification are identified as follows:

- approach to premature mortality valuation
- use of UNECE average unit damage values estimated from AEA Technology (1999). UNECE values will be lower than EU unit damage values since UNECE includes EU and poorer economies in transition
- omission of impacts on ecosystems, cultural assets (within materials damage) and visibility impacts. The impacts of NH_3 emissions relate only to health and agriculture, i.e. impacts to ecosystems through eutrophication are excluded, and
- use of average unit pollutant damage values rather than the relevant marginal damage values.

In response to the first area of uncertainty, i.e. the approach to premature mortality valuation, secondary benefit estimates are found using VOSL and separately VOLY. Assuming VOLY means secondary benefits fall by roughly 50%. Note that the VOLY estimates are themselves subject to unknown error due to the fact that they are not founded in sound economic theory.

The omission of impacts with potentially large benefits from the control of acidifying pollutants (i.e. ecosystems) and the use of UNECE unit damage values suggests that the overall direction of error in the secondary benefit estimates to acidification is biased towards underestimation.

Although the relevant unit pollutant damage values for this type of analysis are marginal values, these values are not known. The second best values are average unit pollutant damage values. We do not know whether the average values are greater or less than the relevant marginal damage values. Thus the direction of bias in the benefit estimates due to this type of uncertainty are unknown.

The reliability of the unit pollutant damages used to estimate the secondary benefits to acidification is measured using the 68% confidence interval around the mean values[26]. Low, mid, and high secondary benefit estimates are given in Table 2.1.8, they suggest that the secondary benefit estimates to acidification can be estimated to within a factor of roughly 4. This indicates the results should be interpreted with caution and considered as a rough assessment of the order of magnitude only.

Secondary benefit estimates to tropospheric ozone: The main areas of uncertainty are identified as follows:

- the treatment of premature mortality valuation;
- the epidemiological uncertainty for the statistical relationship between ozone and mortality. The approach taken in this study makes use of the APHEA (1996) Barcelona study. This selection can be disputed;
- omission of impacts to materials, forests, ecosystems, non-crop vegetation, biodiversity, and
- use of average damage values per tonne of NO_x and VOCs rather than the relevant marginal damage values, uncertainty unknown.

In response to the first area of uncertainty, secondary benefit estimates are calculated using VOSL and separately VOLY to value premature mortality. As noted previously, the VOLY estimates are themselves subject to unknown error due to the fact that they are not founded on sound economic theory. Secondary benefit estimates based on VOLY are roughly 8 times lower than those based on VOSL. Thus, we see that premature mortality is a key issue in the secondary benefit estimates to tropospheric ozone. As mentioned above the epidemiological uncertainty for the statistical relationship between ozone and premature mortality can be disputed.

Due to the absence of information, it has not been possible to measure the reliability of the secondary benefit estimates in the usual fashion, i.e. through the use of confidence intervals to establish low and high secondary benefit estimates. Instead, the reliability of the unit pollutant damage values are tested by cross checking against alternative approaches, for details see Technical Report on tropospheric ozone.

Secondary benefits to urban stress: The main areas of uncertainty are identified as follows:

- the relationships between exposure to PM_{10} and premature mortality and ill-health incidences;
- relationships between exposures to $PM_{2.5}$ and premature mortality and ill-health incidences;
- treatment of premature mortality valuation;
- morbidity valuation estimates;
- inclusion of benefits due to reduced secondary aerosols in the secondary benefit estimates
- for acidification, and
- omission of impacts to visibility.

As a check for the number of ill-health incidences due to PM_{10} exposure, two sets of PM_{10} / health relationships (exposure response functions) are used. The results presented in the sensitivity analysis, Table 2.1.8 are based on functions derived by Maddison et al (1997) in his meta-analysis of several epidemiological studies from North America, South America and Europe. However, the benefit estimates are also calculated in the style of AEA Technology (1999), they make use of exposure response relationships given in the ExternE Project (European Commission, 1998). The results are greater at € 37.7 - 51.7 billion, where the low values assume VOLY and the high values assume VOSL (unadjusted for age). The estimates are greater because they include greater incidences of premature mortality and chronic bronchitis and premature mortality is valued more highly.

24% of the anthropogenic PM_{10} emissions reductions used in this study are due to particles smaller than $2.5 \mu g/m^3$, i.e. reductions in $PM_{2.5}$. Although it is widely believed that smaller particles are more harmful than bigger ones, the exposure response functions showing the relationship between exposure to $PM_{2.5}$ and premature mortality and ill-health incidences are not clearly defined. Thus we do not estimate the benefits of avoided premature mortality and morbidity due to reductions in $PM_{2.5}$.

[26] 90% confidence intervals are not reported. The range of benefit estimates based on the 90% confidence interval is so large that it is questionable if a meaningful interpretation can be made from the results.

In response to the third area of uncertainty, benefit estimates are provided using both the VOLY and VOSL (adjusted for age[27]) approach to premature mortality. With regard to the uncertainty of the valuation of morbidity incidences, two sets of morbidity values are used. The main results are based on values presented in Pearce et al (1996) adjusted for European values, however, we also make use of morbidity values presented in AEA Technology (1999) based on the work by Markandya (European Commission 1998). These estimates are roughly four times greater than the main results and may be explained due to greater incidences of mortality and chronic bronchitis.

The benefits of climate change measures that reduce emissions of NO_x and SO_x and therefore reduce the concentration of secondary aerosols, are already accounted for in the secondary benefit estimate to acidification. The SO_x and NO_x emissions data used in this study are reasonably consistent with the data used in the AEA Technology (1999) study. This suggests that the secondary benefits of reduced secondary aerosols subsumed in the secondary benefit estimates to acidification could be justified.

Total secondary benefit estimates due to climate change related measures may be an underestimate due to the omission of some important effects, such as the benefits due to reductions in $PM_{2.5}$, heavy metals, furans, dioxins, polyaromatic hydrocarbons.

Secondary benefits in general: The second approach to estimating secondary benefits is based on the current literature (see Table 2.1.4). This method takes 'twice' the values for global warming damage avoided, for carbon only. This gives an estimate for the general secondary benefits to all environmental problems due to climate change control. Following this method gives secondary benefits roughly 10 times lower than the secondary benefit estimates to acidification and tropospheric ozone only. This suggests, this methodology is highly uncertain.

Outline guide to economic models of climate change damage

Economic Damage Estimates: Underlying Models

The underlying models for the economic damage estimates are fairly complex. The following is an outline interpretation.

The models deal with small ('marginal') increases in emissions in a base period (e.g. now). This leads to an increase in atmospheric concentrations

$$\partial C_i(s)/\partial E(0)$$

where s is the time of the concentration, 0 is the base year of emission.

In turn, changed concentrations give rise to changed temperatures which depend on the radiative forcing of the gas, concentrations of other gases, climatic feedbacks and the inertia of the climate system:

$$\partial T(t)/\partial C_i(s), \text{ for } t>s.$$

Increased temperatures give rise to (marginal) damage

$$\partial D(t)/\partial T(t).$$

Taking all the links together, the incremental damage done by a marginal emission *at time t* now will be:

$$\partial D(t)/\partial E_i(0) = \partial D(t)/\partial T(t).\int_{0,t} \{\partial T(t)/\partial C_i(s).\partial C_i(s)/\partial E(0)\}\, ds$$

The marginal damage costs of an incremental tonne of emissions are

[27] Maddison et al. (1997) suggests that pollution-related mortality affects largely the elderly (over 85% of premature deaths are in the over 65 group). We assume values of risk aversion are lower for this age group at around 70% of the prevailing risk values. This reduces the VOSL to € million 2.32 (1997 prices).

$$K_i = \int_{0,\tau}[\partial D(t)/\partial E_i(0)].e^{-rt}.dt$$

since damage done is cumulative (i.e. occurs as long as the gas remains in the atmosphere) and needs to be discounted back to the present. r is the discount rate.

So,

$$K_i = \int_{0,\tau}[\partial D(t)/\partial T(t).\int_{0,t} \{\partial T(t)/\partial C_i(s).\partial C_i(s)/\partial E(0)\} ds]e^{-rt}.dt$$

Damage and Radiative Forcing

The ratio of marginal damage from gas i, relative to CO_2, will be the same as the ratio of GWPs if and only if damage is a linear function of radiative forcing. But this is not true, since the damage from a given increase in radiative forcing will depend on previous levels of forcing and the degree of warming already encountered.

As an example, Fankhauser (1995) has an *annual* damage function taking the form:

$$D_t = k_t \{T_t/\Lambda)^{\gamma}.(1+ø)^{t^*-t}$$

where T in this case is surface temperature, Λ is the amount of warming associated with a doubling of CO_2 (in Fankhauser's case, 2.5^o), t* is the time this is expected to occur (2050), k_t is the economic damage done by doubling of CO_2. Parameter γ is the relationship between temperature and damage, i.e. if temperature rises by 1%, damage rises by γ%. ø is a factor which makes impacts greater if they occur before t* and lower if they occur after t* - a rough attempt to account for damage being related to speed of change.

Thus, if doubling of CO_2 damage occurs in 2050 then damage = k_t since t*=t and T_t = 2.5^{o}C. Fankhauser (1995) adopts the following values based on the scientific and economic literature:

Λ = 2.5^o
t* = 2050
γ = range 1 to 3, with best guess 1.3
ø is random with best guess of 0.006

K_t is the damage done from doubling of CO_2 warming, assumed to occur in 2050 and is \$270bn. This is estimated from a 'bottom up' procedure of aggregating individual damages. Damages are adjusted for population and economic growth.

In any period t, then, annual damage is given by

$$D_t = \$270.10^9.(T_t/2.5)^{1.3}$$

The model is not linear. Atmospheric concentrations are linear with respect to emissions; forcing is logarithmic in CO_2 and has a quadratic form for CH_4 and N_2O (following IPCC); temperature change is linear with forcing; and damages are not linear with temperature. Thus use of forcing ratios to measure the *relative contributions* of different gases to *damage* is misleading. An illustration is taken from Fankhauser (1995). The latest GWPs and global damage potentials are reported in Table 2.1.9.

Table 2.1.9 Global warming potential and global damage potential

Gas	Global warming potential ratios (100 years)	Global damage potential ratios Fankhauser (1995)
CO_2	1	1
CH_4	21	20.7
N_2O	310	172.9

Note; to estimate global damage potentials, i) take marginal damage values for C, CH_4 and N given in Table 2.1.3, for the years 2001 - 2010; ii) convert to € (1997 values), we assume 1\$ = € 0.8817748, thus marginal damage for a tonne of, C = € 24.7 , CH_4 = € 139.9, N = € 3664.7; iii) convert to marginal damage values for a tonne of CO_2, CH_4 and N_2O, i.e. CO_2 = € 6.74, CH_4 = € 139.9, N_2O = € 1166; iv) estimate global damage potential ratios, i.e. divide marginal damage values for CO_2 into values for CH_4 and N_2O

3. Policy package

3.1 Key issues

Carbon tax / tradable permits: The EU is unlikely to achieve Kyoto target without either an energy / carbon tax or EU tradable permits / Kyoto flexible mechanisms[28]. For 2010 tradable permits may not be in place quickly enough, despite the numerous sectoral initiatives (e.g. British Petroleum, Shell, etc). Feasibility of EU wide tax is low, but note Member State initiatives already taken or planned: Sweden, (Norway), Denmark, The Netherlands, Finland, UK (Climate Change Levy, for 2001). Also, a tax with negotiated agreements now looks more promising.

It is important to note that where there is carbon trading there is a trade-off between reduced costs of carbon control and reduced secondary benefits to EU-15. Secondary benefits are large in 2010, estimated at: € 28.8 billion for the 'No Trade' scenario and € 21.7 billion for the 'Full Trade' scenario (see Section 2.1.3 on secondary benefits). Thus we see, the secondary benefits are reduced the more carbon trading takes place with non-EU countries. Therefore there is a trade-off between the secondary benefits within the EU versus the cost advantage of trading.

Subsidy removal: although subsidy removal is in the Baseline, it is imperative this takes place in order to secure the reduction in emissions

Aviation tax: Aviation must be brought on board. Pearce and Pearce (1999), show that a an aviation tax is predominantly made up of a tax on carbon (60%) and high level NO_x. This demonstrates the importance of carbon emissions from aircraft.

3.1.1 Recommended policy initiatives

Carbon – energy tax

In order to estimate the size of the tax needed to reduce emissions by -8% 1990 levels in 2010, we turn to earlier estimates of carbon taxes and experience. Gregory (1992) estimates that a $10 bbl oil tax (the original EC tax proposal, with 50% of the tax on energy and 50% on carbon) would reduce baseline demand by 10% maximum, depending on the 'mix' of the tax on energy and on carbon. This seems broadly consistent with the previous work of DRI (1994) where the $10 bbl tax eventually leads to a 11% reduction in primary energy demand in the EU relative to their 'reference' (BAU) scenario. The $10bbl tax on energy is equivalent to $75 per tonne of C, € 63 per tonne of C.

Excise duty (minimum energy tax)

If the full carbon – energy tax is not feasible, then the recommended policy becomes minimum harmonised rates of excise duties. However, the excise tax secures only a fraction of the reductions achieved by the carbon / energy tax. Thus, if the carbon / energy tax is infeasible, the policy package fails to deliver the target.

In 1997, EC proposed a directive on minimum rate of excise duties for all energy products - COM(97)30. It relates to end-users in transport, industry, commercial and domestic sectors but excludes power generation. Table 3.1.1 gives the proposed minimum excise duties for the different categories of fuels and different uses.

[28] Kyoto flexible mechanisms refer to, i) joint implementation with Annex 1 countries (mainly Eastern Europe) and ii) clean development mechanism in non Annex 1 countries (mainly developing countries).

Table 3.1.1 Proposed minimum excise duties for different categories of fuels and different uses

	Motor Fuels				Heating fuels					
	Petrol	Gas oil / diesel	LPG	Nat. gas	Gas oil	Heavy fuel oil	Diesel	LPG	Nat. gas	Elec
Year of intro	€ per 1000 litre	€ per 1000 litre	€ per 1000 kg	€ per GJ	€ per 1000 litre	€ per 1000 kg	€ per 1000 litre	€ per 1000 kg	€ per GJ	€ per kWh
1998	417	310	141	2.9	21	18 (22)	7	10	0.2	0.001
2000	450	343	174	3.5	23	23 (28)	16	22	0.45	0.002
2002	500	393	224	4.5	26	28 (34)	25	34	0.7	0.003

Source: http://europa.eu.int/scadplus/leg/en/lvb/127019.htm

The proposed timetable for the introduction of minimum excise duties (1998, 2000, 2002) cannot be met because they have yet to win the support of EU member states. Ekins and Speck (1998) show that most member states already have excise duties in place for a number of energy products but in many cases they are set lower than the proposed minimum duties. Table 3.1.2 gives the countries non-compliant in 1997 with EC 1998 proposed minimum duties.

Table 3.1.2 Non-compliant countries to EC proposed 1998 minimum excise duties

Country	Product
Spain, Luxembourg, Greece, Austria	unleaded petrol
Spain, Portugal, The Netherlands, Luxembourg, Greece, Finland, Belgium, Austria	diesel
Luxembourg, Belgium	Gas oil ind / com use
Spain, The Netherlands, Luxembourg, Ireland, Germany	Heavy fuel oil
Austria, Belgium, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, UK	Coal
Austria, France, Germany ,Greece, Ireland, Italy, Luxembourg, Portugal, Spain, UK	Natural gas
Austria, France, Germany, Greece, Ireland, Luxembourg, The Netherlands, Spain, UK	Electricity

The effects of full implementation of a minimum excise duty are likely to be small for three reasons:

- proposal relates to minimum taxes only, in some cases, such as, coal and lignite the tax rate maybe zero or greater;
- Member states already tax some energy products at levels exceeding the proposed minimum tax rate, such as: petrol, gas oil, heavy fuel oil (see Ekins and Speck 1998), and
- fuels used for power generation are exempt. Natural gas is exempt as long as the market share of natural gas in national energy markets is below 10%.

COHERENCE (1997) suggests that it would reduce CO_2 emissions by 1.5% off baseline emissions in 2007. Reductions in other pollutants are 2.5% for particulate matter (Urban stress), 1.25% for SO_2 and 0.5 - 1% for NO_x (Acidification), and VOCs (Tropospheric ozone), respectively.

Trading under Kyoto Protocol

The use of tradable permits can curb CO_2 emissions and not raise the tax burden or change the existing tax structure, yet give emitters greater flexibility to reduce emissions than direct regulation of fuel or carbon use. The permit would be an allowance to use fossil fuels with a carbon content of a given amount of C. Or one permit equals one tonne of carbon, this would grant the use of a quantity of fossil fuels which contain one tonne of carbon. If permits were established for the full range of greenhouse gases, it would be necessary to weight gases according to their agreed global warming or damage potential. The permit could be used, stored or traded and the national authority could use tradable carbon permits as an instrument to restrict national CO_2 emissions by limiting the number of permits made available.

Tradable permit systems can offer a known effect on emissions but permit prices are uncertain, thus the distributional effects through permit trade are also uncertain. The chances of 'carbon leakage[29]' are less if a large number of countries are involved in the permit system. This is one of the reasons why a tradable permit system for the whole of the EU will be more effective than a system introduced in only one country.

However, where there is carbon trading there is a trade-off between reduced costs of carbon control and reduced secondary benefits to EU-15. Carbon emissions reduction has large secondary benefits, in 2010, these are estimated to be: NT-AP: € 28.8 billion and for the FT-AP: € 21.7 billion (see Section 2.1.3 on secondary benefits). As would be expected the secondary benefits to the EU are reduced the more carbon trading takes place with non-EU countries. Evidence suggests cost savings to EU15 from trading via the Kyoto flexibility mechanisms will be substantial, some € 7.4 billion Capros (1999). Therefore there is a trade-off between domestic effort (with secondary benefits) within the EU versus the cost advantage of trading, for CO_2 control in Europe. A simple illustration of this trade-off is provided at the end of this section.

Aviation Tax

Aircraft contribute to environmental pollution and nuisance in several ways: noise at airports, local air pollution, regional air pollution via NO_x and VOC emissions, and global pollution through CO_2 emissions and high level NO_x emissions. Pearce and Pearce (1999) show how a tax can be devised which varies by aircraft type and airport characteristics, thus approximating a 'true' externality tax. The economic value of noise nuisance is derived from a meta-analysis of hedonic house price studies, producing an index which links house price depreciation to a unit of noise. The resulting economic values will therefore vary with the level of house prices, and housing density in the surrounding noise 'footprint'. The economic value of air pollutants is taken from established studies on the willingness to pay to avoid pollution, and a new estimate is derived for high level NO_x emissions based on recent IPCC estimates of the relative contributions of aircraft NO_x and CO_2 to global warming. Table 3.1.3 illustrates the tax for selected aircraft types.

Table 3.1.3 Aviation tax for selected aircraft

Aircraft type	Total tax per short haul movement €
A310	500
B747-400	1220
B767-300	535
MD82	380

While it has been argued that aviation taxes cannot be imposed unilaterally because of the provisions of the 1947 Chicago Convention, it is far from clear that this is correct. First, several countries have imposed unilateral aviation taxes based on environmental criteria (Switzerland, Sweden). Second, the non-discrimination clause in the Chicago Convention relates solely to rights of transit across ICAO countries. An environmental tax sets a price condition on transit but is a measure designed explicitly for environmental purposes.

In order to determine a broad indication of the effectiveness of an aviation tax on emissions reduction we turn to Centre for Energy Conservation and Environmental Technology (1998), they have estimated an aircraft emissions tax designed to internalise CO_2 and NO_x emissions. The Centre's own estimate of a broad-based tax is based on their being no NO_x global warming impacts, but includes acidification and local pollution impacts. They approximate this to be $0.2 per litre of fuel. They estimate that such a charge would lower aircraft CO_2 emissions by 80 mtCO_2, about 22 mtC in 2020, this is equivalent to roughly 10 mtC in 2010. The global benefits of such a tax would therefore be 10 mtC x € 25 per tC = € 250 million for 2010 (i.e. emissions reduction multiplied by marginal unit damage value for carbon). This value is

[29] The direct effect of reduced emissions in one set of countries could be partly offset by increased emissions from non-signaturies. This effect is termed 'carbon leakage' (Fankhauser, 1995).

expressed in present value terms since the 'price' of € 25 per tC already incorporates future effects. Unfortunately, the costs of implementing the tax are not known and should, ideally, include effects on consumers' and producers' surplus. On the other hand, if € 25 per tC is the marginal damage from global warming, then, if this damage estimate is thought to be indicative of an optimal tax, the tax should automatically generate the highest net benefits.

Methane tax

Methane tax on fossil fuel emissions

In principle, a comprehensive greenhouse gas tax would cover all greenhouse gases using their relative global warming potentials (GWPs) as weighting factors. For methane this can be given as:

$$T_{CH4} = T_{CO2} * (GWP_{CH4} / GWP_{CO2})$$

Thus, if CO_2 has a normalised GWP of 1, and methane has a GWP of X, then any CO_2 tax of € T per tonne CO_2 can be expressed as a tax of € T.X per tonne of methane. In so far as there is substitution between the sources of greenhouse gases, such a comprehensive tax would ensure that optimal substitution takes place alongside the required overall reduction in emissions.

In practice, the picture is complicated in various ways. First, GWP is not necessarily the same thing as damage in economic terms, so that the relevant tax on methane, say, should be:

$$T_{CH4} = T_C * (MD_{CH4} / MD_C)$$

Where MD is the marginal damage from methane (CH_4) and carbon (C) respectively. Second, some sources of methane emission are less easy to measure. Most methane emissions in the EU come from agriculture, waste and fossil fuel conversion.

Fossil fuel sources can be treated in terms of the previous equations, using either the GWP approach or the marginal damage approach. Based on the EC proposal for a carbon tax ($75 per tC or $20 per tCO_2) and the GWP rating for CO_2 and CH_4 as unity and 21 respectively, the methane tax can be estimated as $420 per tonne CH_4, € 353 per tonne of CH_4.

Methane tax on livestock

Taxation of methane from agriculture can also be applied provided it is accepted that the tax will not be ‘perfect’ in the sense of allowing for detailed variations in livestock emissions. Adger and Brown (1994) provide estimates of average CH_4 emissions for the UK by type of livestock, allowing for slurry management, age of cattle and whether dairy cattle are in milk or not. The results suggest around 56 kg CH_4 per year per head for beef cattle, 97.4 kg per year per head of dairy cattle, 2.9 kg CH_4 per year per head of pig and 8 kg CH_4 per year per head of sheep.

Given that the EC proposal for a carbon tax is the recommended policy at $75 per tonne of C and the methane tax estimate at € 353 per tonne of CH_4, the per capita tax on livestock is given in Table 3.1.4.

Table 3.1.4 Methane tax on livestock

	Emission factor CH_4 tonne per head	T_{CH4} = € 353 per tonne of CH_4 € per capita
Beef	0.056	20
Dairy	0.097	34
Pig	0.0029	1
Sheep	0.008	3

Substitution for SF_6, HFCs, PFCs

The Kyoto Protocol also includes HFC, PFC, SF_6 gases. HFCs are the main component of the three gases. The preliminary cost-benefit analysis based on work by Ecofys (1998) (see Section 2.3) suggests that reducing HFCs is expensive at some € 87 per tonne of CO_2 equivalent (2010 prices) compared to the marginal damage estimates for 2010, assumed to be € 25 per tonne. Based on Ecofys (1998) the maximum reduction could be 3mtC for SF_6 and PFCs.

March Consulting (1999), suggests that some reductions can be obtained cheaply relative to the marginal social costs of damages. A number of the reduction measures the report suggest pass the CBA test (when benefits are the avoided marginal damage cost). The total reduction that can be achieved by these measures (namely, energy efficiency measures in refrigeration, HFC23 emissions from manufacture and extruded polystyrene product emissions) is around 4.8 million tonnes of CO_2 equivalent or 1.2 million tonnes of C equivalent. Assuming that the other EU Member States would implement the same measures with the same percentage reduction effect, the upper bound of savings from this action would be about 4 million tonnes of C equivalent[30].

There are existing voluntary agreements (VAs) relating to some of the fluorinated GHGs. March Consulting (1999) suggest extending the VAs with targets, a recommendation that would have general applicability throughout the EU. However, some doubts have been cast over the cost-efficiency of VAs. This suggests that measures may need to be more fiscally based.

If an EU-wide carbon / energy tax was imposed it would, if applied to the three gases above, embrace a larger number of measures than a marginal damage-based tax since the tax would be of the order of $75 per tC, or $20 per tCO_2. = € 17 per t CO_2. However, even a lower tax should, according to the results of the report by March Consulting (1999), induce significant energy efficiency measures in the relevant markets. It is unclear why, if the negative costs are as shown, such measures have not already been put into place, independently of the climate change agenda. However, even a modest tax might ensure that these measures are brought about.

3.1.2 Secondary benefits

The policies recommended above will have major implications for other environmental problems. In particular they will benefit the issue of acidification, low level ozone and urban stress. It is not possible to evaluate separately the secondary benefit effects of each of the above measures. Instead we estimate the secondary benefits for the overall 'policy package' for NT and FT variants of the AP scenario. For the NT variant, secondary benefit estimates are € 28.8 billion, whilst for the FT variant they are, € 21.7 billion.

The climate change problem will benefit from policy initiatives targeted at other environmental problems. In particular those recommended for acidification, i.e. the NO_x and SO_x taxes, through the general reduction in energy derived from fossil fuels. Climate change will also benefit from policy initiatives for waste management that reduce biodegradable waste going to landfill sites, through the reduction of methane emissions. Total secondary benefits estimate for the AP scenario in waste management are estimated at € 400 million.

[30] The total EU emissions are taken to be about 10 Mt of C equivalent (FCCC/CP/1998/INF.9). However, this is based on reported emissions data by Belgium, France, Germany, Greece, Netherlands, and the UK only.

3.1.3 Effectiveness of policy package: an illustration

The effectiveness of the intended policy package is set out in Table 3.1.5. This serves as an illustration only.

Table 3.1.5 Climate change targets and the expected emissions reduction of some policies

	MtC
1990 Baseline C emissions, (estimated from all GHGs)	**1074**
2010 Baseline C emissions, (estimated from all GHGs)	**1149**
Target of -8% of 1990 emissions	**988**
Reduction required	**161**
Effectiveness of recommended policy initiatives (illustrative only)	
Carbon / energy tax: Effect of \$10bbl tax on energy (\$75tC / €63tC tax = 10% reduction in emissions	(-115)
(Minimum energy tax (excise duties) 1.5% reduction in emissions) to be implemented if C tax is not feasible	(-17)
Trading under Kyoto Protocol	(-67)
Aviation tax	(-10)
Max reduction of HFC, SF_6, PFC: if C tax is put in place we anticipate energy efficiency measures to be made in many markets: refrigeration, industrial, small commercial, supermarket, air conditioning, domestic.	(-1.2) - (-4)
Methane tax	nk
Possible secondary benefits from policies targeted at other problems	
waste management policies to reduce biodegradable waste to landfill sites	-17

The recommended policy actions that have the greatest effect on carbon emissions are the carbon / energy tax and carbon trading. It both these policies are implemented then the AP scenario emission reduction target will be overridden by 21 mtC (i.e. 161 - (115 + 67)). If however, we assume all policies are introduced except the carbon / energy tax, (i.e. minimum excise duty, aviation tax, trading, substitution of other GHGs) there will be a shortfall of 63 mtC. Again, if we assume all policies are introduced except carbon trading, then the shortfall will be 32 mtC. This suggests that some combination of carbon / energy taxes and carbon trading could be necessary in order to meet the AP scenario emission reduction targets.

3.1.4 B/C ratios for policy initiatives

Trading under Kyoto Protocol

The permit price used in the 'Full Trade' AP scenario is € 63.4 per tonne of carbon. The marginal damage and secondary benefit estimate of carbon control is roughly € 185 per tC[31]. This suggests trading may be efficient in cost benefit terms. In other words, if trading is not permitted, or is 'capped' at low levels, then the burden sharing agreement / Kyoto targets are economically inefficient. The permit price of € 63.4 per

[31] €185 per tC comes from marginal damage value plus marginal secondary benefit value. The marginal damage value for carbon is assumed as € 24.7 per tC. The average secondary benefit value is € 160 per tC. This value assumes the secondary benefits of the FT variant are due to carbon control only, the secondary benefit estimate for FT is divided by carbon emissions reduction in FT, i.e. € billion 21.7 / 1.36 x 10^8 tC = € 160 per tC.

tC is very similar to the significantly lower marginal damage and secondary benefit estimate of carbon control based on 'twice' carbon values, i.e. € 49 per tC, which again suggests trading may be efficient.

Capros (1999), assumes that Europe meets roughly 40% of the 2010 target through trading, this ensures a reduction of some 64 mtC. The trading price for carbon is taken as € 63.4 per tonne of C, thus the cost of trading is given as € 4088 million. If we assume the benefits are the cost savings from trading rather than by cutting emissions nationally. CSERGE (1998) estimates a ratio of 3:1 for domestic costs against EIT / LDC costs. If the EU pays € 63.4 tonne C for 64 mtC reduction, i.e. € 4088 million, it would have cost three times this if emissions were cut nationally, i.e. € 12,264 million. Hence the saving is € 8176 million, less any transactions costs from trading. The B/C ratio for carbon trading is thus estimated to be 2:1.

Substitution of the other greenhouse gases: SF_6, PFCs, HFCs

This section conducts a benefit cost test for the reduction of halogenated gases in EU15. Halogenated gases are included in the basket of greenhouse gases regulated under the Kyoto Protocol, they are: HFCs, PFCs and SF_6.

Ecofys (1998), report abatement costs for each gas in tonnes of CO_2 equivalents (for 2010). These are given in Table 3.1.6.

Table 3.1.6 Abatement costs for each gas in tonnes of CO_2 equivalent, 2010

GHG	CO_2 equivalent € per tonne	C equivalent[32] € per tonne
HFC	60-90*	220 - 330
PFC	1 - 6	4 - 22
SF_6	1 - 6	4 - 22

* or € 20 per tonne CO_2 eq, when measures > € 100 per tonne CO_2 are excluded

Marginal damage estimates for 2010 are assumed to be € 25 per tonne C. On this basis, assuming the lower bound abatement costs, the control of SF_6 and PFCs, have a high benefit cost ratio; at the upper bound the control of PFCs and SF_6 is just worth while. The control of HFCs involves net costs.

The analysis assumes it is correct to compare these gases in terms of their C-equivalent, i.e. through weights derived from global warming potentials. As noted with the main greenhouse gases, however, GWPs do not necessarily correspond to the ratio of marginal damages. The procedure is biased to this extent.

For the scenarios considered in Ecofys (1998) we compare costs and benefits of reducing HFC, PFC and SF_6, the results are given in Table 3.1.7.

Table 3.1.7 Costs and Benefits of reducing HFC, PFC and SF_6 emissions

GHG	Maximum reduction in EU-15 Mt C-equivalent	Costs € million	Benefits € million
HFC	16	3520 - 5280	400
PFC	1	4 - 22	25
SF_6	2	8 - 44	50

The above cost benefit analysis for halogenated gases indicates that a 3 mt C reduction will yield net benefits. A 16mt C-equivalent reduction of HFCs ensures net costs, however, it is possible that a smaller reduction may yield net benefits. For the purposes of this analysis it is assumed that the optimum reduction would be 3 mt C.

A detailed report for the UK (March Consulting, 1999) suggests that some reductions can be obtained cheaply relative to the marginal social costs of damages. A number of the reduction measures the report suggests pass the CBA test (when benefits are the avoided marginal damage cost). The total reduction that can be achieved by these measures (namely, energy efficiency measures in refrigeration, HFC23 emissions

[32] CO_2 equivalent converted to C equivalent at 1t C = 3.67 tCO_2

from manufacture and extruded polystyrene product emissions) is around 4.8 million tonnes of CO_2 equivalent or 1.2 million tonnes of C equivalent.

Assuming that the other EU Member States would implement the same measures with the same percentage reduction effect, the upper bound of savings from this action would be about 4 million tonnes of C equivalent[33].

Herd size reduction for the control of methane from agriculture

In the case of agriculture it is possible to estimate per capita livestock taxes based on emission factors and marginal global warming damage estimates. However, methane from agriculture poses some difficult problems for policy design. The two main sources of agricultural methane are enteric fermentation in the guts of ruminants, and anaerobic decomposition of slurry (manure). A policy of reducing herd size will secure reductions in both these sources of methane. Adger and Brown (1994) conduct a cost-benefit study of reducing herd size in the UK using estimates of global warming damage as given above. Costs are defined as the foregone net revenues to farmers of reducing herd size, adjusted for the distortionary effects of CAP subsidies to the livestock sector. Benefits are defined in terms of the reduced global warming damage due to reduced CH_4 emissions. Even at high marginal damage estimates of $US 66 per tC equivalent, the benefits of herd size control are less than the costs.

Note that nothing follows from this with regard to the costs and benefits of wider policies such as CAP reform. In that case there are other costs and benefits to be accounted for and it would be legitimate to count the methane reduction benefits as benefits arising from that overall package of subsidy reform. Table 3.1.8 gives the costs and benefits of controlling UK herd size.

Table 3.1.8 Benefits and costs of controlling UK herd size: methane only

	B/C at $20 tC equ	B/C at $66 tC equ
Beef	0.025	0.248
Dairy	0.018	0.177
Sheep	0.040	0.391
Pigs	0.003	0.031

Source: Adger and Brown (1994)

Clearly, there are other benefits of controlling herd size besides the impact on global warming, notably impacts arising from the control of ammonia (relevant for eutrophication). Nonetheless, the benefit cost ratios above suggest that herd size control may be either an inefficient way of dealing with the problem of methane releases, or that methane control is not justified in cost-benefit terms for the agricultural sector. Based on the above analysis, whilst ammonia control benefits are not estimated, it seems unlikely that herd size control would pass a cost-benefit test.

[33] The total EU emissions are taken to be about 10 Mt of C equivalent (FCCC/CP/1998/INF.9). However, this is based on reported emissions data by Belgium, France, Germany, Greece, The Netherlands, and the UK only.

3.1.5 The carbon trading trade-off

There exists a trade-off between domestic effort for the control of GHGs and emission trading for CO_2 control in Europe. The following four diagrams serve as a basic illustration only, of the trade-off between the secondary benefits within EU and the cost advantage of trading.

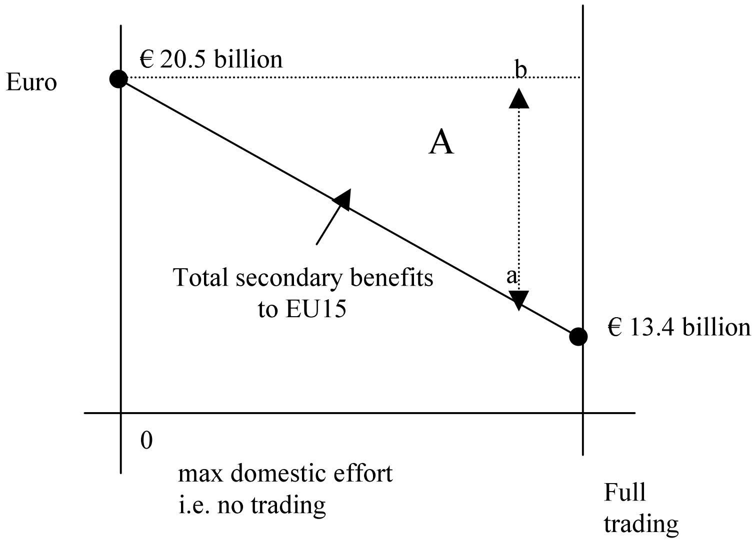

Figure 1: Total secondary benefits to EU

The more trading there is the lower the CO_2 emission reduction in EU15 and hence the lower the secondary benefits (SO_2 etc). If we assume full trading the cost in terms of forgone secondary benefits is given as area A in Figure 1. Figure 2 shows the cost of trading in terms of foregone secondary benefits

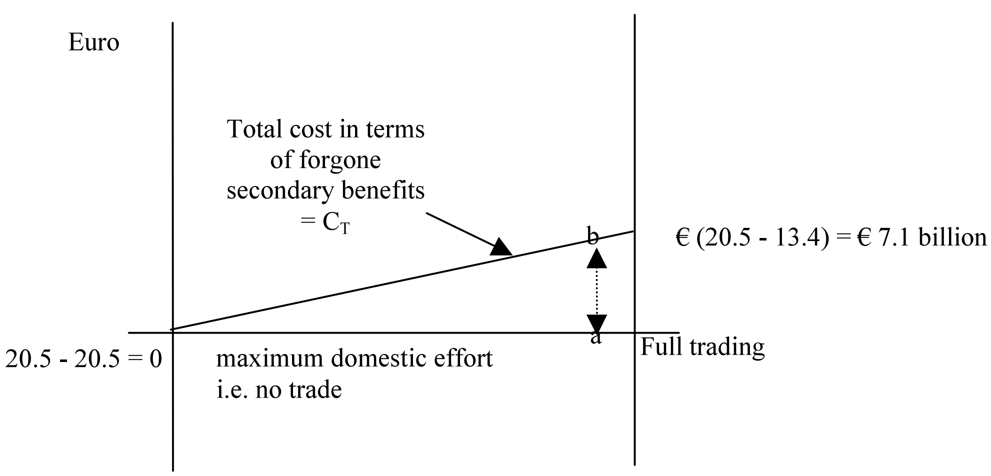

Figure 2: Total cost in terms of forgone secondary benefits

Figure 3 shows the abatement costs (C_A) borne by EU15. These are lower under trading (Capros (1999) suggests 40% lower).

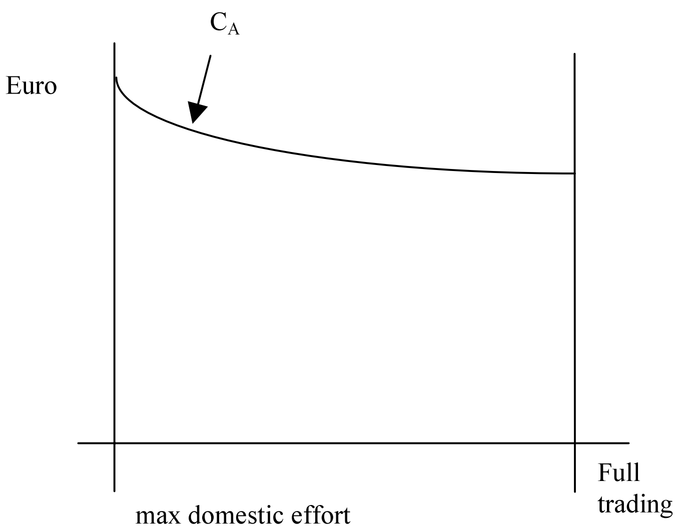

Figure 3 Abtatement costs

The total cost of meeting the 8% Kyoto target is given in Figure 4

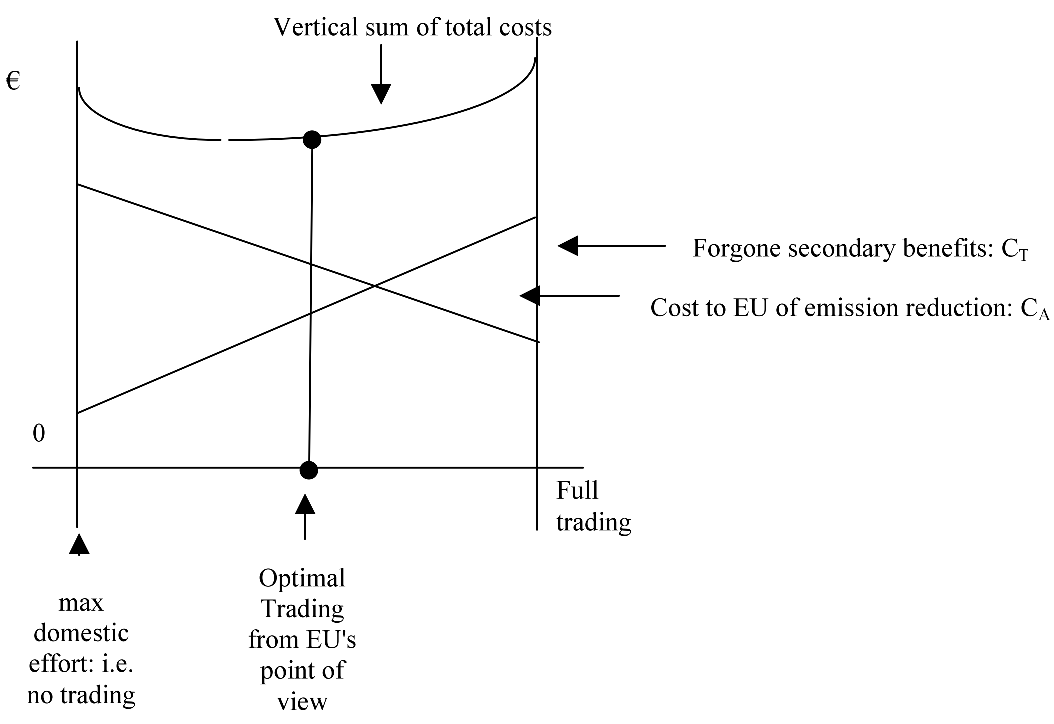

Figure 4: The optimal level of trading

3.1.6 Policy package summary section

Table 3.1.9 summarises the information for the suggested policy initiatives for climate change control. Information permitting, the benefits, the costs, the benefit / cost ratio and the effectiveness of each policy initiative is provided.

Table 3.1.9 Summary of policy initiatives and estimates of effectiveness, benefits and for each policy.

Policy measure	Effect mtC	Benefits € million	Costs € million	B/C ratio
Carbon - energy tax €63 per tonne ($75 per tC)	115	2800 to 5700	n.k	-
Excise duty (min. energy tax)	17	420 to 840	n.k	-
Trading under Kyoto Protocol – assuming the EU reduces 40% of the 2010 target this way	64	8200 to 9800[34]	4300 transaction costs	2 - 2.4
Aviation tax: rates per aircraft given in text. At €27 per 1000 passenger km	10	250 to 500	n.k	-
CH_4 tax on fossil fuel emissions at € 353 per tonne	n.k	n.k	n.k	-
CH_4 tax on livestock (see the text for this action for detailed figures)	n.k	n.k	n.k	
Substitution measures on SF_6, HFCs, PFCs	1.2 to 4	30 to 100 60 to 200	1.5 to 5[35]	6 - 66
Secondary Benefits				
Waste management policy initiatives (secondary benefit)	17	430	n.k	-

Lower benefit estimates are based on marginal damage estimates of € 24.7 per tonne of C, adapted from Fankhauser (1995). Upper benefit estimates use € 49 per tonne of C i.e. marginal damage values and secondary benefits.

3.2 Policy Assessment

A number of policy options are recommended (see Section 2.2.2), however, the main policy initiatives are: i) carbon / energy tax, ii) tradable permits for greenhouse gases, iii) aviation tax, and iv) the substitution of other greenhouse gases, (SF_6, PFCs, HFCs) through energy efficiency in refrigeration.

[34] Benefit estimates are as follows: The lower benefit estimates are the cost savings from trading rather than by cutting emissions nationally, see section 3.1: Trading under Kyoto Protocol for details. Whilst the upper values include cost savings from trading and the primary benefits to the world of avoided damage due to reduced GHG emissions (i.e. 8176 + (64 x 25) = € 9776 million).

[35] March Consulting (1999).

3.2.1 Causal criterion

Table 3.2.1 lays out the driving forces behind the climate change problem, the underlying causes of these driving forces are also identified.

Table 3.2.1 Driving forces and underlying causes of climate change

	Driving force	Underlying cause		
		MF	IntF	ImpF
D1	Changes in economic structure			
D2	Transport growth			
D3	Growth energy (electricity) demand in commerce and domestic sector			
D4	Low energy prices and slow improvement of energy efficiency	X	X	
D5	Cement production			
D6	Global deforestation	X		
D7	Livestock increase	X		
D8	Inorganic fertiliser and manure, excessive use of	X		
D9	Methane emissions from landfill	X		
D10	Acid production, responsible for 15% of N_2O emissions	X		

X = main underlying cause, MF = market failure, IntF = intevention failure, ImpF = Implementation failure. Note that for driving forces D1, D2, D3, D5, and D7, the main causes are due to growth in population and real income.

The carbon / energy tax, tradable permits for greenhouse gases, aviation tax and the substitution of other GHGs are all policy initiatives that address the underlying causes of climate change, i.e. market failure and intervention failure. The aviation tax should be designed to account for the multi-pollutant nature of air travel and for the localised conditions in which some of the externalities occur (i.e. noise pollution, air pollution at local, regional and global levels). Such a tax would address the underlying causes of climate change as well as noise nuisance and acidification.

3.2.2 Efficiency criterion

Benefit-cost ratio of the AP scenario

Table 3.2.2. presents the benefit cost ratios for the 'policy packages' that achieve the NT and FT variants of the AP scenario. The benefit cost ratios are established by comparing i) primary benefits only with the welfare costs and separately the direct costs of climate change control and ii) primary and secondary benefits with the welfare costs and separately the direct costs. The benefit cost ratios in Table 3.2.2 assume premature mortality is valued with VOSL, results based on VOLY are given in brackets.

Table 3.2.2 B/C ratios for NT and FT AP scenario

	Welfare costs			Direct costs		
	Low	mid	high	low	mid	high
NT: PB	0.1	0.2	0.5	0.1	0.3	0.7
NT: PB + SB to EU15		1.5 (0.9)			1.9 (1.2)	
FT: PB	0.1	0.4	0.9	0.2	0.6	1.4
FT: PB + SB to EU15		1.9 (1.2)			2.9 (1.9)	

NT = No Trade AP scenario, FT = Full Trade AP scenario, PB = primary benefit, SB = secondary benefit. Note; B/C ratios assume premature mortality is valued with VOSL, however, values given in brackets refer to B/C ratios where premature mortality is valued with VOLY.

To estimate the B/C ratios for GHG emissions control, the benefit estimates for reduced CO_2, CH_4 and N_2O are compared to the costs for CO_2 and non CO_2 reduction.

Both variants of the AP scenario pass the cost benefit test when primary and secondary benefits of climate change control are compared with welfare costs and separately direct costs.

Despite the loss of some secondary benefits, the FT variant has higher B/C ratios than the 'No Trade' variant, due to the substantial resource cost savings. The Kyoto policy is far more likely to pass a benefit-cost test with trading than without. The FT AP scenario assumes roughly 50% carbon trading and 50% domestic reduction, thus, in order to meet the AP emission reduction targets, a mix of domestic reduction and trade is recommended.

Benefit cost ratio for Kyoto targets

The 'carbon values' in the 'No-trade' AP scenario are the marginal cost of abatement for each country such that it achieves its EU burden sharing target. These marginal costs range from € 80 to 480 per tonne carbon. It is important to note that this range is well above the low, mid and high, marginal damage estimates used in the benefit analysis of the NT-AP scenario (i.e. in 2010: €8, €25, €57 per tC, based on Fankhauser (1995)). This indicates that the Kyoto targets are themselves economically inefficient.

Benefit assessment of 'No Trade' and 'Full Trade' AP scenarios

Benefit estimates are based on reduced environmental impacts due to reductions in emissions of CH_4, N_2O and CO_2 only for the 'No Trade' and 'Full Trade' AP scenario. The primary benefit estimates are calculated according to the unit damage values (low, mid, high values) estimated by Fankhauser (1995). The upper bound estimates for the mid-range estimates use unit damage values based on Eyre (1997).

The secondary benefit estimates take the secondary pollutant emissions reductions due to climate change control and values them according to the unit pollutant damage values derived for acidification and tropospheric ozone and urban stress. Estimates assume premature mortality is valued with VOSL, estimates based on VOLY are given in brackets.

Table 3.2.3 gives the primary benefits, secondary benefits and total benefits for the 'No Trade' and 'Full Trade' AP scenario in 2010 only.

Table 3.2.3 Avoided environmental damage in 2010 only

	Primary benefits only € billion			Secondary benefits only € billion	Total € billion
	low	Mid	High		mid
No Trade	1.2	3.7 - 5.7	8.5	20.5 (11.5)	24.2 (15.2)
Full Trade	1.2	3.7 - 5.7	8.5	13.4 (7.5)	17.1 (11.2)

Carbon emissions reduction generates large secondary benefits. As would be expected the secondary benefits to the EU are reduced the more carbon trading takes place with non-EU countries. The secondary benefits are composed of secondary benefits to acidification, tropospheric ozone and urban stress. The benefits to acidification for the NT variant are € 13.4 billion with a range of € 3.4 to 50.3 billion, whilst for the FT variant, € 7.3 billion a range of € 1.5 to 28.1 billion. Secondary benefit estimates to tropospheric ozone only for the NT variant are € 2.8 billion and for the FT variant, € 1.5 billion. Unfortunately due to information limitations, it is not possible to test the reliability of the secondary benefit estimates for tropospheric ozone by the usual method of confidence intervals.

Secondary benefits to urban stress in the AP scenario, due to reduced primary PM_{10} are, € 4.5 billion (VOSL-age adjusted) or € 2.6 billion (VOLY). Total secondary benefit estimates to acidification, tropospheric ozone and urban stress are, NT € 20.5 billion (from 13.1 + 2.8 + 4.5) and for the FT variant € 13.4 billion (from 7.3 + 1.5 + 4.5).

Secondary benefit estimates based on the 'twice' carbon values methodology give NT secondary benefits are € 3.3 to 5.4 billion and for the FT variant, € 1.7 to 2.8 billion.

Evidence suggests the cost savings to EU-15 from trading via the Kyoto flexibility mechanisms are substantial, at some € 7.4 billion (based on Capros et al (1999), i.e. additional costs NT less additional costs FT in 2010, € 16.5 billion - € 9.1 billion, see below or, main report *Chapter 3*). Therefore there is a trade-off between secondary benefits within the EU versus the cost advantage of trading.

Costs of AP scenarios

Table 3.2.4 presents the welfare costs and direct costs for the NT and FT variants of the AP scenario.

Table 3.2.4 Welfare costs and direct costs for climate change control

	Additional costs (costs AP 2010 - Baseline costs 2010) € billion	
	Welfare costs	Direct costs
NT	16.5	13.0
FT	9.1	5.9

The full welfare losses are estimated by GEM-E3, Capros (1999). Costs of carbon reduction differ greatly depending on the policies assumed in the AP scenarios. Where carbon reduction is achieved by national efforts alone, as assumed in the 'No Trade' AP scenario costs are high at € 16.5 billion. However, when international trading is permitted, i.e. 'Full Trade' scenario, costs are considerably lower, estimated to be € 9.1 billion (see *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface*).

B/C ratios for the recommended policy options

Benefit estimates for the recommended policy options; carbon / energy tax, trading and aviation tax are given below. Where possible the B/C ratios for these policy options are given, however, in general the costs of policies are unknown. The B/C ratios are estimated for the control of other greenhouse gases (HFCs, PFC and SF_6) and for a methane tax on livestock.

Carbon tax: benefits of a carbon tax achieving a 115 mtC reduction are estimated to be € billion 2.8 (i.e. emissions reduction multiplied by marginal damage of carbon, 115 x 24.7). The benefit estimates of the carbon tax is biased towards underestimation due to the omission of secondary benefits to other environmental problems.

Aviation tax: benefits of an aviation tax achieving a 10 mtC reduction are estimated to be € 250 million (i.e. emissions reduction multiplied by marginal damage of carbon, 10 x 24.7).

Benefit - cost ratio for carbon trading via the Kyoto flexibility mechanisms: the permit price of € 63.4 per tonne of carbon used in the 'Full-trade' AP scenario is below the marginal damage and secondary benefit estimates for carbon control. This suggests trading is efficient in cost benefit terms.

Benefit / cost ratio for methane tax on livestock: costs are defined as the foregone net revenues to farmers of reducing herd size, adjusted for the distortionary effects of CAP subsidies to the livestock sector. Benefits are defined in terms of the reduced global warming damage due to reduced methane emissions. Even at high marginal damage estimates of € 58 per tC equivalent ($US 66 per tC eq.), the benefits of herd size control are less than the costs. B/C ratios range from: 0.03:1 for pigs, 0.4:1 for sheep, 0.2:1 for diary and 0.2:1 for beef. The B/C ratios suggest that herd size control may either be an inefficient way of dealing with the problem of methane emissions or that methane control is not justified in cost-benefit terms.

Benefit / cost ratio for the control of other greenhouse gases: The preliminary cost-benefit analysis based on Ecofys (1998) (see Section 2.2.5) shows that the reduction of certain halogenated gases is justified in cost benefit terms. The B/C ratio for a reduction in PFC and SF_6 (3mt C equivalent) is estimated to be 6.25 - 1.1:1. A 16mtC eq reduction of HFC, however, does not pass such a test, the B/C ratio is estimated at 0.07-0.1:1. Although, it is possible that a smaller reduction could pass the B/C test. March Consulting (1999) suggest that a number of measures, namely; energy efficiency measures in refrigeration, HFC23 emissions from manufacture and extruded polystyrene product emissions do pass a cost benefit test. The total reductions in emissions such measures can achieve are reported as 1.2 - 4 million tonnes of carbon equivalent reduction. This could be achieved if the carbon / energy tax is applied to all greenhouse gases.

Cost-effectiveness

Carbon / energy tax and tradable permit schemes for greenhouse gases are cost minimising policy initiatives. The secondary benefits associated with these policies; i.e. the reduction of traffic, noise and air pollution raises the cost-effectiveness ratio considerably.

Similarly the secondary benefits associated with an aviation tax (such as reduced noise pollution, local air pollution) suggest the cost-effective criterion is met.

A methane tax on livestock will have other benefits besides the impact on global warming, notably the impacts arising from the control of ammonia, i.e. eutrophication. However, it is unlikely the control of herd size through a methane tax will be cost efficient.

Energy efficiency measures in refrigeration employed for the substitution of other greenhouse gases (SF_6, PFCs and HFCs) are cost effective policies.

Public opinion

Eurobarometer (1995) reports that Europeans generally favour the introduction of 'green taxes' to change behaviour and alleviate environmental deterioration, 83% of Europeans 'totally agree / tend to agree' with the proposal to increase taxes on practices that pollute the environment. Even though, many EU countries have already introduced carbon taxes and some industries are participating in 'infant' trading schemes, it is widely held that there is strong household and industrial opposition to the introduction of carbon taxes, trading and aviation tax.

3.2.3 Administrative complexity

Carbon tax: in principle, carbon taxes are administratively feasible. The carbon content of different fuels is known with reasonable accuracy so that a tax levied on the fuel as opposed to its processed form, e.g. electricity, should approximate emissions. Moreover, since each tonne of CO_2 does the same 'global warming' damage (CO_2 is a uniformly mixed pollutant) an emission tax can be set according to the damage done, thus approximating a 'true' externality tax. There is, of course, substantial uncertainty about the marginal damages from CO_2: estimates in the benefit assessments range from € 8 to 57 per tonne C in 2010, with a central estimate of € 24.7 per tonne C.

Where a carbon tax is levied on electricity, average damage can be estimated by computing the mix of fuels into electricity generation and making adjustments for conversion efficiencies according to the fuel type. Thus, the carbon content of the 'average' kWh of electricity can be estimated. However, marginal damages are less easy to allocate to electricity since the last unit of electricity will tend to come from the highest unit cost generating source. While this is likely in many cases to be the most polluting, this is not necessarily so.

Carbon trading: Carbon trading through a tradable permits system appears to avoid the difficulties of sulphur trading because CO_2 damage is constant per tonne CO_2 whereas damages per tonne SO_2 varies by emitting source. Thus one-to-one carbon trading appears feasible. However, since carbon is produced jointly with SO_x, NO_x, PM_{10} etc, in fact the damage done by one tonne of CO_2 varies by location (Heintz and Tol, 1996). Substantial carbon trading within the EU could therefore give rise to regionally differentiated damages from jointly produced pollutants.

Energy taxes: if taxing according to the carbon base of fuels is complex, it is tempting to think that energy-based taxes will be administratively easier. Nonetheless, fuels would have to be taxed on an oil equivalent basis, so that fuels would still have to be differentially taxed. More importantly, any administrative gains have to be weighed against the loss of environmental efficiency if fuels are not taxed according to carbon content. Much depends on the extent to which fuels switching between fuels (both between carbon and non-carbon fuels, and between carbon fuels) is feasible.

Aviation tax: this is feasible by differentiation of aircraft and airport. It can be easily implemented through the landing fee system. There are disputes as to whether such a tax can be introduced in the context of the Chicago Convention (1947), but there are suggestions that this tax is consistent with this Convention.

Substitution of other greenhouse gases through energy efficiency in refrigeration: Institutions are already in place, therefore administrative complexity is minimal

3.2.4 Equity criterion

By income groups: a carbon / energy tax will be regressive. However, some social payment from the tax revenues, which will be very large (see *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface)* may be made to alleviate this effect. Tradable permit systems can offer a known effect on emissions but the permit prices are uncertain, thus the distributional effects through permit trade are uncertain

By spatial unit in EU; this is taken care of by the EU burden sharing agreement. For details of the change in welfare in each Member State, see *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface*.

Sustainable development; global warming is a future orientated problem. Assuming future generations are richer than current generations, this in effect means we are transferring monies from poor to rich. The justification for this are as follows; (a) future generations have limited 'vote' due to limited cross-generational markets and (b) possibility that global warming will actually reduce their wellbeing, i.e. risk that they won't be richer than us. (Schelling, 1999)

3.2.5 Jurisdictional criterion

Climate change is a global issue and hence EU acting together provides the most efficient solution. Action should therefore be centralised.

If an aviation tax can be shown to be consistent with the Chicago Convention, aviation taxes can be charged unilaterally by any one country. Several countries have imposed unilateral aviation taxes based on environmental criteria already (i.e. Sweden, Switzerland).

Macroeconomic effect

Details of the macroeconomic effects of the climate change control strategies are given in *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface.*