

## **Economic efficiency of cross sectoral emission trading in CO<sub>2</sub> in the European Union**

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### **ABSTRACT**

*Most economic analysis and modelling studies of emission trading in greenhouse gases have been on a fairly aggregate international level and implicitly assumed governments to be the main actors. The models have mainly varied in terms of country coverage without addressing which sectors could take part in trading. In addition, little attention has been paid to the effects of trading within the European Union (EU). We show that the Member States of the EU can save as much as a third of their compliance costs to reach their Kyoto commitment of –8% of from 1990, if they start trading in CO<sub>2</sub> among themselves. The gains would further increase if trade would be conducted among Annex B Parties.*

*To date, analysis has mostly started by assuming that countries would have already adopted internally optimal climate policies before entering international emission trading. In reality, this is unlikely to be true. We show that international emission trading could be more important than estimated by conventional models, when trading would correct for domestic policy imperfections. In particular, we show that the welfare gains from EU-wide emissions trading could be six times higher, if the alternative reference case, called the “cheese slicer”, was used as the point for comparison.*

*We also show that a step-wise implementation of an emission trading scheme is fair to the early movers in-as-far-as the permit price will remain practically unaltered if the power generation sector is the first mover. The equilibrium price is about €32/t CO<sub>2</sub> regardless who else would be trading. Thus, not only is it fair to start with power generation sector, but this also makes both environmental and economic sense.*

*The results of this study are based on the PRIMES energy systems model assuming that energy related CO<sub>2</sub> emissions could be traded by different sectors. The Kyoto target for EU as a whole is –8% from their 1990 emissions this was also taken as the target for the CO<sub>2</sub> emissions. Thus, implicitly it was assumed that the non-CO<sub>2</sub> gases would also reach the –8% target. In order to be as realistic as possible, in all cases the analysis is based on the “Burden Sharing” agreement, where the EU Member States take differentiated targets from –28% to +27%.*

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## 1. INTRODUCTION

Most economic analysis and models of emission trading in greenhouse gases have been on fairly aggregate international level and implicitly assumed governments to be the main actors. The models have mainly varied in terms of country coverage (e.g. Annex B, non-Annex B, OECD countries only etc.) in the trading regime.

Several studies concluded that if all Annex B countries traded amongst themselves, the cost of complying with Kyoto (or other climate) target would be reduced significantly. For instance, in a recent study by Coherence (1999) it was estimated that the compliance cost for all Annex B countries would be reduced by 58% if trading was allowed among all Annex B countries. The compliance cost for the EU would be reduced by 15%. Other studies give similar orders of magnitude and show that the cost of complying with the Kyoto Protocol are significantly lower under international emissions trading than if any of the major industrial countries would implement the Protocol target individually. This is confirmed by all general equilibrium model results shown in Table 1 and also by the world energy model Poles that demonstrates that, without trading the EU countries would need to raise the price of CO<sub>2</sub> by €38 per ton in 2010. It would rise only by €20 with international emissions trading.

**Table 1: Cost of reducing a ton of CO<sub>2</sub> in 2010 with Annex B trading and without trading – results from different models**

€ <sub>99</sub> per ton of CO <sub>2</sub>	With	Without trading		
	Annex B Trading	EU	US	Japan
WorldScan	5	22	10	20
GREEN	7	64	41	17
GEM-E3	15	56	61	92
World				
G-CUBED	16	72	24	28
AIM	18	60	45	59
POLES	20	38	31	65
SGM	21	39	49	116
EPPA	23	92	59	132
MS-MRT	24	58	75	118
GTEM	32	216	101	175
OXFORD	58	252	107	273

Sources: 1) AIM, EPPA, G-CUBED, GTEM, MS-MRT, OXFORD and SGM: Energy Journal (1999). The costs of the Kyoto Protocol: A Multi-Model Evaluation. Special Issue. 2) GREEN and WorldScan: OECD (1998) Economic Modelling of Climate Change. Report of an OECD Workshop. OECD Headquarters, 17-18 September, 1998 (available at <http://www.oecd.org/dev/news/environment/modelling.htm>). 3) POLES: Coherence (1999) "Kyoto protocol and emissions trading: potential cost savings and emission reductions" in Economic Evaluation of Quantitative Objectives for Climate Change (available at <http://europa.eu.int/comm/environment/enveco/studies2.htm>) 4) GEM-E3 World: Capros (1999) GEM-E3 Elite research project. Final report to the European Commission, DG Research.

Notes: As the models report different costs in different years, they have been converted to 1999 euros by GDP deflators of the EU, the US and Japan. For Annex B trading the average of the deflators was used. The average exchange rate in 1999 from was used to convert dollars to euros. This was 1,0653.

The stereotype among (European) policy makers seems to be that the US is thought to have relative cheap abatement options compared to the EU and Japan. Further, this stereotype assumes that Japan would find it much more difficult to fulfil its target than the EU. Basically the stereotype is founded on high (low) the energy efficiency of Japan (the US). Comparing the models in Table 1 reveals that not only are the marginal abatement costs across models very different from one another, but even the ranking

between countries is different. The stereotype rank, i.e. the US having the lowest and Japan the highest marginal abatement costs, prevails only in three models (Poles, EPPA and Oxford). While most models predict the US to have lowest marginal abatement cost, this is not the case in Green, GEM-E3, SGM and MS-MRT models. Finally, quite many models predict Japan to have lower marginal abatement costs than the EU (Worldscan, G-Cubed, AIM and GTEM). As the differences in marginal abatement costs are the reason for emission trade to exist, it is no wonder that the model predictions are quite different among the buyers and sellers of international emission trading.

In all these models the EU has been analysed as a single entity. In reality, the fifteen Member States are all Parties to the Kyoto Protocol. Thus, it would be of interest to see what impact the effect of EU-wide trading would have to the EU countries and compare the internal market equilibrium cost to the marginal abatement costs shown in Table 1.

Böhringer et al. (1999) analysed the effects of emission trading among six EU Member States<sup>2</sup> and found that the compliance costs would be reduced by about 10% if EU countries would trade with one another. A striking feature of the Böhringer et al. results is the fact that the UK was predicted to lose in an EU wide trading regime. Being an oil exporter, the UK would have lost due to the deteriorated terms of trade. However, the counterfactual of this result was that there would not have been any trading among the other EU Member States. The counterfactual could have been that other EU Member States would start trading among themselves, while the UK would opt out. Unfortunately, Böhringer et al. did not investigate this possibility. However, it is likely that if an EU-wide trading scheme existed (regardless of the wish of the UK), it would be more advantageous for the UK to be part of this scheme than to stay outside.

Böhringer (forthcoming) has used a computable general equilibrium analysis model to estimate the effect of intra-industry trading in CO<sub>2</sub> among EU Member States. He found that full emission trading within the EU would reduce compliance costs by almost 40%. He also found that restricting emission trading only to the power supply sector would still reap major benefits, i.e. about 20% reduction in compliance costs. In a general equilibrium framework he was able to analyse the terms-of-trade impact of emission trading.

Most of the emission trading analysis has started from the assumption that countries would be in an internal equilibrium before entering in international emission trading. In other words, the models assume that political decision-making has been perfectly (economically) rational and has had all required information for making the decisions of allocating the emission reduction targets in a national context. An alternative interpretation is that the models have assumed that each country starts international emission trading from a situation where it has traded emissions within its borders. In reality these assumptions do not hold. Thus, international emission trading could be more important than estimated by models, since international trading would correct for domestic policy failures. Furthermore, all models having EU as the single trading partner have implicitly assumed that the EU would have been in an internal equilibrium, i.e. that

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<sup>2</sup> The Member States included in the analysis were Denmark (-25%), France (0%), Germany (-25%), Italy (-7%), Spain (+17%) and the United Kingdom (-10%). The figures in parenthesis are the burden sharing figures used in Böhringer et al simulations. These are not the same numbers than in the Burden Sharing Agreement concluded among the EU Member States in June 1999 (see footnote 9).

it would have implemented an EU-wide emission trading scheme. Thus, all such models have underestimated the potential benefits from emission trading to EU Member States. Such underestimations may partly explain why the interest in international emissions trading has been lukewarm in some EU Member States.

The European Commission adopted a Green Paper on European wide emission trading. In addition, several Member States, notably Denmark and the UK as well as Austria, Finland, France, Germany, Ireland, the Netherlands and Sweden have started to look into the possibilities of using greenhouse gas emission trading as an additional means of reducing their greenhouse gas emissions. The purpose of this study is to analyse the economic effects of an EU-wide emission trading scheme with different alternative scenarios. Some of the scenarios vary the number of participating Member States while others have different sectors participating in the trading regime. In order to compare the results against an alternative reference case a so-called “cheese slicer” scenario was developed to demonstrate the gains from emissions trading in the case of domestic policy failures.

In this paper we assume that all energy related sectors participate in emission trading. It is also assumed conservatively that the contribution from the other greenhouse gases would in aggregate be the same as for CO<sub>2</sub>. In other words, the emission reduction target for CO<sub>2</sub> is assumed to be in 2008-2012 an 8% reduction from the base year 1990. In reality, the emissions from non-CO<sub>2</sub> greenhouse gases are likely to reduce by more than 8% in the baseline projections (Ecofys, forthcoming) thus implying that the target for CO<sub>2</sub> needs to be lower than 8%. However, as data on historic and projected non-CO<sub>2</sub> greenhouse gases are very uncertain we adopted a conservative approach in this paper assuming -8% target for CO<sub>2</sub> for the EU.

This study is structured as follows: First we describe the model as well as the methodology of analysing the economic effects of reducing greenhouse gas emissions through different policies. Then we present and discuss the results of different policy simulations and also analyse the effects of a policy failure by constructing an alternative reference case called the “cheese slicer”. We conclude by a discussion of the policy relevance of the results and highlight areas for further work.

## 2. METHODOLOGY

PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in European Union (EU) Member States<sup>3</sup>. The model determines the equilibrium by finding the prices of each energy form such that the quantity producers find best to supply match the quantity consumers wish to use. The equilibrium is static (within each time period) but repeated in a time-forward path, under dynamic relationships. The model is solved in five-year intervals starting from 2000.

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<sup>3</sup> PRIMES is a partial equilibrium model for the European Union energy system developed and maintained at the National Technical University of Athens, E3M-Laboratory led by Prof. Capros. The most recent version of the model covers all EU member-states except Luxemburg, uses Eurostat as main data source and is updated with 1995 being the base year. PRIMES is a result of collaborative research under a series of projects supported by the programme Joule of directorate General for Research of the European Commission.

As an energy system model, the calculations in PRIMES reflect a partial equilibrium solution. In other words the rest of the economy is considered unchanged under the imposition of alternative emission reduction schemes. At a general equilibrium level, system adjustments, other than those occurring in the energy system, might induce further changes in welfare.

The different emission reduction schemes are applied as global (i.e. at the national level) or sectoral constraints in solving the model. The mechanism through which the CO<sub>2</sub> constraint is attained involves the attribution of an appropriate economic value to the reduction of CO<sub>2</sub> emissions. Equivalently, the ability to emit CO<sub>2</sub> implies a scarcity value and is allocated an implicit price. There are corresponding changes in the relative prices, reflecting the CO<sub>2</sub> emissions that each commodity or activity involves, which economic agents, i.e. producers and consumers of energy, face. This, of course, leads to adjustments in the behaviour of agents. This induces a general trend to shift away from activities that cause CO<sub>2</sub> emissions.

Given the technical features and design of the model, the imposition of global or sectoral emissions constraints is equivalent to the inclusion of a variable, which reflects the economic costs imposed by this constraint.<sup>4</sup> This shadow variable is the marginal abatement cost that is associated with the emission constraint and represents the economic cost of avoiding the last (marginal) unit of carbon that is required by the constraint.<sup>5</sup>

An alternative way to think about the link between an emission reduction target and associated marginal abatement cost is to assume the emission target is achieved through the creation of a hypothetical market for emission permits in a regime with auctioning of the initial allocation, i.e. in such a manner that producers and consumers of energy buy the right to emit CO<sub>2</sub>. Evidently, acquiring such permits being 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 energy system responds to the imposition of a CO<sub>2</sub> constraint by changes in relative energy prices. These changes reflect the carbon content of each fuel and provide incentives to the economic agents to reduce their CO<sub>2</sub> "consumption". Consequently, the resulting changes in relative prices would effectively reflect the CO<sub>2</sub> intensity of each fuel. In such a market, the emission target is reflected in the number of permits that are issued. The marginal abatement cost is equivalent to the price of permits that the market would establish for any given emission reduction target. Both the permit price and marginal abatement cost reflects the degree of ease or difficulty faced in reaching the target.

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<sup>4</sup> 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 or sectoral 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.

<sup>5</sup> One ton of CO<sub>2</sub> emitted contains 12/44 tons of carbon. Therefore, if the marginal abatement cost is Euro 1 per ton of CO<sub>2</sub> then the corresponding value per ton of carbon amounts to Euro 3.67 (i.e. 44/12).

The analysis starts from a baseline scenario, which takes into account current policies and trends without including specific (additional) effort to reduce CO<sub>2</sub> emissions. Starting from this baseline, the model is run for each scenario to determine the least cost solution, corresponding to the level of CO<sub>2</sub> emissions in 2010, which is implied by the emission reduction constraints. These scenarios are defined to reflect and examine alternative emission trading schemes, varying the set of sectors and Member States that participate in the scheme. Non-participating sectors face individual emission reduction targets and consequently individual marginal abatement costs, which can and most likely will differ from those of sectors participating in the trading scheme. The model determines the allocation of efforts, necessary to meet the emission constraint, to sectors and Member States participating in the trading bubble.

The model distinguishes between energy demand and supply sectors. Emissions are accounted for in a sector, only if directly emitted from fossil fuel combustion in the sector. Hence the analysed trading schemes can be classified as “downstream”. Emissions indirectly incorporated in electricity and steam use (including district heating) are considered in the power and heat generation sectors. Consequently the emission reduction target for sectors may be interdependent, since for example a demand sector (e.g., a cement kiln) shifting the energy mix in favour of electricity might induce higher emissions in a supply sector (e.g., a power plant generating electricity). A systems analysis model, such as PRIMES, ensures consistent representation of these interdependencies and a consistent calculation of emission reduction efforts and marginal costs.

The analysis draws conclusions by considering the differences between the results of emissions constrained cases and the baseline and reference scenarios. These differences cover 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 model provides simultaneous estimations of the marginal abatement and energy system costs induced by these changes, by sector and country. Following a least cost methodology, the marginal abatement 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 assessing the total abatement cost of reaching any given target.

The economic interpretation of the costs for the economy arising from these marginal costs is complex. The imposition of a CO<sub>2</sub> constraint induces an external cost to CO<sub>2</sub> consuming agents compared to baseline conditions. However, from the perspective of societal welfare the constraint aims to internalise the external cost of emitting CO<sub>2</sub>, so to improve the allocative efficiency of the overall economy. Under such a constraint, the system bears a loss of welfare (compared to baseline, ignoring the economic benefits of averted climate change), for each ton of CO<sub>2</sub> avoided, equal to the marginal abatement cost corresponding to that ton. Therefore, total abatement cost implied by an emission constraint is equal to the area (the integral) below the marginal abatement cost curve.<sup>6</sup>

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<sup>6</sup> Successive runs of the PRIMES model, using increasing emission reduction targets, were made so as to obtain a marginal abatement cost curve for the European energy system by member state. The latter was obtained by mapping the resulting marginal abatement costs against the reduction target, in comparison to the baseline scenario.

This estimation comes from partial equilibrium analysis since PRIMES covers only the energy demand and supply system, the rest of the economy being considered unchanged under the imposition of emission reduction targets. Consequently the above estimation does not include any macro-economic indirect effects resulting from the allocation of larger funds in energy demand and supply to obtain higher efficiency and less carbon intensity. Furthermore, any deviation from a least cost allocation, which as already described is assumed among the different demand and supply sectors, for example because of policy implementation failure, could entail higher compliance costs. In order to investigate these issues, a general equilibrium framework would have to be used.

### 3. THE RESULTS

In this section, we describe first how the baseline and the reference case have been constructed. Then we report the results of a series of PRIMES model runs.

Each model run case involves a different emission trading scheme, which is defined by considering different sets of sectors and countries participating in trading of emission permits in order to reach the collective emission target. Obviously a large number of combinations is possible. The analysis focuses on three different groupings of sectors, defined as follows:

- Sectoral Group S1: Power and steam generation including refineries, steam generation from industrial boilers (energy supply sectors) and district heating.
- Sectoral Group S2: Energy intensive industries including iron and steel, non-ferrous, building materials (cement, glass etc.), chemicals and paper and pulp.
- Sectoral Group S3: Rest of energy demand sectors including other industrial sectors, households, tertiary and transports.

The groupings of countries were defined as follows.

- Country Group EU3: Belgium, Germany and the Netherlands
- Country Group EU7: Belgium, Denmark, Finland, France, Netherlands, Sweden and the UK
- Country group EU8: Group EU7 and Germany
- Country group EU14: All EU Member States without trading with Annex B countries

From a policy perspective it is challenging to establish mechanisms that would lead to a least-cost allocation of emission reduction efforts across sectors and Member States. The scope of the analysis is to examine alternative emission trading regimes both in terms of sectors and Member States and to evaluate their cost effectiveness in achieving the EU Kyoto commitment.

In order to test how important the assumption that EU-wide emission trading would start from a situation where all Member States would be in an internal equilibrium, an alternative reference (“cheese slicer”) was constructed. Comparing the “cheese slicer” case with the reference case provides information on the costs occurring from a non-efficient allocation of targets within a Member State. Furthermore comparing the

reference case with policy cases involving additional emission trading among sectors across countries provides information about the costs due to non-efficient allocation of emission reduction effort among Member States. Whenever a trading scheme is expanded by including additional sectors and/or countries, the total abatement costs are expected to fall, since this allows for higher flexibility in choosing abatement options and hence more efficiency. If not, the new participants would have no motivation to join.

### 3.1. The Baseline Case

The **baseline case** does not involve specific emission reduction targets and serves as the counterfactual. The baseline case as defined in the context of this study is the one developed with PRIMES in the so-called Shared Analysis exercise and published in November 1999 (Capros et al).

This baseline case was conceived as the most likely development of the EU energy system in the future. It incorporated and extrapolated current trends and the effects of all policies in place and in the pipeline. These include dynamic trends of technological progress, effects from restructuring of markets as a consequence of liberalisation of electricity and steam, and gas markets in Europe and issues related to sectoral patterns of economic growth in the EU. No additional policies and measures aiming at further reducing CO<sub>2</sub> emissions so as to comply with the Kyoto commitments have been included.

The only difference between the Shared Analysis baseline and the baseline case used in this study concerns the agreement reached between the European Commission and initially the European (ACEA), but later also Japanese (JAMA) and Korean (KAMA), car automobile industry under the terms of which the industry is committed to reduce the average CO<sub>2</sub> emission output for all new cars to 140 g/km by 2008<sup>7</sup>. This so-called ACEA agreement compares with a current level of emissions of about 186g/km. An intermediate target of 170g/km was set for 2003. The industry has also undertaken to make available to the market cars that emit 120 g/km by 2000 and to undertake further improvements beyond 2008 (an initial target for the average of new cars was set at 120g/km for 2012). As the costs of implementing this programme are not disclosed, it is assumed that the agreement induces zero supplementary cost. In other words, the agreement is implicitly assumed to boost technological progress.

Despite some saturation trends for specific energy uses in the EU there is no complete de-linking between energy use and economic growth under baseline conditions. In the baseline, energy consumption increases by 15.6 % from 1990 to 2010, while the Gross Domestic Product (GDP) is forecasted to grow by 54.5 % over the period.

The impact of the introduction of the ACEA agreement in the baseline scenario is to reduce energy demand for liquid fuels by 28 Mtoe in 2010 compared to the Shared Analysis baseline. As a consequence CO<sub>2</sub> emissions increase by only 4.1 % in 2010 compared to 6.7 % in the Shared Analysis baseline. However, the EU does not achieve the Kyoto commitment. Table 2 indicates the projected evolution of CO<sub>2</sub> emissions by Member State.

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<sup>7</sup> For details, see [http://europa.eu.int/comm/environment/co2/co2\\_agreements.htm](http://europa.eu.int/comm/environment/co2/co2_agreements.htm).

**Table 2: Baseline case - CO<sub>2</sub> emissions from energy<sup>8</sup> by Member State and sector in the EU**

	CO <sub>2</sub> emissions (Mt of CO <sub>2</sub> )			Decomposition of CO <sub>2</sub> emissions in 2010 (Mt of CO <sub>2</sub> )			Difference from Shared Analysis Baseline in 2010	
	1990	2010	% change	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	Mt of CO <sub>2</sub>	% change
AU	55.0	53.0	-3.6	13.4	8.1	31.4	-1.7	-3.2
BE	104.8	121.7	16.2	30.1	20.8	70.9	-2.1	-1.7
DK	52.7	53.5	1.5	27.9	1.7	23.9	-1.0	-1.9
FI	51.3	72.4	41.0	40.8	8.0	23.6	-1.1	-1.6
FR	352.4	376.2	6.8	68.3	30.5	277.5	-12.7	-3.3
GE	951.6	800.3	-15.9	335.8	59.6	404.9	-20.4	-2.5
GR	70.9	106.1	49.6	53.6	9.9	42.6	-1.4	-1.3
IR	30.1	41.9	39.3	17.4	2.3	22.1	-0.8	-1.9
IT	388.0	418.0	7.7	162.5	36.6	218.9	-11.2	-2.6
NL	153.0	201.4	31.6	77.5	12.9	111.0	-3.7	-1.8
PO	39.1	64.9	66.2	30.9	6.6	27.4	-1.5	-2.2
SP	201.9	266.4	32.0	101.4	29.1	135.9	-6.5	-2.4
SV	50.5	60.2	19.2	16.5	8.6	35.1	-2.5	-4.0
UK	566.9	557.3	-1.7	205.8	33.3	318.2	-13.6	-2.4
EU14	3068.1	3193.3	4.1	1182.0	267.9	1743.4	-80.2	-2.5

Source: PRIMES Notes: AU: Austria, BE: Belgium, DK: Denmark, FI: Finland, FR: France, GE: Germany, GR: Greece, IR: Ireland, IT: Italy, NL: the Netherlands, PO: Portugal, SP: Spain, SV: Sweden and UK: the United Kingdom. PRIMES does not include Luxembourg.

S1: Power and steam generation including refineries, steam generation from industrial boilers (energy supply sectors) and district heating.

S2: Energy intensive industries including iron and steel, non-ferrous, building materials (cement, glass etc.), chemicals and paper and pulp.

S3: Rest of energy demand sectors including other industrial sectors, households, tertiary and transports

Large differences exist in the trends of CO<sub>2</sub> emissions growth among EU Member States. Only three Member States are projected to manage to reduce emissions below 1990 namely, Austria, Germany and United Kingdom. In Denmark a near stabilisation of CO<sub>2</sub> emissions in 2010 to their 1990 level is expected. All other Member States expect to see increases in emissions between 1990 and 2010 varying from 6.8 % in France to more than 65 % in Portugal. In six Member States, CO<sub>2</sub> emissions are expected to increase significantly, i.e. by more than 30 % between 1990 and 2010. These huge divergences between EU countries reflect a large number of factors including economic growth and changing market structures.

The effect of the incorporation of the ACEA agreement is also not uniform across the EU Member States. Emission reductions in comparison to Shared Analysis baseline range from 1.3 % in Greece to 4 % in Sweden reflecting the different structural characteristics of the transport sector across Member States.

### 3.2. The Reference Case

In the **reference case** the Kyoto commitment, as distributed in the Burden Sharing agreement<sup>9</sup>, is implemented separately by each of the EU Member States through actions

<sup>8</sup> Excluding emissions from international bunker fuels (from ships) but including emissions from both domestic and international air transport. Emission factors, definitions and the basic energy balances used are those published by Eurostat.

within each Member State's territory. More specifically, the reference case involves a reduction of energy-related CO<sub>2</sub> emissions by 8 % (in 2010 as compared to 1990) in the EU. Each Member State is assumed to undertake measure to reduce CO<sub>2</sub> emissions according to the target defined in the Burden Sharing Agreement (e.g. Denmark reduces CO<sub>2</sub> emissions to 21 % below 1990).

This reference case implies that no trading of emission permits is undertaken across national borders in the EU. The CO<sub>2</sub> emission reduction target is implemented at the Member State level and allocated to the sectors (consumers and producers of energy) at least cost. In other words, the marginal abatement cost is equalised across the sectors in each Member State, a situation that could be interpreted as each and every country having implemented a domestic emission trading regime, but no exchange of permits allowed across Member State borders.

It is expected that the reference case will lead to higher total abatement costs as compared to cases involving emission trading in some sectors, since the latter results by definition in a more efficient allocation by allowing higher degree of freedom. This reference case is an idealised situation, desirable but not necessarily achievable in a real-world policy setting. If the sectoral allocation of the emission reduction target is centrally decided within each Member State, a least cost allocation is unlikely to arise (e.g., because of information constraints and asymmetries).

Table 3 summarises the evolution of CO<sub>2</sub> emissions in the EU Member States under the assumptions of the reference case, including the reduction achieved by each Member State as well as the corresponding marginal abatement cost. The table shows that the costs differ substantially across Member States when each one has to reduce emissions unilaterally according to the Burden Sharing Agreement. The average marginal abatement cost at the EU level is of €<sub>9</sub> 54.3/tCO<sub>2</sub> avoided. This corresponds to the EU-wide permit price of MS-MRT, AIM and GEM E3 models while it is higher than SGM, Poles and Worldscan models (and lower than the rest) (Table 1). In the PRIMES reference case, Germany would achieve its target with a cost of €<sub>9</sub>13.5/tCO<sub>2</sub> at the margin while the corresponding figure for Netherlands is €<sub>9</sub>150.7/tCO<sub>2</sub>. In other words, without EU-wide emission trading, it is likely that, Belgium, Finland and in particular the Netherlands would find it relatively expensive to reach the emission reductions according to the Burden Sharing Agreement. On the other hand, France and Germany are likely to find it easier to reach the reduction targets.

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<sup>9</sup> In June 1999, the EU Member States agreed to meet the Kyoto reduction target of 8% given in Annex B of the Kyoto Protocol on the basis of a Burden Sharing Agreement. The Burden Sharing Agreement has been applied separately to CO<sub>2</sub> emissions and not to the whole range of GHG. By implying the emission reduction targets as in the Burden Sharing agreement on 1990 CO<sub>2</sub> emissions the resulting emission reduction from 1990 levels for the EU would be 8.7%. In that sense, a correction factor has been applied on the emission reduction targets imposed by the Burden Sharing agreement so that the Kyoto protocol emission reduction target (8% from 1990 levels) to be achieved as regards CO<sub>2</sub> emissions. The adjusted targets are: Austria -13.0%; Belgium -7,5%; Denmark -21.0%; Finland 0.0%; France 0.0%; Germany -21.0%; Greece 25.0%; Ireland 13.0%; Italy -6.5%; Luxembourg -28.0%; Netherlands -6.0%; Portugal 27.0%; Spain 15.0%; Sweden 4.0%; and the UK -12.5%. The results obtained are within tolerance limits for a numerical model. For example, in the case of Denmark the emission reduction computed by the model amounts to 20.4% instead of 21.0% as in the Burden Sharing Agreement. Any differences are marginal deviations.

**Table 3: The reference emission reduction case among sectors in the EU Member States**

	CO <sub>2</sub> emissions (Mt of CO <sub>2</sub> )			Burden Sharing Agreement	Change from Baseline	CO <sub>2</sub> emissions reduction by sector in 2010 (% change from Baseline)			Marginal abatement cost	Compliance costs
	1990	2010	% change	% change	Mt CO <sub>2</sub>	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	Eur'99/tCO <sub>2</sub>	Mio Eur'99
AU	55.0	48.3	-12.1	-12.3	-4.7	-10.8	-9.7	-7.8	28.4	47.9
BE	104.8	97.5	-6.9	-6.8	-24.1	-25.8	-25.6	-15.6	89.3	962.7
DK	52.7	41.7	-20.8	-20.4	-11.8	-34.8	-6.0	-8.2	47.9	258.0
FI	51.3	51.7	0.7	0.8	-20.7	-39.7	-14.7	-14.1	63.5	582.5
FR	352.4	354.8	0.7	0.8	-21.4	-4.6	-9.6	-5.5	20.6	251.6
GE	951.6	757.5	-20.4	-20.4	-42.7	-7.8	-4.3	-3.5	13.5	300.6
GR	70.9	89.3	25.9	25.9	-16.8	-24.8	-4.3	-7.2	39.0	450.3
IR	30.1	34.3	14.1	13.9	-7.6	-29.3	-2.9	-10.9	53.5	175.9
IT	388.0	365.5	-5.8	-5.8	-52.5	-24.5	-7.3	-4.6	33.3	867.9
NL	153.0	144.9	-5.3	-5.3	-56.6	-32.1	-38.5	-24.0	150.7	3466.4
PO	39.1	49.7	27.2	28.0	-15.2	-43.0	-6.9	-5.5	41.1	338.5
SP	201.9	233.3	15.6	15.9	-33.1	-23.9	-5.5	-5.3	27.7	467.4
SV	50.5	52.9	4.7	4.8	-7.3	-17.6	-14.4	-9.0	39.7	130.7
UK	566.9	499.9	-11.8	-11.8	-57.4	-13.2	-11.4	-8.3	31.9	725.5
EU14	3068.1	2821.4	-8.0	-8.0	-372.0	-18.2	-10.5	-7.4	54.3	9026.0

Source: PRIMES Notes: see table 2 for a description of sectors and countries.

Energy supply sectors are estimated to be the most responsive to the implementation of the Kyoto targets, followed by energy intensive industries, while other demand sectors seem rather insensitive as regards emissions reduction. However, there are significant differences across EU Member States reflecting, to a large extent, the different dynamics in each Member State's energy system, the existing structure of energy production and the prospects of industrial restructuring. The CO<sub>2</sub> intensity of power generation plays a key role in the ease with which a country can adjust to the imposition of a CO<sub>2</sub> constraint. In addition, the different effort required in the Burden Sharing Agreement results in significant distortions as regards the contribution of the different sectors. As the low cost possibilities in energy supply sectors get exhausted, the achievement of targets call upon demand-side actions. For example, in the Netherlands and Belgium, in which relatively high effort is required to reach the target of the Burden Sharing Agreement, the reduction achieved in energy supply sectors is less or equally significant to that of energy intensive industries.

The compliance cost<sup>10</sup> of reaching the emission reduction targets, is estimated to be in 2010 M€<sub>9</sub> 9026 per year in the EU. This is 0.075% of the projected annual GDP in the EU in 2010. Within each Member State the analysis assumes that a least-cost allocation of the emission reduction target to the various energy demand and supply sectors is possible. Any deviation from a least cost allocation, for example because of policy implementation failure or the lack of a central authority to possess sufficient information to fix such an allocation, could entail higher total abatement costs.

<sup>10</sup> The compliance cost is measured as the area below the marginal abatement cost curve for a given level of emission reduction. This curve is considered as if it represented a cost-supply curve for the energy demand/supply sector for a service providing emission reduction. This evaluation of welfare or compliance cost is under partial equilibrium assumptions, following the coverage of the PRIMES model. In this sense the compliance cost is the welfare cost. A similar evaluation under general equilibrium would lead to different numerical values.

### 3.3. The economic effects of international and EU-wide emission trading to EU Member States

Taking the most recent estimate of an international emission trading price of €<sub>9</sub> 17.7/tCO<sub>2</sub> from the POLES model<sup>11</sup>, the PRIMES model estimates that international emission trading would be the most cost effective means to reach the Kyoto target of -8%. Total compliance costs in 2010 under Annex B full trading is estimated to be 48.6% or M€<sub>9</sub> 4390 lower compared to the reference case (compare Tables 4 and 3). However, in this case EU Member States (with the exception of Austria and Germany) would achieve their Burden Sharing target by purchasing emission permits from other Annex B Parties for 150 MtCO<sub>2</sub> emissions. This corresponds to 4.9% of 1990 CO<sub>2</sub> emissions in the EU. Germany and Austria are projected to become also sellers of emission permits for 6.6 and 0.3 Mt CO<sub>2</sub>, respectively.

**Table 4: Impact of international (Annex B) emission trading on EU Member States**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	-0.3	-1.0	0.3	0.5	-0.5	0.3	17.7	17.7	-37.5	44.0	-8.1
BE	17.4	5.5	3.5	8.4	17.8	-17.4	17.7	17.7	-80.2	363.7	-62.2
DK	7.1	5.7	0.1	1.3	16.9	-7.1	17.7	17.7	-63.0	168.1	-34.8
FI	13.5	10.4	0.8	2.2	26.1	-13.5	17.7	17.7	-72.1	319.6	-45.1
FR	3.6	1.3	0.3	2.0	1.0	-3.6	17.7	17.7	-13.8	246.5	-2.0
GE	-6.6	-2.0	-0.7	-3.9	-0.9	6.6	17.7	17.7	31.6	300.2	-0.1
GR	3.4	1.6	0.2	1.6	3.9	-3.4	17.7	17.7	-54.5	190.4	-57.7
IR	4.3	2.8	0.0	1.5	12.7	-4.3	17.7	17.7	-66.9	107.1	-39.1
IT	21.3	15.8	0.8	4.7	5.8	-21.3	17.7	17.7	-46.8	709.1	-18.3
NL	42.1	15.8	4.0	22.4	29.1	-42.1	17.7	17.7	-88.2	860.1	-75.2
PO	10.2	9.1	0.2	0.9	20.6	-10.2	17.7	17.7	-56.9	217.0	-35.9
SP	12.6	9.7	0.4	2.5	5.4	-12.6	17.7	17.7	-35.9	407.7	-12.8
SV	3.4	1.1	0.6	1.7	6.5	-3.4	17.7	17.7	-55.4	92.6	-29.2
UK	18.1	4.9	1.6	11.7	3.6	-18.1	17.7	17.7	-44.4	612.5	-15.6
EU14	150.4	80.8	12.1	57.5	5.3	-150.4		17.7	-67.3	4638.5	-48.6

Source: PRIMES Notes: see table 2 for a description of sectors and countries.

If trading is restricted only to EU Member States, benefits from trading compared to the reference case are reduced to M€<sub>9</sub> 3070 (or 34 %) (compare Tables 5 and 3). In other words the additional benefits of Annex B trading compared to EU-wide trading reach up to M€<sub>9</sub> 1320. In the case of full intra-EU trading, Austria, Germany, France, Spain and the UK are projected to become net sellers of emission permits at a price of €<sub>9</sub> 32.6/tCO<sub>2</sub>. The other Member States are estimated to buy emission permits. In 2010, emission permits for 70.9 Mt CO<sub>2</sub>, i.e. 2.5 % of total CO<sub>2</sub> permits in circulation, are projected to be exchanged across EU Member States.

<sup>11</sup> Based on POLES model calculations, co-ordinated with the model runs of PRIMES model as regards Kyoto compliance under a regime of emission permits trading between Annex B countries, permit prices, leading Annex B to meet the Kyoto targets, have been found to be uniform at €<sub>9</sub> 17.7/tCO<sub>2</sub>.

**Table 5: Full trading for EU**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	-0.9	-0.5	-0.1	-0.3	-1.9	0.9	32.6	32.6	15.0	45.7	-4.5
BE	13.7	4.2	2.5	7.0	14.0	-13.7	32.6	32.6	-63.5	610.7	-36.6
DK	3.2	2.4	0.0	0.7	7.6	-3.2	32.6	32.6	-31.9	239.8	-7.0
FI	8.8	6.8	0.5	1.5	17.1	-8.8	32.6	32.6	-48.6	488.4	-16.2
FR	-14.4	-6.2	-0.7	-7.6	-4.1	14.4	32.6	32.6	58.6	198.3	-21.2
GE	-51.2	-33.8	-1.9	-15.5	-6.8	51.2	32.6	32.6	142.1	3.9	-98.7
GR	1.1	0.5	0.1	0.6	1.3	-1.1	32.6	32.6	-16.4	229.0	-49.2
IR	2.3	1.4	0.0	0.9	6.7	-2.3	32.6	32.6	-39.1	156.6	-11.0
IT	0.8	0.6	0.0	0.2	0.2	-0.8	32.6	32.6	-2.1	865.2	-0.3
NL	36.5	13.2	3.4	19.9	25.2	-36.5	32.6	32.6	-78.4	1477.0	-57.4
PO	3.4	2.9	0.1	0.4	6.8	-3.4	32.6	32.6	-20.7	332.2	-1.9
SP	-3.1	-1.7	-0.2	-1.2	-1.3	3.1	32.6	32.6	17.9	464.4	-0.6
SV	1.1	0.3	0.2	0.6	2.1	-1.1	32.6	32.6	-17.9	129.5	-0.9
UK	-1.3	-0.5	-0.1	-0.7	-0.3	1.3	32.6	32.6	2.2	716.7	-1.2
EU14	0.0	-10.4	3.9	6.5	0.0	0.0		32.6	-39.9	5957.4	-34.0

Some very interesting findings emerge in the case of a partial trading scheme covering only Belgium, Germany and the Netherlands, while all others operate on the basis of the Burden Sharing Agreement (compare Tables 6 and 3). The cost savings in comparison to the reference case are 29% or M€<sub>9</sub> 2600.

**Table 6: Effects of emission trading among all sectors in Belgium, Germany and the Netherlands**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	13.5	4.1	2.5	6.9	13.8	-13.5	32.6	32.6	-63.5	605.8	-37.1
DK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.9	0.0	258.0	0.0
FI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.5	0.0	582.5	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.6	0.0	251.6	0.0
GE	-49.5	-32.7	-1.8	-15.0	-6.5	49.5	32.6	32.6	142.1	59.7	-80.1
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	36.0	13.0	3.4	19.6	24.8	-36.0	32.6	32.6	-78.4	1458.9	-57.9
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.7	0.0	130.7	0.0
UK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.9	0.0	725.5	0.0
EU14	0.0	-15.5	4.0	11.5	0.0	0.0		34.8	-35.9	6420.7	-28.9

Source: PRIMES Notes: see table 2 for a description of sectors and countries

The Member States in the trading regime – Germany being the net seller of permits, while Belgium and the Netherlands being net buyers – would face a permit price that is identical to that of a full intra-EU trading regime (€<sub>9</sub> 32.6/tCO<sub>2</sub>). The corresponding average marginal abatement cost at the EU level increases by about 6.7% at €<sub>9</sub> 34.8/tCO<sub>2</sub> avoided. In other words, the expected outcome of this partial trading scheme does not deviate substantially from the one of the optimal trading scheme (deficits of M€<sub>9</sub> 463 in terms of compliance costs compared to intra-EU trading). In addition such a partial scheme provides an incentive for other EU Member States to join (as they see the gains in the form of lower permit prices in the scheme), instead of complying with their

commitments individually. Therefore a stepwise introduction is feasible, provided that the trading regime starts with those participants (sectors and Member States) gaining the most from participation.

For example, a less successful partial trading regime is the one set for EU7 for which the analysis identifies higher deviation (compared to the Belgium, Germany and Netherlands trading scheme) from full intra-EU trading regime both in terms of permit price and of total abatement costs. (See annexes gives details also of other scenario runs).

To further investigate the gradual introduction of a trading scheme the analysis considers the impacts of introducing an emissions trading regime only for energy supply sectors (or for energy supply sectors and energy intensive industries) against the results of the full intra-EU trading.

If starting from the EU Burden Sharing Agreement it is more efficient to commence with a scheme covering energy supply sectors (power and steam generators). It emerges that the permit price expected to result from this partial trading regime across energy supply sectors across Member States would be equivalent (€<sub>99</sub> 32.3/tCO<sub>2</sub>) to the permit price prevailing in a full intra-EU trading system (compare Tables 7 and 3). The corresponding average marginal abatement cost at the EU level would be €<sub>99</sub> 45.3/tCO<sub>2</sub> (about 40% higher than that of full intra-EU trading).

**Table 7: Effects of emission trading energy supply sectors in all EU Member States**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	-0.5	-0.5	0.0	0.0	-1.0	0.5	32.3	29.8	5.2	45.0	-6.1
BE	4.5	5.0	-0.4	-0.1	4.7	-4.5	32.3	81.4	-8.9	737.2	-23.4
DK	2.1	2.3	0.0	-0.2	5.1	-2.1	32.3	35.9	-25.1	235.1	-8.9
FI	6.1	6.2	-0.1	-0.1	11.7	-6.1	32.3	42.2	-33.5	486.4	-16.5
FR	-3.1	-3.3	0.0	0.2	-0.9	3.1	32.3	23.6	15.0	220.4	-12.4
GE	-22.3	-25.8	1.0	2.5	-2.9	22.3	32.3	28.5	111.4	53.0	-82.4
GR	0.4	0.4	0.0	0.0	0.4	-0.4	32.3	33.7	-13.6	222.6	-50.6
IR	1.2	1.4	0.0	-0.1	3.6	-1.2	32.3	41.0	-23.4	156.4	-11.1
IT	0.9	0.9	0.0	0.0	0.2	-0.9	32.3	32.5	-2.4	865.2	-0.3
NL	9.8	12.4	-0.7	-1.9	6.8	-9.8	32.3	119.2	-20.9	2494.1	-28.0
PO	2.7	2.7	0.0	0.0	5.4	-2.7	32.3	33.7	-18.1	324.7	-4.1
SP	-1.6	-1.8	0.1	0.1	-0.7	1.6	32.3	31.1	12.5	466.9	-0.1
SV	0.3	0.3	0.0	0.0	0.5	-0.3	32.3	36.9	-7.0	128.1	-2.0
UK	-0.5	-0.6	0.0	0.0	-0.1	0.5	32.3	32.1	0.5	723.0	-0.3
EU14	0.0	-0.4	-0.1	0.5	0.0	0.0		45.3	-16.6	7158.2	-20.7

Source: PRIMES Notes: see table 2 for a description of sectors and countries

The power and steam generators in Austria, France, Germany, Spain and the UK would become net sellers of emission permits, while the generators in all other Member States would be net buyers. In total, they trade emission permits for 28 Mt CO<sub>2</sub> in 2010. This amounts to about 1% of all permits in circulation.

Companies in other sectors not being involved from the outset would then have an interest in joining the trading scheme, since they would gain from permit prices, which are projected to be lower than specific taxes or levies that they would need to face to reach their target.

The incorporation of energy intensive industries in the above-defined trading regime has positive but rather small impacts in terms of compliance costs (24% or M€<sub>99</sub> 2163 from reference case and an additional gain of M€<sub>99</sub> 295 for energy supply sectors) (compare

Tables 8 and 3). The average marginal abatement cost at the EU level is €<sub>99</sub> 43.3/tCO<sub>2</sub> or 33% higher than under full intra-EU trading. However, the permit price for trading across energy supply sectors and energy intensive industries increases to €<sub>99</sub> 33.3/tCO<sub>2</sub> (+2.2% from intra-EU trading level, +6.8% from energy supply sectors trading level). In this case the UK would become also a net buyer of emission permits. The volume of emission permits exchanged in 2010 between energy supply sectors and energy intensive industries amounts to 41.9 Mt CO<sub>2</sub> or about 1.5% of permits in circulation.

The above findings, i.e. a stepwise approach appears practicable and attractive in terms of definition of countries and sectors to participate in a first partial trading scheme so as to provide incentives to non participants to join, are further confirmed by examining a partial trading regime for energy supply sectors of Belgium, Germany and the Netherlands. In this case the cost savings would be limited to 14.2% or M€<sub>99</sub> 1280 from the reference case. The average marginal abatement cost at the EU level is €<sub>99</sub> 47.2/tCO<sub>2</sub> or 44.5 % higher than in the case of intra-EU trading while the price of emission permits for the trading club is €<sub>99</sub> 31.2/tCO<sub>2</sub>. The energy supply sector of Germany would be the seller of emission permits (17.3 Mt CO<sub>2</sub>), while energy supply sectors of Belgium and the Netherlands would be buyers. In view of the significantly lower permit price formulated in the trading scheme compared to the average marginal abatement cost, other sectors inside the same region and in other EU Member States would see that it would be beneficial for them to participate in the trading regime.

**Table 8: Emission trading among energy supply and energy intensive sectors in all EU Member States**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	-0.7	-0.6	-0.1	0.0	-1.5	0.7	33.3	31.1	9.5	42.3	-11.6
BE	7.0	4.6	2.5	0.0	7.2	-7.0	33.3	67.6	-24.3	742.6	-22.9
DK	2.4	2.6	0.0	-0.2	5.9	-2.4	33.3	36.5	-23.8	251.9	-2.4
FI	7.3	6.9	0.5	-0.1	14.0	-7.3	33.3	40.4	-36.3	521.4	-10.5
FR	-3.0	11.6	2.4	-17.1	-0.9	3.0	33.3	26.7	29.6	130.1	-48.3
GE	-37.5	-42.6	-1.6	6.7	-5.0	37.5	33.3	31.6	134.8	-13.9	-104.6
GR	1.3	0.5	0.0	0.7	1.4	-1.3	33.3	34.2	-12.2	238.7	-47.0
IR	1.7	1.6	0.0	0.1	4.9	-1.7	33.3	41.0	-23.4	166.6	-5.3
IT	1.1	0.0	0.0	1.1	0.3	-1.1	33.3	33.3	0.0	836.9	-3.6
NL	15.4	13.0	3.4	-1.0	10.7	-15.4	33.3	107.8	-28.5	2318.3	-33.1
PO	2.4	2.3	0.0	0.0	4.8	-2.4	33.3	34.3	-16.7	324.9	-4.0
SP	-0.6	-6.5	-0.4	6.3	-0.3	0.6	33.3	32.5	17.4	455.1	-2.6
SV	0.2	0.1	0.1	0.0	0.3	-0.2	33.3	36.2	-8.8	123.0	-5.9
UK	3.1	-0.7	-0.1	3.9	0.6	-3.1	33.3	32.7	2.6	725.5	0.0
EU14	0.0	-7.2	6.8	0.5	0.0	0.0		43.3	-20.2	6863.4	-24.0

Source: PRIMES Notes: see table 2 for a description of sectors and countries

### 3.4. Additional benefit of emissions trading: What if the countries do not start from an equilibrium?

The results attained so far are probably underestimating the potential impact of emission trading because of the reference case assumption that Member States reduce emissions within their territory at least cost (equal marginal abatement cost across all energy suppliers and consumers), an assumption not likely to hold in reality.

To relax this assumption and illustrate the importance of a least cost allocation within Member States, an **alternative reference case** has been defined. The underlying assumption is that every Member State applies to each individual sector uniformly the

emission reduction target as given by the Burden Sharing Agreement (e.g. the every sector in Denmark has to achieve the 21 % reduction in isolation). This Member State level allocation is evidently less efficient than a least-cost one, but has the advantage to be defined by a simple “democratic” rule since all sectors have the same reduction target in percentage terms, irrespectively of the sector’s reduction options and abatement costs. This is of course a sort of Solomonic decision and the corresponding model run case is labelled **“cheese-slicer” case**<sup>12</sup>. Such an emission reduction case is expected to be the “worst case” relative to the magnitude of the total abatement costs.<sup>13</sup>

Although seemingly simple, the exact definition of the sectoral targets under the “cheese-slicer” case is more complex, because of the interdependencies: e.g. demand and supply of electricity are in different but interconnected sectors. In addition, because of economic restructuring within a sector, this may reach dynamically (e.g., in 2010) and “spontaneously” (i.e. under baseline conditions) an emission level lower than the emission reduction target for the sector, relative to the emission level of 1990. For such a case it is assumed that the sector has no emission reduction target on top of the baseline and the other sectors collectively face a lower emission reduction target.

**Table 9: The “Cheese Slicer” Case**

	CO <sub>2</sub> emissions (in Mt)			Burden Sharing Agreement	Change from Baseline	CO <sub>2</sub> emissions reduction by sector in 2010 (% change from Baseline)			Marginal abatement cost	Compliance costs
	1990	2010	% change	% change	Mt CO <sub>2</sub>	Energy supply sectors	Energy intensive industries	Other demand sectors	Eur99/tCO <sub>2</sub>	Mio Eur99
AU	55.0	48.0	-12.7	-12.3	-5.0	-2.4	-3.3	-14.1	142.4	252.4
BE	104.8	97.6	-6.8	-6.8	-24.0	-13.3	-7.9	-26.0	219.4	2410.4
DK	52.7	42.0	-20.3	-20.4	-11.5	-23.9	-17.3	-19.1	74.8	414.8
FI	51.3	51.7	0.8	0.8	-20.7	-46.5	-14.1	-2.4	75.3	694.3
FR	352.4	355.0	0.7	0.8	-21.2	1.4	-0.2	-8.0	71.6	600.4
GE	951.6	757.5	-20.4	-20.4	-42.8	-2.2	0.6	-8.8	135.4	2225.9
GR	70.9	89.4	26.0	25.9	-16.7	-12.5	-19.1	-19.1	122.9	890.7
IR	30.1	34.2	13.8	13.9	-7.7	-25.1	3.7	-15.3	107.4	399.7
IT	388.0	364.8	-6.0	-5.8	-53.3	-14.9	-0.1	-13.3	99.2	2579.1
NL	153.0	143.9	-6.0	-5.3	-57.6	-23.4	-35.4	-31.4	174.5	4491.1
PO	39.1	50.3	28.7	28.0	-14.6	-23.0	-28.7	-20.7	137.4	848.7
SP	201.9	233.1	15.5	15.9	-33.3	-10.9	0.7	-16.6	94.8	1414.4
SV	50.5	53.0	4.9	4.8	-7.2	-44.9	-3.0	1.3	64.0	227.6
UK	566.9	499.4	-11.9	-11.8	-57.9	-2.0	0.4	-16.9	128.5	3058.1
EU	3068.1	2819.8	-8.1	-8.0	-373.6	-10.1	-4.2	-13.9	125.8	20507.8

Source: PRIMES Notes: see table 2 for a description of sectors and countries

The potential contribution of domestic trading regimes, as defined in the reference case, to the achievement of the country specific emission reduction target are clearly illustrated by the cheese slicer case. The cost in comparison to the reference case would increase by 127.2 % or M€<sub>99</sub> 11482 (compare Tables 9 and 3). The corresponding average marginal abatement cost at the EU level, €<sub>99</sub> 125.8/tCO<sub>2</sub> avoided, would be about 230 % higher than in the reference case.

<sup>12</sup> Following the slicer used in Scandinavian countries to peel a slice of cheese. This principle is called in German “*Rasenmäherprinzip*” (lawnmower principle), in Dutch “*kaasschaaf methode*”, in Swedish “*osthyvelprincip*”, in Finnish “*juustöhöyläperiaate*”. This principle or method is often used when the government budget needs to be cut by x%. The same x% would be allocated to all budget lines of different ministries without any economic consideration, mainly because of information asymmetries.

<sup>13</sup> An even worse situation would be that total exemption of specific sectors from any reduction target allowing them to develop with any emission constraint at all.

The cheese slicer case is very helpful to understand the economic impact of deviations from the least-cost solution as regards the allocation of effort to the different sectors. A characteristic example is the case of Germany. In the reference case Germany is the Member State that could achieve its target at quite modest cost. However, in the cheese slicer case where each sector must achieve the Burden Sharing target separately, Germany would face very high compliance costs. The corresponding marginal abatement cost increases to €<sub>9</sub> 135/tCO<sub>2</sub> (ten times higher compared to the reference case). This result is due to the evolution of the German energy system under baseline conditions. Both energy supply sectors and energy intensive industries achieve the Burden Sharing Agreement target for 2010 in the context of the baseline scenario (reducing emissions by 22% and 39% from 1990 levels, respectively, compared to an emission reduction target of 20.4%). In the absence of incentives to further reduce their emissions (i.e. a trading regime across sectors) all the additional effort required to achieve the Burden Sharing target is allocated to other demand sectors (and more specifically to household and transport sectors, since other industrial and the tertiary sector (over)achieve their emission reduction target under baseline conditions). As discussed in the reference case, demand-side abatement efforts require very high carbon shadow prices, hence resulting in a significant increase of total abatement costs for Germany.

### 3.5. Summary of results

Table 10 illustrates the main findings for the alternative policy cases examined. The main result is that emission trading across sectors and Member States (regardless the extent of the trading scheme) is more cost efficient, than if Member States would implement the Burden Sharing Agreement individually. Gains in terms of total abatement costs, compared to the reference case, range from 9.3% up to almost 50% depending on the emissions trading scheme. The increase in total costs from a non-efficient allocation in the “cheese-slicer” case amounts to 127% relative to the reference case. This indicates the importance of allocation of targets among sectors at the Member State level.

Figure 1 summarises the different trading schemes, including the case where the EU Member States would be trading with the other Annex B Parties.

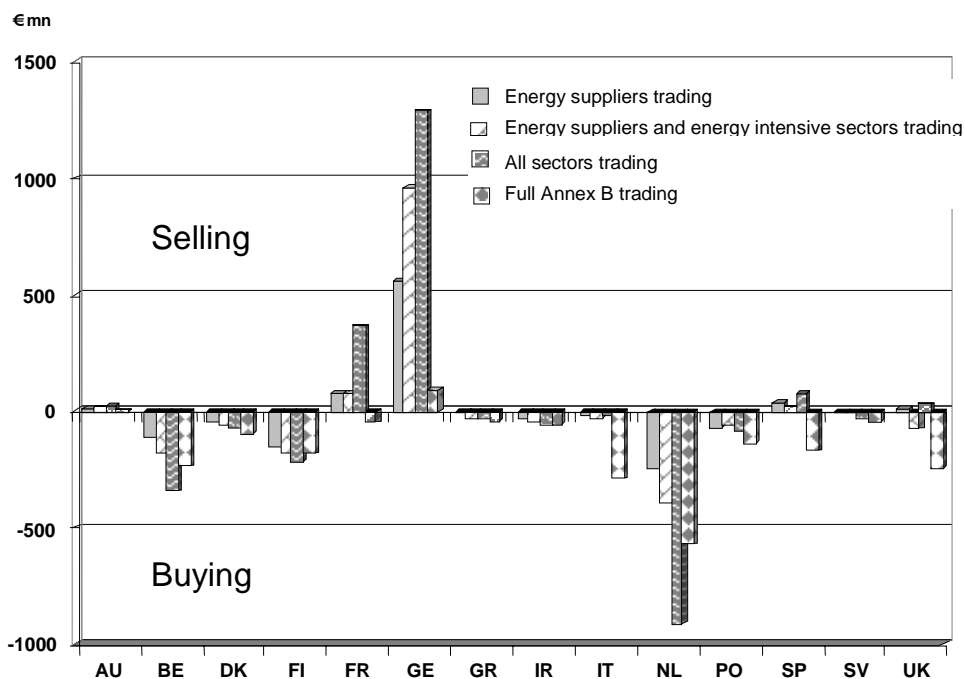
If the gains from emission trading are compared with the GDP, it is possible to see how important trading would be for particular Member States (Figure 2). While Germany is projected to be a major seller of permits, these gains are small relative to its GDP. The gains for the Netherlands are projected to be important even in relative terms. Also Finland and Belgium are projected to gain from emission trading in relative terms. Surprisingly, even if the gains in absolute terms seem to be small for Greece, they are important in relation to its GDP.

**Table 10: Cost effectiveness of alternative emission trading regimes**

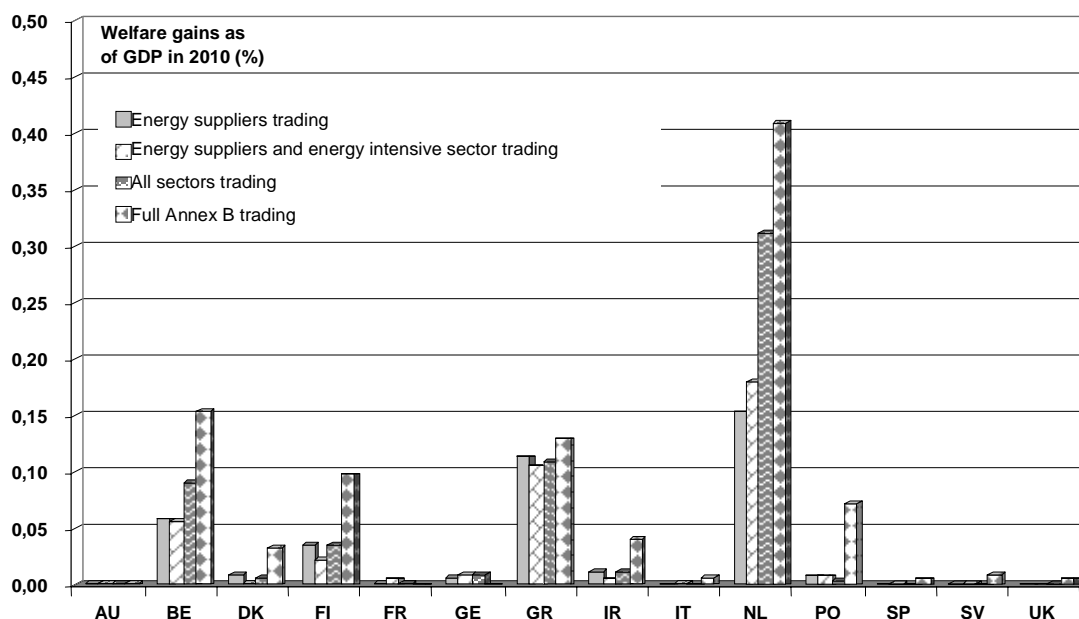
Permit trading schemes	Reduction of total compliance cost from reference case (in %)	Marginal abatement cost or permit price in €/tCO <sub>2</sub>	
		For participants in trading	Average for the outsiders
Alternative reference case	+ 127.2 %	n.a.	125.8
Reference case	<b>100.0 %</b>	n.a.	54.3
<u>Country trading cases</u>			
Full trading EU 3	- 28.9 %	32.6	34.8
Full trading EU 7	- 26.0 %	46.4	38.4
Full trading EU 8	- 29.9 %	32.6	33.3
Full trading EU 14	- 34.0 %	32.6	32.6
Full Trading Annex B	- 48.6 %	17.7	17.7
<u>Sectoral trading cases</u>			
Energy supply sectors EU3	- 14.2 %	31.2	47.2
Energy supply sectors EU7	- 9.3 %	52.5	49.2
Energy supply sectors EU8	- 18.1 %	31.2	45.6
Energy supply sectors EU14	- 20.7 %	32.3	45.3
Energy supply and energy intensive sectors in EU7	- 13.9 %	56.0	49.0
Energy supply and energy intensive sectors in EU8	- 21.4 %	32.6	43.4
Energy supply and energy intensive sectors in EU14	- 24.0 %	33.3	43.3

EU3: Belgium, Germany, the Netherlands. EU7: Belgium, Denmark, Finland, France, the Netherlands, Sweden, and UK. EU8: EU7 and Germany. EU14: all EU Member States except Luxembourg.  
 n.a.: not applicable.

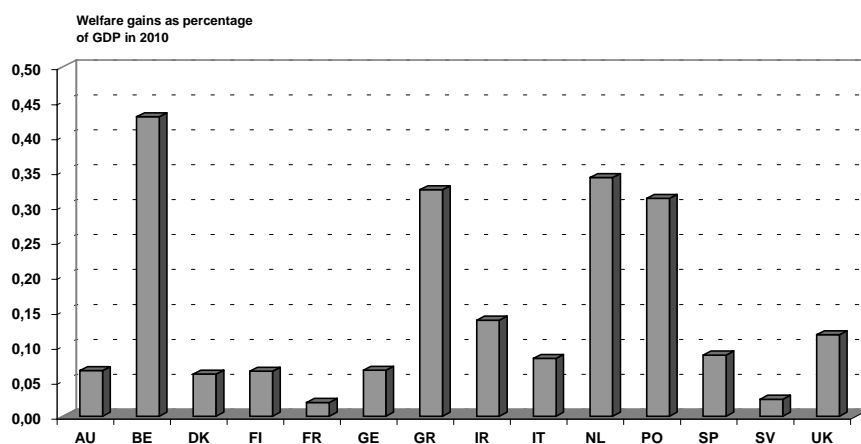
**Figure 1:  
 Sellers and buyers in EU-wide and Annex B allowance trading**



**Figure 2:**  
**Welfare gains as a percentage of GDP in 2010 in EU-wide and Annex B trading**



**Figure 3:**  
**Welfare gains from EU-wide emissions trade in power supply and energy intensive sectors compared with Alternative Reference (“Cheese Slicer”) Case**



#### 4. THE RELEVANCE OF THE RESULTS AND SUGGESTIONS FOR FURTHER RESEARCH

While the analysis represents a major step forward compared to conventional analytical and modelling work of international emission trading on the basis of marginal abatement cost curves by country, a number of caveats apply.

The figures are probably underestimates of the real potential. This is because the PRIMES model, which is based on sectoral rather than country-wide marginal abatement

cost schedules, incorporates the ‘representative firm’ assumption. This means that the model assumes the existence of a number of homogenous firms by sector. Hence, one can only analyse differences between sectors, but not investigate systematically the potential gains from trade that might be achievable within a sector, made up by a number of companies operating one or several installations. In practice, installations differ in terms of age, production capacity, technology etc. Thus, all models, including PRIMES, will most likely underestimate the impacts of emission trading.

Only CO<sub>2</sub> was analysed. The Kyoto Protocol covers five other greenhouse gases (CH<sub>4</sub>, N<sub>2</sub>O, SF<sub>6</sub>, PFCs, and HFCs) as well as a limited number of forestry-related carbon sinks and provides hence for the possibility of inter-gas trading in carbon equivalents.

No transaction costs were modelled. The analysis abstracts also from reality in the sense that it assumes a frictionless permit market with no transaction costs incurred in carrying out trades. The impact of transaction costs may over the medium-term be negligible, although they could be an important factor in the early stage of a trading market. Transaction costs can be expected to be the lower the larger the market and the more participating companies. While transaction costs need to be considered in the design of a trading scheme, they do not constitute a major hurdle towards an efficient and functioning permit market.

In addition, other market ‘set-up’ and ‘infrastructure’ costs have been disregarded. Under this category we subsume the administrative costs related to design and implementation of a scheme: e.g., fixing allocation methods and formulae, determining participating sources, installation and maintenance of permit and emission registers, reporting of emissions and permit transactions, regular compliance checks, enforcement. Most of these costs will arise independent of which instrument is used to achieve a desired emission target.

An important factor we have not attempted to analyse is enforcement and sanctions and possible incentive effects triggered by the nature of enforcement rules. Our analysis implicitly assumes 100 % compliance by all participants in the trading scheme (as well as outside). However, if financial sanctions levied per excessive ton of CO<sub>2</sub> are lower than the market price, one would rationally expect some non-compliance to occur, e.g. when the non-compliant actor only has to pay a financial penalty and is not taken away an equivalent number of permits from a future allocation (automatic offset provision). At the same time, differing amounts of financial sanctions across sectors and/or Member States and varying stringency of enforcement (i.e., differences in the probability of being made liable for excessive emissions) could have an important influence on the performance of a permit market. In general, we consider both the stringency and the likelihood of a sanction crucial for the outcome of a trading scheme.

By focusing on energy-related CO<sub>2</sub> emissions in a cost-effectiveness analysis we fail to take into account ancillary effects of greenhouse gas emissions reductions in a systematic and comprehensive way. A reduction of quantities of combusted fossil fuels will also mean improved local and regional air quality (acid rain, particulate matter etc.). Such co-benefits could be quite important, in particular since they occur much earlier than the

benefits from avoided or averted climate change. On the other hand reduction of greenhouse gases might also trigger negative ancillary effects<sup>14</sup>.

Finally, the analysis focusing on sectors in a partial equilibrium setting suffers from drawbacks that conventional country-level general equilibrium models are better suited to cover. On the other hand, what is gained is a technologically much richer, and thus more realistic, analysis.

PRIMES can not investigate the effects of alternative allocation methodologies – most importantly the implications of auctioning vs. grandfathering in the initial allocation of emission permits. Auctioning with revenue recycling e.g., through reduction of other distorting taxes could improve economic efficiency and result in a so-called "double dividend". Bosquet (2000) has surveyed recently the evidence of double-dividend and concluded that in most empirical estimates (conducted mainly in Europe) such potential existed. General equilibrium models, if they full employment, would not be likely to catch such effects.

In this analysis, the implicit assumption was that the sectors covered under the trading regime would also be the ones that would carry out trading. Thus, the system implicitly assumed a downstream trading system. However, analytically it would not make any difference if the system was an upstream one. For instance, in the case where all sectors traded, it could have been also assumed implicitly that the trading regime would have been upstream. Had the analysis assumed transaction costs, it would have been interesting to analyse the effect of the introduction of an upstream system (with low transaction costs) vs. a downstream system (with higher transaction costs).

This paper, as well as most of the other similar papers, analyse emission trading so that everyone complies fully with their obligations within one budget period. Thus, it is not possible to bank (or borrow) allowances for (or from) the second budget period. As the Kyoto Protocol allows for such behaviour, it would be important to incorporate banking in the analysis of emission trading.

Further, to add realism to the analysis it would be important to incorporate the institutional framework of the trading regime. Models usually skip such complicated design issues and assume implicitly a standard blueprint trading regime (with no transaction costs). As the real life applications (e.g. the trading regime being designed in the UK) are likely to be much more complicated, the models should be able to shed some light on the pros and cons of such systems.

Finally, the PRIMES model did not allow us to look at terms of trade effects and balance of payment impacts<sup>15</sup>. In international trading among governments the transfer and acquisition of emission permits may have an impact on a country's exchange rate. However, in view of the European Monetary Union comprising 11 (and soon 12) out of 15 EU Member States, these effects are less of a concern in the analysis of EU-wide emission trading.

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<sup>14</sup> See for instance papers presented in at the *Expert Workshop on Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies*, 27-29 March 2000 organised by Resources for the Future. Washington DC.

<sup>15</sup> The G-Cubed model (McKibbin et al 1999) can offer such insights.



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## Annex 1

The following tables summarise the results obtained with PRIMES model for the different emission permit regimes examined in the context of the study.

**Table A-1: Energy supply sectors trading for EU3**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	5.5	6.1	-0.5	-0.1	5.6	-5.5	31.2	81.7	-8.6	756.8	-21.4
DK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.9	0.0	258.0	0.0
FI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.5	0.0	582.5	0.0
FR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.6	0.0	251.6	0.0
GE	-17.3	-20.3	0.8	2.1	-2.3	17.3	31.2	27.5	103.8	144.4	-51.9
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	11.8	15.0	-0.9	-2.3	8.2	-11.8	31.2	119.2	-20.9	2548.7	-26.5
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.7	0.0	130.7	0.0
UK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.9	0.0	725.5	0.0
EU14	0.0	0.8	-0.5	-0.3	0.0	0.0		47.2	-13.1	7746.3	-14.2

**Table A-2: Energy supply sectors trading for EU7**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	3.3	3.8	-0.3	-0.1	3.4	-3.3	52.5	81.1	-9.2	919.0	-4.5
DK	-0.8	-0.9	0.0	0.1	-1.9	0.8	52.5	51.7	8.1	255.8	-0.9
FI	1.3	1.3	0.0	0.0	2.4	-1.3	52.5	55.0	-13.3	581.7	-0.1
FR	-5.7	-6.1	0.1	0.3	-1.6	5.7	52.5	32.0	55.7	100.3	-60.1
GE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	300.6	0.0
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	9.4	11.9	-0.7	-1.8	6.5	-9.4	52.5	120.2	-20.2	2912.2	-16.0
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	-0.8	-0.8	0.0	0.0	-1.4	0.8	52.5	45.6	14.8	125.9	-3.7
UK	-6.7	-7.7	0.2	0.7	-1.3	6.7	52.5	43.4	35.9	640.3	-11.8
EU14	0.0	1.6	-0.7	-0.8	0.0	0.0		49.2	-9.4	8183.7	-9.3

**Table A-3: Energy supply sectors trading for EU8**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	4.6	5.1	-0.4	-0.1	4.7	-4.6	31.2	81.7	-8.6	722.0	-25.0
DK	2.2	2.4	0.0	-0.2	5.2	-2.2	31.2	35.1	-26.7	231.0	-10.5
FI	6.0	6.2	-0.1	-0.1	11.7	-6.0	31.2	41.5	-34.6	476.7	-18.2
FR	-3.1	-3.3	0.0	0.2	-0.9	3.1	31.2	23.3	13.4	221.7	-11.9
GE	-20.1	-23.5	1.0	2.5	-2.7	20.1	31.2	27.5	103.8	82.0	-72.7
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	9.8	12.4	-0.7	-1.9	6.7	-9.8	31.2	119.2	-20.9	2467.1	-28.8
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	0.4	0.4	0.0	0.0	0.8	-0.4	31.2	36.7	-7.7	126.5	-3.2
UK	0.2	0.2	0.0	0.0	0.0	-0.2	31.2	31.6	-1.0	717.7	-1.1
EU14	0.0	-0.2	-0.2	0.4	0.0	0.0		45.6	-16.0	7392.8	-18.1

**Table A-4: Energy supply and energy intensive sectors trading for EU7**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	3.6	2.4	1.3	-0.1	3.7	-3.6	56.0	73.7	-17.5	908.1	-5.7
DK	-1.0	-1.1	0.0	0.1	-2.5	1.0	56.0	54.8	14.5	246.9	-4.3
FI	1.0	0.9	0.1	0.0	1.9	-1.0	56.0	57.3	-9.7	579.1	-0.6
FR	-7.3	-14.4	-2.9	10.0	-2.1	7.3	56.0	40.8	98.6	-55.3	-122.0
GE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	300.6	0.0
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	11.9	9.6	2.7	-0.5	8.2	-11.9	56.0	111.9	-25.7	2742.8	-20.9
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	-1.3	-1.0	-0.3	0.0	-2.5	1.3	56.0	50.1	26.2	120.5	-7.8
UK	-6.8	-9.5	-1.6	4.2	-1.4	6.8	56.0	48.0	50.6	577.1	-20.5
EU14	0.0	-13.1	-0.7	13.8	0.0	0.0		49.0	-9.7	7767.8	-13.9

**Table A-5: Energy supply and energy intensive sectors trading for EU8**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	6.7	4.3	2.4	0.0	6.8	-6.7	32.6	67.5	-24.5	720.8	-25.1
DK	2.3	2.5	0.0	-0.2	5.5	-2.3	32.6	35.9	-24.9	244.5	-5.2
FI	6.9	6.5	0.5	-0.1	13.3	-6.9	32.6	39.9	-37.1	501.7	-13.9
FR	-3.0	9.3	2.0	-14.3	-0.8	3.0	32.6	26.3	27.8	130.3	-48.2
GE	-31.0	-36.0	-1.6	6.6	-4.1	31.0	32.6	30.8	128.6	32.5	-89.2
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	14.6	12.3	3.2	-0.9	10.0	-14.6	32.6	107.7	-28.5	2271.4	-34.5
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	0.2	0.1	0.1	0.0	0.4	-0.2	32.6	35.9	-9.7	121.7	-6.9
UK	3.4	-0.4	-0.1	3.8	0.7	-3.4	32.6	32.3	1.3	723.0	-0.3
EU14	0.0	-1.4	6.4	-5.0	0.0	0.0		43.4	-20.0	7093.8	-21.4

**Table A-6: Full trading for EU7**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	9.8	3.2	1.6	5.0	10.1	-9.8	46.4	46.4	-48.0	749.0	-22.2
DK	0.4	0.4	0.0	0.0	1.0	-0.4	46.4	46.4	-3.0	252.0	-2.3
FI	2.8	1.8	0.2	0.7	5.4	-2.8	46.4	46.4	-26.8	544.5	-6.5
FR	-21.8	-2.7	-1.1	-18.0	-6.1	21.8	46.4	46.4	125.9	-52.6	-120.9
GE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	300.6	0.0
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	30.7	11.3	2.8	16.5	21.2	-30.7	46.4	46.4	-69.2	1885.8	-45.6
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	-1.2	-0.5	-0.1	-0.6	-2.3	1.2	46.4	46.4	17.0	121.0	-7.5
UK	-20.7	-8.5	-1.3	-10.9	-4.1	20.7	46.4	46.4	45.6	531.1	-26.8
EU14	0.0	5.1	2.2	-7.2	0.0	0.0		38.4	-29.1	6679.2	-26.0

**Table A-7: Full trading for EU8**

	Change of country specific emissions from Reference emission reduction case (Mt CO <sub>2</sub> )					Emission permits trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors (S1)	Energy intensive industries (S2)	Other demand sectors (S3)	% change	Mt CO <sub>2</sub> (+sellers / buyers)	Price (Eur'99/tCO <sub>2</sub> )	Eur'99/tCO <sub>2</sub>	% change from reference	Mio Eur'99	% change from reference
AU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.4	0.0	47.9	0.0
BE	13.9	4.3	2.5	7.1	14.2	-13.9	32.6	32.6	-63.5	618.5	-35.8
DK	3.3	2.5	0.0	0.8	8.0	-3.3	32.6	32.6	-31.9	245.3	-4.9
FI	9.1	7.0	0.5	1.6	17.5	-9.1	32.6	32.6	-48.6	496.4	-14.8
FR	-13.8	-5.9	-0.6	-7.2	-3.9	13.8	32.6	32.6	58.6	219.2	-12.9
GE	-49.5	-32.7	-1.8	-15.0	-6.5	49.5	32.6	32.6	142.1	58.5	-80.5
GR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0	0.0	450.3	0.0
IR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	53.5	0.0	175.9	0.0
IT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	867.9	0.0
NL	37.0	13.4	3.5	20.2	25.6	-37.0	32.6	32.6	-78.4	1493.0	-56.9
PO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.1	0.0	338.5	0.0
SP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7	0.0	467.4	0.0
SV	1.1	0.3	0.2	0.6	2.1	-1.1	32.6	32.6	-17.9	128.9	-1.4
UK	-1.1	-0.5	-0.1	-0.6	-0.2	1.1	32.6	32.6	2.2	721.0	-0.6
EU14	0.0	-11.6	4.2	7.4	0.0	0.0		33.3	-38.7	6328.7	-29.9