The Economic Effects of EU-Wide Industry-Level Emission Trading to Reduce Greenhouse Gases

Results from PRIMES Energy Systems Model

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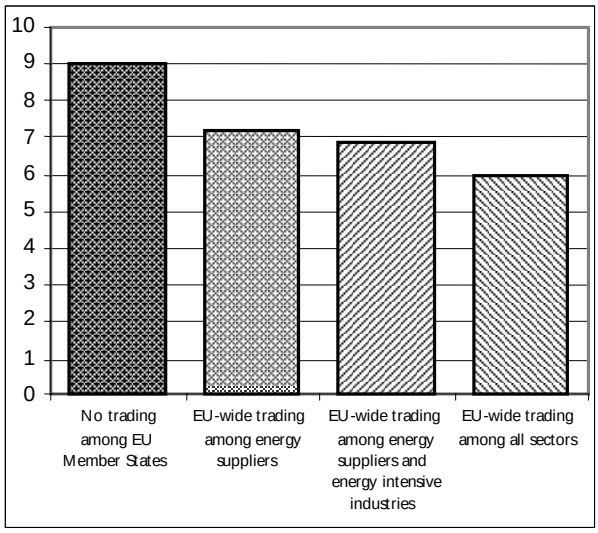
Summary

This study analyses the economic importance of EU-wide trading, carried out in addition to a cost effective implementation at the individual Member State level e.g., by national emission trading. If each country implemented its target under the Burden Sharing Agreement individually, the total annual cost for the EU to reach the Kyoto target would be €9.0 billion (see Figure 1)[1].

Figure 1: Cost of reaching the Kyoto target to EU Member States in 2010 (€ billion)



If only energy suppliers participated in the emissions trading scheme the annual compliance cost would be lower, i.e. €7.2 billion and the EU Member States would save €1.8 billion per annum (or 21% from the no EU-wide trading case) with 28 Mt of CO_2 traded within the EU. If the scope of EU-wide trading was enlarged to include also energy intensive industries (iron and steel, non-ferrous metals, construction materials, chemicals, and paper and pulp industries) the annual savings would increase to €2.1 billion (or 24%) in 2010, while permits for 42 Mt of CO_2 would be exchanged.

If all sectors participated in emissions trading in the EU, the gains from emission trading would increase to €3 billion per annum (or 34%) in 2010. In this case some 70 Mt of CO_2 would be traded across EU Member States. This would be about 2.5% of all EU CO_2 emission permits in circulation in 2010.

The price of emission permits would be about €33 per tonne of CO_2, in all emission trading regimes studied, which is well within the range estimated by other model-based emission trading analyses. As the price of emission allowances for those sectors participating in the trading regime would be at relatively moderate level a step-wise implementation of an emission trading system appears to be attractive to the industries entering the scheme first.

[1] All monetary amounts in this report refer to euros at 1999 price level.

The analysis assumes that energy suppliers and energy intensive industries already participate in national emissions trading schemes in all sectors, or reach their target in any other least cost manner. In order to understand how important this assumption is, an Alternative Reference case was developed. In this case it was assumed that Member States do not allocate their respective Burden Sharing targets in a cost effective manner but give the same target uniformly to all sectors. For instance, if the target was -4% for a Member State, this would be assumed to apply to every sector individually in that country. In this case the annual compliance costs of EU Member States could be as high as €20.5 billion in 2010. An EU-wide permit trading scheme would help in rectifying inefficiencies and the gains from EU-wide trading would be higher – up to €14.5 billion instead of €3.0 billion per annum.

1. Introduction

The purpose of the study is to provide a detailed analysis of alternative emission trading schemes in the European Union (EU) as discussed in the European Commission's Green Paper on Greenhouse Gas Emissions Trading within the European Union (COM (2000)87).[2] Both intra and inter-sectoral trading regimes among EU Member States have been analysed. The analysis was carried out with the energy system model PRIMES.[3]

The analysis starts from the assumption that each Member State achieves individually its specific target under the Council of (Environment) Ministers' Burden Sharing Agreement.[4] According to the model analysis this case does not result in a least-cost allocation of reduction efforts for the EU. A series of intra-EU emission trading cases are examined, varying the number of sectors participating in an emission trading system in order to reach such a least cost allocation.

Intuitively, one would expect that the more sectors are included in a trading scheme the lower would be the compliance cost, while reaching the same overall reduction in emissions. This study examines that intuition and quantifies how important such gains might be.

Given the uncertainty as regards the evolution of non-CO_2 GHG emissions, this study assumes that the EU reduction target of 8% so that the Burden Sharing Agreement applies to energy related CO_2 emissions only.[5] The horizon of the analysis is 2010, as being the middle year of the first commitment period of Kyoto Protocol (2008 to 2012). It was assumed that energy consumers and producers would anticipate the emission reduction commitments and undertake efforts already

[2] Available at http://europa.eu.int/comm/environment/docum/0087_en.htm

[3] For a detailed description of PRIMES, see e.g. "Economic Evaluation of Quantitative Objectives for Climate Change", which is available at http://europa.eu.int/comm/environment/enveco/studies2.htm#5

[4] In June 1999 the EU Member States agreed to meet the Kyoto reduction target of 8% so that the target for each Member State was adjusted from the uniform 8 % given in Annex B of the Kyoto Protocol. 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%.

[5] In other words, this study uses -8% as the target for energy related CO_2. If it would be more cost-effective to reduce emissions of other greenhouse gases, the target would for energy related CO_2 would be lower. If it would be less cost effective, the target would be higher.

before 2010 so that the alternative trading schemes would be implemented as of 2005.

Besides the exclusion of non-CO_2 GHG emissions, there are several additional caveats to be mentioned. The three main ones are: i) Potential **ancillary benefits** from reducing CO_2 emissions are not taken into account. This omission is unlikely to systematically bias the results of EU-wide trading.[6] ii) Throughout the study it has not been possible to include the effects of having several companies within one sector – the analysis is based on a **"representative firm"**.[7] This is likely to cause an underestimation of the gains from emissions trading. iii) **Transaction costs** involved in the exchange of allowances have not been estimated (they depend primarily on the institutional set-up). In this study the allowance market is assumed to be perfect and frictionless without any transaction costs.[8]

This study is structured as follows: The second section defines the baseline and reference cases. The third section deals with the impacts of the implementation of alternative emission trading regimes in the EU. In the final section some conclusions are drawn. The annex describes the methodology of this study as well as the key features of the PRIMES model. The terms "emission permit" and "emission allowance" are used interchangeably in this study. All monetary amounts in this report refer to euros at 1999 price level.

2. The Baseline and Reference Cases

2.1. The Baseline Case

The Baseline case (also called "business-as-usual") does not involve specific emission reduction targets but assumes that no new environmental or energy related policies would be implemented. The baseline case was developed in the Shared Analysis exercise of European Commission's Energy Directorate-General in 1999[9] and includes all policies and measures agreed upon by the end of 1997.

For the purposes of this study the baseline has been updated to incorporate the effects from the ACEA/KAMA/JAMA negotiated agreements[10] 1999 and 2000. In these agreements car manufacturers committed themselves to reduce the average

[6] However, in the case of emission trading within Annex B it would have been necessary to estimate such effects. However, due to time limitations and because of the scope of this study (i.e. EU-wide emissions trading), such analysis was not carried out.

[7] In practice individual companies within a sector differ in scale, production technology, plant size or age etc., having different energy efficiency rates and hence possibilities for energy savings and efficiency improvement. As the PRIMES model (as many other models) is based on the "representative firm" assumption, it is likely to give an under-estimate of the gains from EU-wide emissions trading. It would thus be very important to carry out similar analysis with plant level data. However, such models are not available at the EU level.

[8] Existing emission allowance programs function with transaction costs of about 1 or 2% of the permit value. In the early phase an allowance market might though be 'burdened' with transaction costs as high as 5%.

[9] 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. See also http://www.shared-analysis.fhg.de/

[10] See http://europa.eu.int/comm/environment/co2/co2_agreements

CO_2 emission for all new cars sold in the EU to 140 g/km by 2008. This 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). The agreement assumes fuel quality will not hamper its implementation. Being part of the baseline the implementation cost of this agreement are not taken into account in the analysis.

This baseline scenario was conceived as the most likely development of the energy system in the future in the context of extrapolating current knowledge, policies in-place etc. It incorporated current trends and the effects of all policies in place and in the pipeline (such as 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 European Union), while excluding any additional policies and measures that aim at further reducing CO_2 emissions so as to comply with the Kyoto commitments.

In the baseline case, 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. Energy consumption is projected to increase by 15.6% from 1990 to 2010 while the Gross Domestic Product is projected to grow by 54.5%.

The impact of the introduction of the ACEA agreement in the baseline case is to reduce energy demand for liquid fuels by 28 Mtoe[11] in 2010 compared to the Shared Analysis baseline. As a consequence CO_2 emissions increase by only 4.1% from 1990 to 2010, compared to 6.7 % in the unadjusted Shared Analysis baseline. Table 1 illustrates the projected evolution of CO_2 emissions by Member State[12] in the baseline case.

[11] Mtoe stands for million tonnes of oil equivalent.

[12] The PRIMES model does not include Luxembourg and so it has been excluded from the analysis. Because of economic restructuring it is expected that this member state will substantially reduce carbon dioxide emissions relative to 1990. The results should not be affected by this omission, since Luxembourg's share of total EU CO_2 emissions in 1990 amounted only to 0.35%.

Table 1: Baseline case - CO_2 emissions from energy[13] by country and sector in the EU in 1990 and 2010

	CO_2 emissions (in Mt)			Decomposition of CO_2 emissions in 2010 (Mt of CO_2)			Difference from Shared Analysis Baseline in 2010	
	1990	2010	% change	Energy supply sectors	Energy intensive industries	Other demand sectors	Mt of CO_2	% 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
EU	3068.1	3193.3	4.1	1182.0	267.9	1743.4	-80.2	-2.5

Notes: ACEA Agreement is included in the baseline. It is assumed that the target for energy related CO_2 is –8% from 1990 emissions. Throughout the study the abbreviations are as follows Austria (AU), Belgium (BE), Denmark (DK), Finland (FI), France (FR), Germany (GE), Greece (GR), Ireland (IR); Italy (IT), Netherlands (NL), Portugal (PO), Spain (SP), Sweden (SV) and the United Kingdom (UK). Source: PRIMES

There are very large differences in the trends of CO_2 emissions among EU Member States. Only three Member States manage to reduce emissions below 1990 namely, Austria, Germany and United Kingdom. In Denmark a near stabilisation of CO_2 emissions in 2010 to their 1990 level is observed. In all other Member States there are significant increases in emissions between 1990 and 2010 varying from 6.8 % in France to more than 65 % in Portugal. In six Member States, CO_2 emissions are expected to increase by more than 30 % between 1990 and 2010.

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, ranges from 1.3% in Greece up to 4% in Sweden, reflecting the different structural characteristics of the transport sector across Member States.

These huge divergences between EU countries reflect a large number of factors including economic growth and changing market structures.

2.2. The Reference Case ("Least Cost, No EU-Wide Trading")

The Reference case was developed for analytical purposes to illustrate what the compliance costs would be if the Kyoto commitment was implemented separately by each of the EU Member States through actions within each country. In the Reference case Member States reduce energy-related CO_2 emissions according to their respective targets in the Burden Sharing Agreement.

[13] Excluding emissions from international bunker fuels (aviation and ships) but including emissions from both domestic air transport and navigation. Emission factors, definitions and the basic energy balances used are those published by Eurostat.

This Reference case corresponds to no trading of emission allowances by any sector across the European Union. The CO_2 emission reduction target is implemented at the Member State level and therefore, it is allocated to the sectors (consumers and producers of energy) at least cost but of course separately within each Member State. In other words, the marginal abatement cost is equalised across the sectors in each Member State. This situation is equivalent to the expected results if each Member State had implemented a domestic emission trading regime, but no exchange of allowances was allowed across Member States[14].

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 because of e.g. information constraints.

Table 2: The Reference Case: Each EU Member State reaches Kyoto target in 2010 separately, according to the Burden Sharing Agreement

	CO_2 emissions (in Mt)			Burden Sharing Agreement	Change from Baseline	CO_2 emissions reduction by sector in 2010 (% change from Baseline)			Marginal abatement cost	Compliance costs
	1990	2010	% change	% change	Mt CO_2	Energy supply sectors	Energy intensive industries	Other demand sectors	Eur'99/tCO_2	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
EU	3068.1	2821.4	-8.0	-8.0	-372.0	-18.2	-10.5	-7.4	54.3	9026.0

Notes: ACEA Agreement is included in the baseline. It is assumed that the target for energy related CO_2 is -8% from 1990 emissions. Source: PRIMES

Table 2 summarises the evolution of CO_2 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.[15] The marginal efforts and costs differ substantially across Member States when each one has to reduce emissions unilaterally according to the Burden Sharing Agreement. While the marginal abatement cost at the EU level is €54.3/tCO_2 avoided, Germany achieves its target with a cost of €13.5/tCO_2 at the margin, while the corresponding figure for

[14] Alternatively, this could be interpreted as if each Member State was able to allocate the emission reduction objective to each sector so that the economic distortions would be as small as possible.

[15] The Burden Sharing Agreement has been applied separately to CO_2 emissions and not to the whole range of greenhouse gases. By implying the emission reduction targets as in the Burden Sharing agreement on 1990 CO_2 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_2 emissions. 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 insignificant deviations.

Netherlands is €150.7/tCO_2. In other words, if no emission allowance trading takes place, it is likely that, Belgium, Finland and in particular the Netherlands will find it very expensive to reach the emission reductions according to the Burden Sharing Agreement. On the other hand, France and Germany are likely to find it relatively easy to reach the reduction targets.

The marginal abatement costs are the key drivers of the analysis. Sectors in Member States with marginal abatement cost above the EU average are expected to buy emissions from those in Member States with marginal abatement costs lower than the EU average.

From Table 2 it is evident that energy supply sectors are the most responsive to the introduction of the Burden Sharing targets, followed by energy intensive industries while other demand sectors are rather insensitive as regards emissions reduction. However, significant differences across EU Member States exist. These reflect to a large extent different dynamics in each Member State's energy system, the existing structure of energy production and the prospects of industrial restructuring. The CO_2 intensity of power generation plays a key role in the ease with which a country can adjust to the imposition of a CO_2 constraint. In addition, the different effort required in the Burden Sharing Agreement results in distortions as regards the contribution of the different sectors. As the low cost possibilities in energy supply sectors get exhausted, the achievement of targets needs demand-side actions. For example, in the Netherlands and Belgium, where the PRIMES model suggests that relatively high effort is required to reach the target of the Burden Sharing Agreement, the reduction achieved in energy supply sectors is less than or equally significant as that of energy intensive industries.

If each Member State reached its Burden Sharing target alone (without EU-wide trading or any flexible mechanisms under the Kyoto Protocol), the total welfare cost – or compliance cost[16] – of reaching the emission targets are estimated to be in 2010 is €9026 million per year. This figure represents 0.075% of projected GDP of the EU in 2010. Within each Member State the analysis assumes that a least-cost allocation of the emission reduction target to all 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 compliance costs.

2.3. The Alternative Reference Case ("Cheese Slicer")

An extreme Alternative Reference case has been defined for the purpose of this study to illustrate how important it is to reach the Burden Sharing Agreement in a least cost manner within each Member State. In other words, the purpose of the Alternative Reference case is to show how sensitive the estimated gains from EU-wide trading are to the assumed behaviour of the Member States in the absence of an EU-wide trading scheme.

[16] As mentioned the welfare or 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. A similar evaluation under general equilibrium would result in different numerical values.

In the Alternative Reference case, it is assumed that within a Member State the emission reduction target as defined in the Burden Sharing Agreement must apply to each individual sector. For instance, the Alternative Reference case assumes that for Danish[17] energy suppliers and users every sector would reduce its emissions by 21% and no emission trading would be allowed among these sectors. This allocation is evidently more expensive than the least-cost one. However, such a rule is often used because it seems on the surface "democratic", 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 a Solomon decision and the corresponding model run case is termed **"Cheese Slicer"** case.[18]

Table 3 gives the details of the "Cheese Slicer" case. Such an emission reduction case is expected to result in very high compliance costs.[19] The compliance costs would increase from €9.0 billion (in the Reference case) to €20.5 billion (in the "Cheese Slicer" case).

Table 3: The "Cheese Slicer" Case: Each sector within each EU Member State reaches Kyoto target in 2010 separately, according to the Burden Sharing Agreement

	CO_2 emissions (in Mt)			Burden Sharing Agreement	Change from Baseline	CO_2 emissions reduction by sector in 2010 (% change from Baseline)			Marginal abatement cost	Compliance costs
	1990	2010	% change	% change	Mt CO_2	Energy supply sectors	Energy intensive industries	Other demand sectors	Eur'99/tCO_2	Mio Eur'99
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

Notes: ACEA Agreement is included in the baseline. It is assumed that the reduction target for energy related CO_2 is 8% from 1990 emissions. *Source*: PRIMES

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

[17] Denmark agreed to reduce its emissions from 1990 level by 21% for the first commitment period of the Kyoto Protocol (2008 to 2012).

[18] Driven by the slicer used in Scandinavian countries to peel an equally thick slice of any piece of cheese. If a government (or an organisation) has decided to save e.g. 8% of its expenditure it finds it often impossible to allocate this savings target because each ministry (or division) maintains that it is "impossible to save". Thus, the government has to retort to "sharing the pain equally" (and allocates the 8% savings target to each ministry). This inefficient allocation method is called in some countries the "Cheese slicer principle". In some other countries it is called the "Lawn mower principle".

[19] An even worse situation would be that of total exemption of specific sectors from any reduction target allowing them to grow as in the baseline.

emission level of 1990. In such cases 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.

3. Economic Effects of EU-wide Emissions Trading

Given the baseline scenario and the two reference cases, a number of policy cases are defined and analysed. Each case involves a different emission trading scheme, which is defined by considering different sets of sectors participating in EU-wide trading of emission allowances 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:

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

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

- Rest of energy demand sectors including other industrial sectors, households, tertiary and transport.

In all cases all EU Member States are assumed to participate in the EU-wide trading scheme. For illustrative purposes, also a variant is introduced where EU Member States participate in international emissions trading with other Annex B countries of the Kyoto Protocol.

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 compliance costs are expected to fall, since this allows for wider flexibility in choosing abatement options.

3.1. Emission Trading among Energy Supply Sectors in the EU

To investigate a gradual introduction of a trading scheme the analysis first considers the impacts of introducing an emission trading regime only for energy supply (power and steam generating) sectors against the results of the Reference case. It is economically justifiable to commence with a scheme covering energy supply sectors as seen in Table 4.

Table 4: Effects of EU-wide emission trading among energy supply sectors

	Change of country specific emissions from Reference emission reduction case (Mt CO_2)					Emission permit trading		Marginal abatement cost outside the trading regime		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors	Energy intensive industries	Other demand sectors	% change	Mt CO_2 (+sellers /- buyers)	Price (Eur'99/tCO_2)	Eur'99/tCO_2	% 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
EU	0.0	-0.4	-0.1	0.5	0.0	0.0		45.3	-16.6	7158.2	-20.7

Source: Primes.

The power and steam generators in Austria, Germany, France, Spain, and the UK would become net sellers of emission allowances, while the generators in all other Member States would become net buyers. In total, they trade emission allowances for 28 Mt CO_2 in 2010. This would be about 1% of all EU CO_2 emission permits in circulation in 2010[20]. In this scheme energy suppliers would reduce their emissions by 0.4 Mt of CO_2 more than in the Reference case.

The interesting result is that the allowance price estimated to result from this partial trading regime covering energy supply sectors across Member States would be more or less equivalent (€32.3/tCO_2) to the allowance price prevailing in a full intra-EU trading system (€32.6/tCO_2 – see Table 6 in section 3.3). The corresponding marginal abatement cost faced outside the trading regime at the EU level would be €45.3/tCO_2 (about 40% higher than that of full intra-EU trading).

3.2. Emission Trading among Energy Suppliers and Energy Intensive Industries in the EU

The incorporation of energy intensive industries in an EU-wide trading regime has positive but rather small impacts in terms of compliance costs (Table 5). The compliance costs would reduce by a further of €295 million. Thus, if energy supply and energy intensive industries participated in an EU-wide emission trading scheme, they would save €2163 million. This is 24% less than in the Reference Case.

[20] Note that 2010 emissions are 8% less than 1990 emissions according to the Kyoto target for the EU.

Table 5: Effects of EU-wide emission trading among energy supply and energy intensive sectors

	Change of country specific emissions from Reference emission reduction case (Mt CO_2)					Emission permit trading		Marginal abatement cost outside the trading regime		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors	Energy intensive industries	Other demand sectors	% change	Mt CO_2 (+sellers /-buyers)	Price (Eur'99/tCO_2)	Eur'99/tCO_2	% 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
EU	0.0	-7.2	6.8	0.5	0.0	0.0		43.3	-20.2	6863.4	-24.0

Source: Primes.

The marginal abatement cost outside the regime at the EU level is €43.3/tCO_2. However, the allowance price for trading across energy supply sectors and energy intensive industries increases marginally to €33.3/tCO_2. In this case the UK would turn also a net buyer of emission allowances. The volume of emission allowances exchanged in 2010 between energy supply sectors and energy intensive industries reaches 41.9 Mt CO_2. This would be about 1.5% of all EU CO_2 emission permits in circulation in 2010.

Despite the slight increase in terms of marginal abatement cost for the EU and even though the cost savings would be significantly lower than in a full intra-EU trading regime (see sections 3.3 below) the results suggest that getting these sectors in the trading regime is economically attractive. The reason is that starting with the power and steam generating as well as the energy intensive sectors would not entail a significant deviation from the optimum (in terms of price of emission allowances they would face, because the utilities have the same 'joint' target on the EU level, as they would have individually in Member State trading schemes)[21]. Companies in other sectors not involved in the scheme would then have an interest in joining the trading club, since they would gain from allowance prices lower than taxes or levies raised specifically for them.

3.3. Emission Trading among All Sectors in the EU

In the presence of emission trading among all sectors in the EU benefits from trading compared to the Reference case reach up to €3070 million (or 34%) (Table 6). In the case of full intra-EU trading, Germany, France, Spain, UK and Austria

[21] It is vital to recall that EU-wide trading starts (in the "Reference Case") from the fact that the marginal abatement costs are equalised across all sectors in each Member State. In other words, the differences within each Member State have already been ironed out before EU-wide trading starts. Thus, it is conceivable to have a situation where the marginal abatement cost at EU level will not change much. However, the average cost will fall.

would more than achieve their Burden Sharing target and become net sellers of emission allowances at a price of €32.6/tCO_2. All other Member States would find it more cost effective to supplement national abatement efforts with the acquisition of emission allowances. In 2010 emission allowances for 70.9 Mt CO_2 are exchanged across EU Member States. This would be about 2.5% of all EU CO_2 emission permits in circulation in 2010.

Table 6: Effects of EU-wide emission trading among all sectors

	Change of country specific emissions from Reference emission reduction case (Mt CO_2)					Emission permit trading		Marginal abatement cost for all sectors		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors	Energy intensive industries	Other demand sectors	% change	Mt CO_2 (+sellers /- buyers)	Price (Eur'99/tCO_2)	Eur'99/tCO_2	% 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
EU	0.0	-10.4	3.9	6.5	0.0	0.0		32.6	-39.9	5957.4	-34.0

Source: Primes.

3.4. International Emissions Trading among Annex B countries

Table 7 illustrates how relevant an EU-wide emission trading regime would be compared with a full international scheme among Annex B countries. Such a scheme would be even more cost effective than EU-wide trading. Total compliance costs in 2010 under Annex B full trading are 48.6% or €4390 million lower than in the Reference case. In other words the additional benefits of Annex B trading compared to intra-EU trading amount to €1320 million.

Table 7: International emission trading (among Annex B countries) among all sectors: Effects to EU Member States

	Change of country specific emissions from Reference emission reduction case (Mt CO_2)					Emission permit trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors	Energy intensive industries	Other demand sectors	% change	Mt CO_2 (+sellers /- buyers)	Price (Eur'99/tCO_2)	Eur'99/tCO_2	% 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
EU	150.4	80.8	12.1	57.5	5.3	-150.4		17.7	-67.3	4638.5	-48.6

Notes: It is assumed that the international allowance price would be €17.7/tCO_2. *Source*: Primes.

Assuming that the international allowance price would be €17.7/tCO_2[22] EU would become a net buyer of emission allowances from other Annex B countries. Thus, in the international emission trading case most EU Member States would not fully implement their respective Burden Sharing target on their own territory, but buy also emission allowances (mainly from Ukraine and Russia) for 150 Mt CO_2 emissions. This corresponds to 4.9% of 1990 CO_2 emissions in the EU. Interestingly, the PRIMES model suggests that at an allowance price of €17.7/tCO_2, Germany and Austria would sell emission allowances of 6.6 Mt CO_2 and 0.3 Mt CO_2, respectively.

3.5. Effects of Policy Failure: EU-Wide Emission Trading against "Cheese Slicer" Case

The results provided thus far probably underestimate the potential impact of emission trading. Recall in the Reference case it was assumed that each Member State is willing and able to design and implement an optimal emission reduction policy irrespective of other Member States. In order to illustrate how important EU-wide emission trading could be, Table 8 shows how much the Member States would gain from EU-wide emissions trading, if they had first allocated the emission reduction targets to their sectors using the Cheese Slicer principle (see section 2.3)

[22] Based on POLES model calculations, co-ordinated with the model runs of PRIMES model as regards Kyoto compliance under a regime of emission allowance trading between Annex B countries, allowance prices, leading Annex B to meet the Kyoto targets, have been found to be uniform at €17,7/tCO_2. Other model analyses result in other permit market prices. The POLES result has been used in this study in order to illustrate the effects of international permit prices on EU-wide trading regimes.

Table 8: Effects of EU-wide emission trading among all sectors compared to the "Cheese Slicer" case

	Change of country specific emissions from "Cheese Slicer" emission reduction case (Mt CO_2)					Emission permit trading		Marginal abatement cost		Compliance cost (including trading costs/revenues)	
	Total	Energy supply sectors	Energy intensive industries	Other demand sectors	% change	Mt CO_2 (+sellers /- buyers)	Price (Eur'99/tCO_2)	Eur'99/tCO_2	% change from "Cheese Slicer"	Mio Eur'99	% change from "Cheese Slicer"
AU	-0.9	-2.3	-0.9	2.3	-1.9	0.9	32.6	32.6	-77.1	45.7	-81.9
BE	13.7	0.3	-1.3	14.7	14.0	-13.7	32.6	32.6	-85.1	610.7	-74.7
DK	3.2	-0.9	0.2	3.8	7.5	-3.2	32.6	32.6	-56.4	239.8	-42.2
FI	8.8	9.7	0.5	-1.4	17.1	-8.8	32.6	32.6	-56.7	488.4	-29.7
FR	-14.4	-10.1	-3.4	-0.9	-4.1	14.4	32.6	32.6	-54.5	198.3	-67.0
GE	-51.2	-52.1	-4.8	5.7	-6.8	51.2	32.6	32.6	-75.9	3.9	-99.8
GR	1.1	-7.9	1.9	7.1	1.3	-1.1	32.6	32.6	-73.5	229.0	-74.3
IR	2.3	0.6	-0.1	1.8	6.7	-2.3	32.6	32.6	-69.6	156.6	-60.8
IT	0.8	-7.5	-1.3	9.6	0.2	-0.8	32.6	32.6	-67.1	865.2	-66.5
NL	36.5	6.0	2.9	27.6	25.4	-36.5	32.6	32.6	-81.3	1477.0	-67.1
PO	3.4	-4.5	2.0	5.9	6.8	-3.4	32.6	32.6	-76.3	332.2	-60.9
SP	-3.1	-16.5	-2.3	15.6	-1.3	3.1	32.6	32.6	-65.6	464.4	-67.2
SV	1.1	5.8	-1.0	-3.7	2.1	-1.1	32.6	32.6	-49.0	129.5	-43.1
UK	-1.3	-62.8	-10.7	72.2	-0.3	1.3	32.6	32.6	-74.6	716.7	-76.6
EU	0.0	-142.3	-18.2	160.5	0.0	0.0		32.6	-74.1	5957.4	-71.0

Source: Primes.

In this case, gains from EU-wide trading would be €11482 million in addition to the gains of EU-wide trading compared with the Reference case (i.e. the least-cost case). The corresponding marginal abatement cost at the EU level under "Cheese Slicer" case increases at €125.8/tCO_2 avoided. This is about 230% higher than in the Reference Case.

The savings from EU-wide emission trading are likely to be higher than those estimated in earlier sections, mainly because – in practice – it is impossible to determine in advance the optimal mix of reduction targets by sector. Even if such a mix was known, it would change over time due to e.g. technological progress and changes in fuel prices. Thus, the optimal targets would need to be readjusted.

EU-wide emissions trading would correct any "mistakes" that would have been made in the initial allocation of the reduction targets to sectors. In other words, it is potentially much more detrimental for a sector to get a too high or too low target, if it is not allowed to engage in EU-wide emission trading.

The "Cheese Slicer" case is very helpful in illustrating the economic impact of deviations from the least-cost solution (the Reference case) as regards the allocation of effort to the different sectors. For instance, in the Reference case Germany could achieve its target at quite modest total costs. In the case that each sector must achieve the Burden Sharing target separately, Germany becomes one of the Member States that face very high compliance costs. The corresponding marginal abatement cost increases to €135/tCO_2 (ten times higher than in 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 Agreement 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 because of relatively low marginal abatement cost in these latter sectors). As discussed in the Reference case, energy demand-side abatement efforts require very high costs. This would imply significant increase of total compliance costs for Germany.

4. Conclusions

From a policy perspective it is challenging to establish mechanisms that lead to a least-cost allocation of emission reduction efforts across sectors and Member States. The scope of the analysis was to examine alternative sectoral emission trading regimes and to evaluate their cost effectiveness in achieving the EU Kyoto commitment. Table 9 summarises the main findings for the alternative policy cases examined.

Table 9: Compliance cost, savings and marginal abatement cost of Reference and Alternative Reference ("Cheese slicer") cases in 2010

	Compliance cost	Savings against **Reference case**		Savings against **Alternative Reference case**		Marginal abatement cost €/tCO_2	
	€ million	€ million	%	€ million	%	For sectors participating in EU-wide trading	For other sectors
No EU-wide trading							
Reference case: Burden sharing target implemented least cost across sectors within a Member State	9026	n.a.	n.a.	11482	56.0	n.a.	54.3
Alternative Reference case: Burden Sharing target allocated uniformly to all sectors within a Member State	20508	-11482	-127.2	n.a.	n.a.	n.a.	125.8
EU-wide trading							
Energy suppliers	7158	1868	20.7	13350	65.1	32.3	45.3
Energy suppliers and energy intensive industries	6863	2163	24.0	13645	66.5	33.3	43.3
All sectors	5957	3069	34.0	14551	71.0	32.6	32.6
Annex B trading: All sectors	4639	4387	48.6	15869	77.4	17.7	17.7

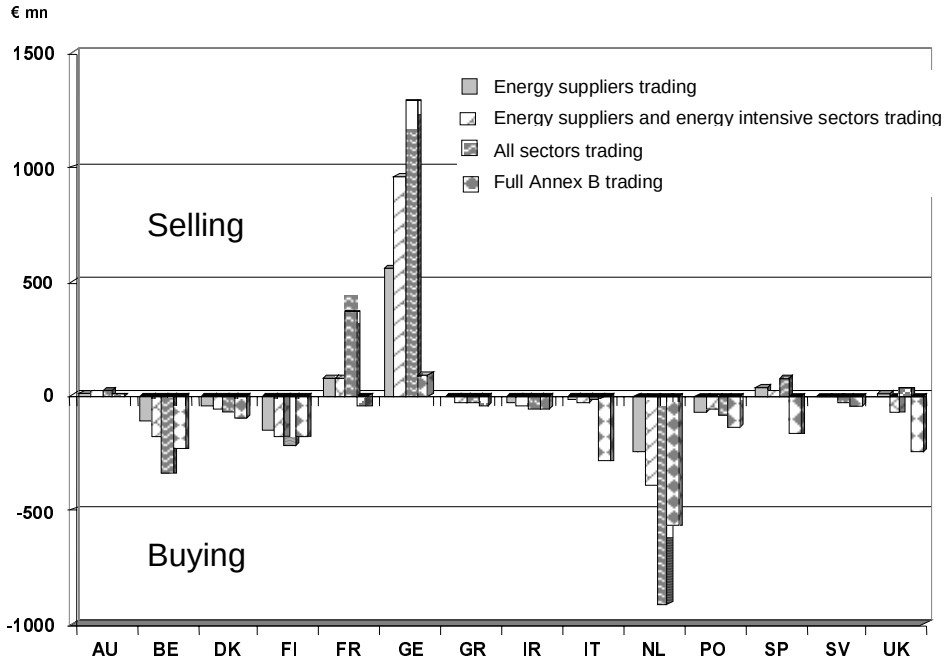
Notes: A negative sign means a cost increase. A positive sign means a cost saving.It is assumed that the international allowance price would be €17.7/tCO_2. Compliance cost and savings are on an annual basis. *Source*: Primes

The main conclusion emerging from the analysis is that emission trading across sectors and Member States results in lower total compliance costs, while achieving the same environmental outcome, than if each Member State implements the Burden Sharing Agreement alone (the Reference case). Gains in terms of total compliance costs, compared to the Reference case, range from 20.7% to 34.0% depending on the emissions trading scheme. The average cost of reduction decreases

accordingly from €24.3/tCO_2 to €18.4/t CO_2 (if energy supply and energy intensive industries trade) [23] although the marginal abatement cost does not change much.

As it is the divergence among marginal abatement costs of Member States or sectors that renders the instrument attractive, it is be important to include in the trading regime players with widely differing marginal abatement costs. The PRIMES model suggests (see Figure 2) that, among the EU Member States, Belgium, Finland and the Netherlands have the highest marginal abatement costs (and thus be net buyers) while France and Germany have the lowest marginal abatement costs (and thus be net sellers). In all cases, the results showed that extending the trading scheme leads to lower costs for each new participant, lower overall costs and consequent gains in welfare. The analysis also suggests that the electricity supply (i.e., power and steam generating) sector is a well-suited candidate to be included in an initial EU trading scheme.

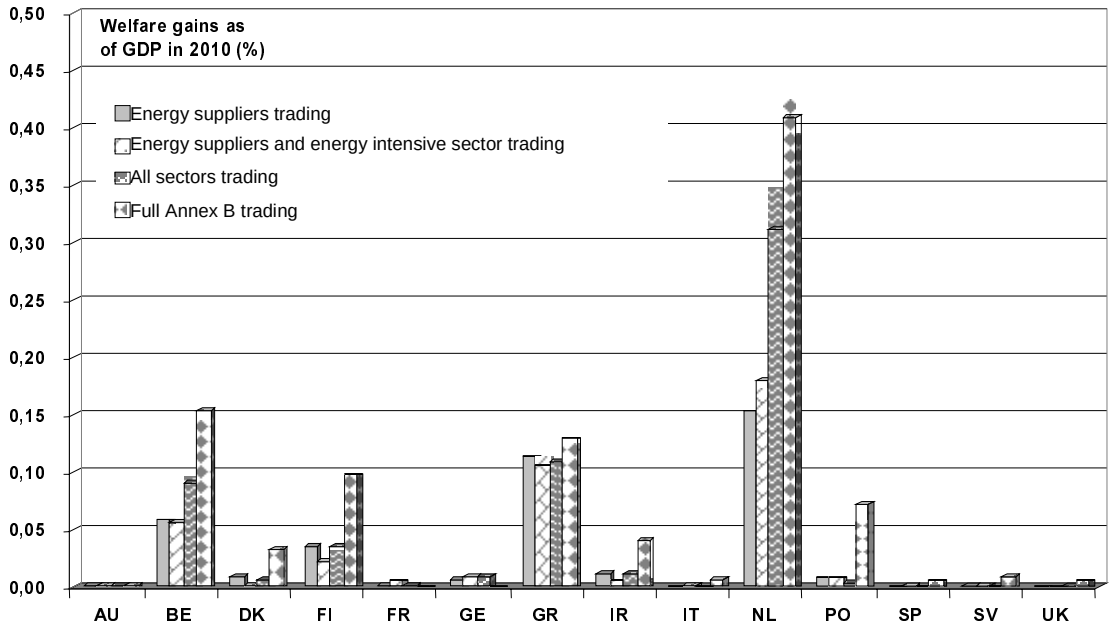
Figure 2: Sellers and Buyers in EU-wide and Annex B allowance trading



The analysis clearly demonstrates substantial economic gains from emission trading in the EU. However, one should not be guided by marginal abatement cost considerations only. It is important to analyse how important the gains from emission trading (or lost opportunities if one does not participate in trading) are compared with the Gross Domestic Product. Figure 3 indicates that while emission trading would not be important for Greece in absolute numbers, the gains from trading are quite important in relation to GDP. In some larger Member States, notably in Germany, the gains from trading may be important in absolute terms, but fairly small in relation with the GDP.

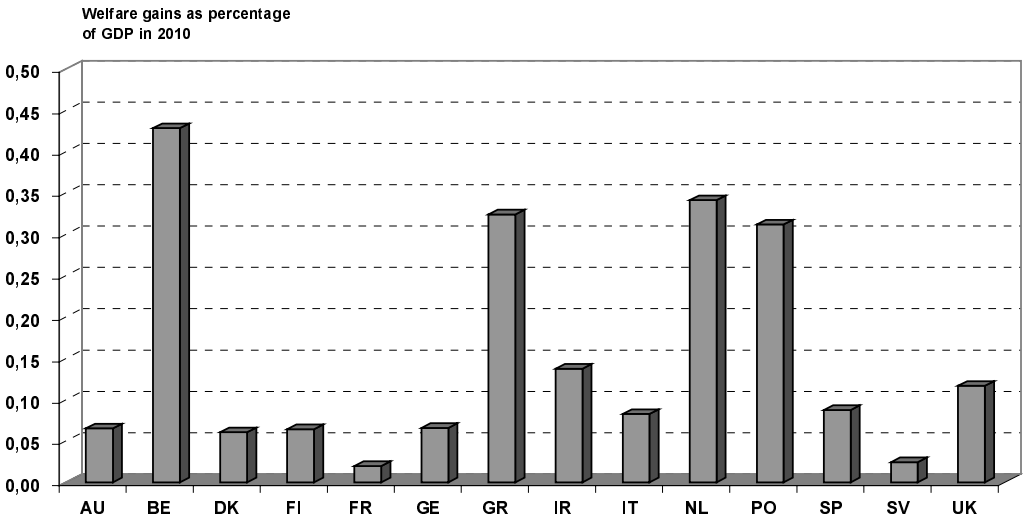
[23] The total cost of compliance (€9026 million) divided by the number of tons reduced from the baseline (327Mt CO_2) gives the average cost in the first case. For energy supply and energy intensive industries the total compliance cost was €6863 million is divided again by the same reduction effort (327Mt CO_2).

Figure 3: Welfare Gains as a Percentage of GDP in 2010 in EU-wide and Annex B permit trading



The increase in total costs from a non-efficient allocation in the "Cheese Slicer" case amounts to 127% compared to the Reference case. This indicates the crucial importance of identifying cost effective policy mixes in Member States either through an optimal allocation of targets among sectors, through optimal taxation or through national emission trading schemes. Joining in an EU-wide emission trading scheme would guarantee such benefits.

Figure 4: Welfare gains from EU-wide emissions trade in power supply and energy intensive sectors compared with Alternative Reference ("Cheese Slicer") Case



The analysis demonstrates that a step-wise implementation of emission trading as

suggested by the Green Paper appears to be economically attractive provided that the trading regime starts with those participants (sectors and Member States) gaining the most from participation. When gradually involving new participants in the trading scheme the analysis concludes that they are likely to face marginal abatement cost that would be quite similar to the cost obtained under comprehensive EU-wide allowance trading. This means that the pioneers have nothing to lose while the non-participants have incentives to join the trading regime.

This study builds on the Burden Sharing Agreement and illustrates how EU-wide emission trading would affect it. When designing environmental policy to meet the greenhouse gas emission reduction target according to the Kyoto Protocol, almost all economic sectors are concerned. As many economic variables change over the period of policy implementation, the policy design needs to take into account this dynamism. Thus, any ex-ante target allocation will most likely be some way off the cost-effective minimum during the target period (2008 to 2012). Emission permit trading is an instrument that allows economic agents to take such changes into account and as such remedy ex-ante unknown "mistakes", while guaranteeing simultaneously that the overall environmental reduction target of 8% is achieved.

Annex A – Description of the PRIMES model

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

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. Such effects cannot be analysed in the PRIMES model.

The different emission reduction schemes are applied as global (i.e. at the Member State level) or sectoral constraints in solving the PRIMES model. The mechanism through which the CO_2 constraint is attained involves the attribution of an appropriate economic value to the reduction of CO_2 emissions. Equivalently, the ability to emit CO_2 implies a scarcity value and is allocated an implicit price. There are corresponding changes in the relative prices, reflecting the CO_2 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_2 emissions.

Given the technical features and design of PRIMES the imposition of a global or sectoral emissions constraint is equivalent to the inclusion of a variable, which reflects the economic costs imposed by this constraint.[24] 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. [25]

An alternative way to think about 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 for emission allowances in an auctioning regime, i.e. in such a manner that producers and consumers of energy buy the right to emit CO_2. Evidently, buying such allowances 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.

[24] 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.

[25] One ton of CO_2 emitted contains 12/44 tons of carbon. Therefore, if the marginal abatement cost is € 1 per ton of CO_2 then the corresponding value per ton of carbon amounts to € 3.67 (i.e. 44/12).

The energy system responds to the imposition of CO_2 constraints in the form 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 CO_2 "consumption". Consequently, the resulting changes in relative prices would effectively reflect the CO_2 intensity of each fuel. In such a market, the emission target is reflected in the number of allowances that are issued. The marginal abatement cost is equivalent to the price of allowances that the market would establish for any given emission reduction target. Both the allowance price and marginal abatement cost reflect the degree of ease or difficulty faced in reaching the target.

The analysis starts from a baseline case, which reflects current policies and trends without including specific effort to reduce CO_2 emissions. Starting from the baseline, for each scenario the model is run in order to compute the least cost solution corresponding to the level of CO_2 emissions in 2010, which is implied by the emission reduction constraints that in turn are defined on the basis of the examined emission-trading scheme, which is defined by the set of sectors in various Member States that participate in the trading scheme. Non-participating sectors face individual emission reduction targets, in other terms individual marginal abatement costs can and most likely will differ from the other sectors. The model determines the allocation of efforts, necessary to meet the emission constraint, to sectors and Member States participating in the trading bubble.

The sectors included are 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 shifting the energy mix in favour of electricity might induce higher emissions in a supply sector such as the one 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 scenario. 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 cost of abated emissions and of the energy system costs of these changes, by sector and Member State. Following a least cost methodology, the marginal abatement cost 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 the marginal cost is complex. The imposition of a CO_2 constraint induces an external cost to the economy compared to baseline conditions. However, from the perspective of

societal welfare the constraint aims to internalise the external cost of emitting CO_2, 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_2 avoided, equal to the marginal abatement cost corresponding to that ton. Therefore, the total abatement cost implied by an emission constraint is equal to the area (the integral) below the marginal abatement cost curve.

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

The additional costs for the economic sectors arising from the higher costs in the provision of the energy service do not represent a direct leakage from the economy. 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. In the end, each economic sector will likely be affected differently. Some may be impacted significantly (e.g. energy intensive industries) or negligibly (even more positive), if they face an increased activity within the new allocation. However, these general equilibrium costs or benefits (in particular those for future generations because of averted climatic change) are not included[26] in the calculations based on PRIMES.

[26] General equilibrium models, such as GEM-E3 are suitable for such calculations. However, details of supply and demand of energy are much less developed in general equilibrium models than in PRIMES.