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Exploring European countries' emission reduction targets, abatement costs and measures needed under the 2007 EU reduction objectives

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Rapport in het kort

Het verkennen van de emissiereductiedoelstellingen, mitigatiekosten en noodzakelijke maatregelen voor de Europese lidstaten onder de 2007 EU-reductiedoelstellingen

Het is technisch mogelijk voor de Europese Unie om de in 2007 aangenomen unilaterale reductiedoelstelling van 20% ten opzichte van het 1990-niveau te halen. De tevens in 2007 aangenomen multilaterale reductiedoelstelling van 30% kan technisch worden gehaald door de inzet van CDM en emissiehandel, maar kan wel leiden tot hogere kosten. Energy efficiency verbeteringen vormen in beide scenario's veruit de belangrijkste reductieoptie, gevolgd door veranderingen in brandstofkeuze en de reducties van niet-CO_2-broeikasgassen. De reductiedoelstellingen en kosten voor de individuele EU-lidstaten in 2020 verschillen aanzienlijk, en zijn sterk afhankelijk van de methode voor de interne differentiatie van emissiereducties (bijvoorbeeld op basis van gelijke kosten of convergentie in hoofdelijke emissies), en in een mindere mate van de EU-reductiedoelstelling zelf (20% unilateraal of 30% multilateraal). Hierdoor is een afspraak over de interne differentiatiemethode belangrijker dan de afspraak over de algemene EU reductiedoelstelling.

Trefwoorden: EU-lastenverdeling, reductiekosten, emissie handelsysteem, post-2012 regime, emissie doelstellingen, toekomstige verplichtingen

Contents

Summary

Under the Kyoto Protocol, the EU Environment Council adopted a greenhouse gas (GHG) emission reduction target of 8% in 1997 for the EU in 2012 relative to 1990. In March 2007 the EU decided to adopt a unilateral target of reducing its GHG emissions by 20% in 2020 compared to 1990 levels. The EU also declared its willingness to reduce its emissions by 30% as its contribution to a global and comprehensive agreement for the period beyond 2012, provided that other developed countries commit themselves to comparable emission reductions, and economically more advanced developing countries also contribute adequately according to their responsibilities and respective capabilities.

This report explores methods for allocating the EU reduction objectives (20% unilateral or 30% multilateral) adopted by the Council of the European Union among the European Member States to analyse the impacts on costs, reduction efforts and distributional effects. More specifically, the analysis focuses on three scenarios based on different assumptions for the level of international participation and the EU reduction objective, i.e.:

1. '*EU 20% unilateral without CDM*': The EU implements its 20% reduction target independently and all other countries implement hardly any climate policy beyond 2012. Emission allowances are traded freely between the EU Member States, but this case assumes no availability of JI (Joint Implementation) and CDM (Clean Development Mechanism) beyond 2012;
2. '*EU 20% unilateral with CDM*': This case is similar to the 'EU 20% unilateral without CDM' case, but now with the availability of international flexibility mechanisms JI and CDM;
3. '*EU 30% in a multilateral regime*': The EU adopts a 30% reduction target as part of a broader coalition, in which Annex I countries and advanced developing countries adopt comparable reduction efforts by 2020. Emissions trading is only allowed within the coalition. Furthermore there is the availability of JI and CDM beyond 2012.

This study also analyses the reduction targets and abatement costs for the 27 EU Member States (the EU-15 countries, i.e. the old EU members, the EU-10 countries, i.e. the new EU members and Bulgaria and Romania, i.e. the latest EU newcomers, hereafter also EU-2 new) in 2020, based on two major types of options for EU burden-sharing and Emission Trading System (ETS) allocation beyond 2012:

1. *Present system,* i.e. initially sharing the overall EU emission target among its Member States and, subsequently each Member State dividing its national target between the ETS and other sectors.
2. *EU burden-sharing with ETS allocation at EU level,* i.e. both the top-down ETS cap and the bottom-up allocation rules are set at EU level, while the EU target for the non-ETS sectors is shared among the Member States.

For the option 1, the six different possible post-2012 regimes for internal EU burden-sharing are selected:

(i) *Grandfathering,* i.e. applying a flat reduction rate for all EU countries to their historic emissions in a certain reference period (Kyoto targets);

(ii) *Per capita convergence,* i.e. differentiation of emission reductions based on a convergence of emission allowances towards an equal per capita emissions in a certain convergence year (2050);

(iii) *Multi-criteria,* i.e. differentiation of emission reductions based on a convergence of the indexed value of a mix criteria, notably (i) income per capita, (ii) emissions per capita, and (iii) emissions per unit GDP (equal weighting);

(iv) *Ability to pay,* i.e. differentiation of emission reductions based on per capita income (Market Exchange Rates MER);

(v) The *'Triptych' approach,* i.e. differentiation of emission reductions based on a variety of sector and technology criteria; and

(vi) The *Equal costs approach,* i.e. differentiation of emission reductions based on equal mitigation costs per country (as a percentage of Gross Domestic Product (GDP) expressed in MER).

For option 2, the allocation between the ETS and non-ETS sector at EU level is based on the allocation schemes (i) *Marginal abatement costs* (i.e. differentiation of emission reductions based on the same marginal abatement costs per country), (ii) *Grandfathering,* (iii) *Triptych* approach. The first option is selected because it reflects the ambition for maximum cost efficiency, the second as this method is used as the present allocation scheme. The third option has been used in the past for the internal EU burden-sharing during the Kyoto negotiations. The allocation of the non-ETS sector is based on *Marginal abatement costs*, *Grandfathering*, *Triptych* and *Per capita convergence* approach. The first three are selected here for the same criteria as described before, and the last is included as it is simple and commonly used.

The report further analyses whether it is technically feasible, and what portfolio of reduction measures (including the Kyoto mechanisms) would be required to meet these EU reduction objectives.

From the aforementioned analysis, the authors draw the following main conclusions:

- It is technically feasible for the EU to meet the 20% reduction target as part of a unilateral regime, with abatement costs in the order of 0.2–0.3% of GDP when CDM is excluded. Including CDM would lower to a third under a cost optimal implementation (unrestricted CDM). It should be noted that these costs only capture direct costs of abatement action not taking into account the costs related to a change in fuel trade or macro-economic impacts (such as sectoral changes or trade impacts).

- Meeting a 30% reduction objective as part of a multilateral regime leads to higher abatement costs for the EU than meeting its independent 20% reduction target in a unilateral regime. The 20% unilateral scenario and 30% multi-lateral regime scenario lead to the same level of domestic reductions for the EU (i.e. 20% compared to 1990 level). However, for the 30% multi-lateral regime the additional reduction to achieve the

30% reduction will be met through CDM and international emissions trading at relatively high costs.

- The emission reduction targets for the various European countries caused by the applied burden-sharing approaches show a wide range for EU burden-sharing and ETS allocation beyond 2012 for both major options.

  More specifically, a uniform reduction target (*Grandfathering*) leads to high reductions for the first option for EU burden-sharing and ETS *Present system* applied to countries which currently have emission growth targets under the Kyoto Protocol; examples are Greece, Portugal and Spain. *Per capita convergence* and the *Multi-criteria* approaches lead to high reductions for countries with relatively high per capita emissions, while the *Ability to pay* approach leads to higher reductions for the EU-15 countries. Even though the *Equal costs* approach leads to high reductions for the EU-10 and some EU-15 countries, the results highly depend on the costs assumptions. The *Triptych* approach takes a kind of central position in terms of differences in reduction targets between countries compared to the other regimes.

  Referring to the second option for EU burden-sharing and ETS *EU burden-sharing with ETS allocation at EU level* the overall reduction targets of countries also show a wide range. Grandfathering leads to high reductions for countries with a growth target under Kyoto (see also option 1). The *Marginal abatement costs* approach leads to high reductions for many EU-10 countries, and Bulgaria and Romania (EU-2 new), and a mixture of high and low reductions for the EU-15 countries. The reductions under the *Triptych* approach are closer to the middle compared to the reduction of all cases.

- The option EU burden-sharing with ETS allocation at EU level leads to more absolute reductions in the non-ETS sectors than in the ETS sectors, as reducing emissions in the non-ETS sector is more cost-effective or more effective in terms of reduction potentials compared to the ETS sector. However, as in the baseline scenario the total emissions in the non-ETS sector (especially from transport) increase more than the emissions in the ETS sector, compared to 1990 levels the reductions the emissions in the ETS sector are larger (especially from industry). For the industry sector the reductions compared to 1990 levers are well above the overall EU reductions (20% or 30%), whereas in the power sector the reductions are just above the overall EU reductions. The reductions for the non-ETS sector show a wide range for all countries.

- There are also large differences in the countries' abatement costs between regimes, obviously except for the Equal costs approach. Generally, the EU-15 countries are confronted with medium costs, while many EU-10 countries and the EU-2 new countries (Bulgaria and Romania) may benefit from emissions trading.

- The 'Triptych' approach seems to result into the most equally spread distribution of reduction efforts and abatement costs among all European countries (more for EU-15 countries and less for EU-10 countries, Bulgaria and Romania) and it also scores high in a qualitative multi-criteria analysis on the basis of environmental criteria, political criteria, economic criteria and technical criteria (compared to the other approaches).

- For many countries, the difference between the various approaches aiming for one overall EU reduction level (of 20% or 30% reduction) can be larger than the difference in reductions needed to reach the overall EU reduction level. Hence, the agreement on the burden-sharing regime may be more significant than the agreement on the overall EU reduction level.

  For example, in the *Present system* for Spain the range covers a reduction of 17% to a growth of 18% for the EU 20% reduction target. This overlaps with the EU 30% reduction target, in which the range covers a reduction of 25% to a growth of 5%. Option 2 *EU burden-sharing with ETS allocation at EU level* shows a similar pattern.

- The EU-15 countries are net buyers on the emissions trading market for the EU 20% unilateral scenarios, while the EU-10 and EU-2 new countries are net sellers. Many EU-10 countries become small buyers for the EU 30% multilateral regime scenario.
- The United Kingdom's 2020 reduction target of 27% – 32% (compared to 1990 levels) is consistent with the range of reductions for the United Kingdom associated with the EU 20% reduction objective found in this study, but lower than our United Kingdom range for the EU 30% target.
- The Netherlands' 2020 reduction target for greenhouse gases of 30% is outside the range resulting from various allocation approaches for meeting the 20% EU target [about 10% – 20% emission reduction], but inside the range for the EU 30% target [about 20% – 30% emission reduction].
- Meeting the EU overall reduction objective requires major changes in the energy system. Energy efficiency improvements represent by far the largest share in emission reductions, followed by fuel shift switch and non-CO_2 reduction options. This study did not analyse the feasibility of the EU 20% renewables target.

1 Introduction

1.1 Background

While there has been much attention in the literature and policy circles for both post-2012 international climate regimes and the – mainly short-term – future of the European Emissions Trading System (ETS), hardly any attention has yet been paid to the issue of future internal EU burden-sharing, and how this may relate to the future of the ETS. The issue of EU burden-sharing has only recently returned to the EU climate policy agenda. One reason for this is that the other issues have generated more immediate concern. This also applies to the international regime, due to uncertainty about the future of the Kyoto Protocol after the withdrawal of the USA, and for the ETS because of its central role in meeting the present EU commitments under the Kyoto Protocol up to 2012.

At the same time, the EU has started defining its medium and long-term international climate strategies. It did so using a 'top-down' rather than a 'bottom-up' approach and from a global perspective. In December 2004, the EU Environment Council concluded that, in order to have a reasonable chance of limiting global warming to 2°C above pre-industrial levels, global emissions would possibly need to peak within two decades, and subsequently be reduced by at least 15% (and possibly as much as 50%) by 2050, compared to 1990 levels. In March 2005 the EC concluded that, as part of a global effort, industrialised countries would need to adopt emission reductions in the order of 15–30% by 2020, and should consider reductions up to 60–80% by 2050.[1] Although these figures are well conditioned by broader participation and other Annex I Parties taking on similar commitments, the EU sent out a strong signal.

On 10 January 2007 the European Commission went another step further by setting out proposals and options for keeping climate change to manageable levels in its Communication 'Limiting Global Climate Change to 2° Celsius: The way ahead for 2020 and beyond'.[2] More specifically, it proposes that (in the context of international negotiations) the EU should pursue the objective of 30% reduction in greenhouse gas emissions (GHG) by developed countries by 2020 (compared to 1990 levels). This is considered necessary to ensure that the world stays within the 2ºC limit. Until an international agreement is concluded, and without prejudice to its position in international negotiations, the EU should now take on a firm independent commitment to achieve at least a 20% reduction of GHG emissions by 2020, via

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[1] http://ue.eu.int/ueDocs/cms_Data/docs/pressdata/en/ec/84335.pdf

[2] The January 2007 Communication follows up and builds on a Communication published by the Commission in February 2005 entitled 'Winning the Battle Against Climate Change', which highlights the need for broader participation by countries and sectors not already subject to emission reductions, the development of low-carbon technologies, the continued and expanded use of market mechanisms, and the need to adapt to the inevitable impacts of climate change (http://ec.europa.eu/environment/climat/future_action.htm).

the EU-ETS, other climate policies and actions in the context of the energy policy. This approach should allow the EU to demonstrate international leadership on climate issues.

The EU Environment Council[3] adopted these conclusions at its meeting in February 2007. More specifically, 'the Council is willing to commit to a reduction of 30% of greenhouse gas emissions by 2020, compared to 1990, as its contribution to a global and comprehensive agreement for the period beyond 2012, provided that other developed countries commit themselves to *comparable* emission reductions, and economically more advanced developing countries adequately contribute according to their responsibilities and respective capabilities.' 'Until a global and comprehensive post-2012 agreement is concluded, and without prejudice to its position in international negotiations, the EU makes a firm independent commitment to achieve at least a 20% reduction of greenhouse gas emissions by 2020 compared to 1990.'

At the beginning of March 2007 the European leaders confirmed the target of a 20% reduction in greenhouse gas emissions by 2020, and additionally agreed on the commitment that renewable energy will comprise 20% of EU energy consumption by the same year. These decisions, in particular on the independent 20% reduction commitment, are quite remarkable for two reasons. First, the EU has not yet fully explored the economic implications of such targets via a range of economic and energy-system models[4], especially not for scenarios under limited participation.[5] Second, the EU has still to discuss and agree on the internal allocation of the emission reduction efforts. This is in contrast to the policy process preceding the agreement on the Kyoto Protocol (COP-3, 1997), when the EU made its proposal for a 15% emission reduction target for the industrialised countries after an internal agreement on internal burden-sharing among its Member States (see for further details, Ringius, 1999). However, as the discussions on the new climate targets in the Environmental Council already indicated, the issue of how to distribute the emission reduction burden internally will again become important. The Council conclusions in March decided that a differentiated approach to the contributions of the Member States is needed, which should reflect fairness, be transparent and take into account the national circumstances of the Member States. The EU Environmental Council recognises that the implementation of these targets will be based on EU policies and on internal burden-sharing agreements. Finally, it invites the European Commission, in close cooperation with the Member States, to immediately initiate a technical analysis to provide a basis for further in-depth discussion.

[3] http://register.consilium.europa.eu/pdf/en/07/st06/st06621.en07.pdf

[4] A staff working paper provides the background analysis for the Communication 'Limiting Global Climate Change to 2° Celsius: The way ahead for 2020 and beyond', which can be downloaded from: http://ec.europa.eu/environment/climat/pdf/ia_sec_8.pdf.

[5] Russ et al. (2005a) uses a macroeconomic model GEM-E3 (Capros et al., 1997) and an energy model POLES (Criqui et al., 2003) to analyse the costs for the EU when the EU reduces emissions by 2025 to 20% below 1990 levels, and no other countries take on commitments beyond 2012. Boeters et al. (2007) analysed limited participation scenarios with EU reductions as high as 10% compared to 1990 levels.

1.2 Three scenarios

Given the fact that the EU has already proposed a 20% (independent) reduction target, this report starts from an internal burden-sharing of the 20% reduction target. More specifically, the report analyses the reduction targets and abatement costs for 27 individual European countries, for an overall target of 20% below 1990 levels in 2020, based on different approaches for internal EU burden-sharing. It also presents the reduction measures (i.e. energy efficiency improvements) needed, as well as the role of external abatement measures (Kyoto mechanisms, CDM and emissions trading) in meeting the reduction commitments in a cost-effective way. It should be noted that the costs presented in this study only capture direct costs of abatement action but not taking into account the costs related to a change in fuel trade or macro-economic impacts (including sectoral changes or trade impacts).

This report refers to the subdivision of the EU[6] into three groups, i.e. the EU-15 countries, i.e. the old EU members, the EU-10 countries, i.e. the new EU members and Bulgaria and Romania, i.e. the latest EU newcomers, hereafter also EU-2 new, as presented in Table 1.1. The group of the 27 EU countries is further referred to as the EU.

Table 1.1: The 27 EU countries[7] plus the three groupings used in this report. The 'EU region' refers to the 27 EU countries as a single group.

EU-15	EU-10	EU-2 new
Ireland	Slovenia	Bulgaria
Belgium	Cyprus	Romania
Germany	Czech Republic	
Denmark	Slovak Republic	
Spain	Hungary	
Finland	Estonia	
France	Poland	
United Kingdom	Malta	
Austria	Latvia	
Greece	Lithuania	
Portugal		
Sweden		
Luxembourg		
The Netherlands		
Italy		

This analysis focuses on three scenarios based on varying assumptions for the participation of world countries and the EU reduction objective, i.e.:

1. '***EU 20% unilateral without CDM***': There is insufficient political will for a collaborative international post-2012 agreement. The EU implements its 20% independent reduction target and all other countries hardly implement any climate policy beyond 2012. Emission allowances are traded freely between the EU Member

[6] Norway, Turkey and Switzerland do not belong to the EU and form no part of the EU-bubble at the time of writing, and are therefore not included in the calculations in this report.

[7] The former Yugoslavia states are not included in calculations for this report. However, the omitted emissions are negligible on the European scale.

States through the Emissions Trading System (ETS). This case assumes no availability of JI and CDM beyond 2012.

2. ‘***EU 20% unilateral with CDM***’: This case is similar to that of the ‘EU 20% unilateral without CDM’, but now includes the availability of international flexibility mechanisms JI and CDM beyond 2012.
3. ‘***EU 30% in a multilateral regime***’: The negotiations succeed in forming a coalition that adopts emission reduction targets, including not just the Annex I countries, but also all advanced developing countries (ADCs) such as China, Mexico, South Korea and Brazil. The EU adopts a 30% reduction target, and other Annex I countries plus ADCs adopt comparable reduction efforts by 2020.[8] Emissions trading is only allowed within the coalition. There is also the availability of JI and CDM beyond 2012, as an emission reduction option in countries with no restrictions on emissions, such as India.

The following section presents these different burden-sharing approaches, but first we briefly describe the new circumstances for EU burden-sharing.

1.3 New circumstances for EU burden-sharing

Compared to the pre-1997 Kyoto Protocol period, there are a number of factors that have changed and will affect the internal EU burden-sharing discussion, including:

- The extension of the EU from 15 to 25 Member States and recently to 27 Member States (as already mentioned above): The extension not only increases the number of Parties whose concerns and interests need to be met; it has also resulted in a greater diversity in national circumstances.[9] The new Eastern European Member States are generally much less wealthy than the other EU Member States and their economies less energy-efficient. Some Member States also have relatively carbon-intensive economies due to the high percentage of coal used in power generation (e.g. Poland, Czech Republic and Bulgaria). Wagner and Michaelowa (2005) have shown that the enlargement allows the EU bubble to expand and to take on a much more stringent target for the second commitment period of the Kyoto Protocol.
- The introduction of the EU-ETS, which came into effect at the beginning of 2005. This system has introduced national caps on the (CO_2) emissions from major emitting sectors (energy production, heavy industry). It implies that emissions from Member States are not only affected by future internal burden-sharing arrangements, but also by the allocations under the ETS. Moreover, in contrast to the internal burden-sharing, the allocation of emissions to sectors under the ETS is subject to the scrutiny of the

[8] Chapter 5 analyses the question as to what level of efforts by other Annex I parties and advanced developing countries could be considered comparable to the EU 30% reduction targets.

[9] The EU enlargement also affects the greenhouse gas bubble under the Kyoto Protocol. It could reduce the gap between business-as-usual and the target during the first commitment period by about 50% (see Michaelowa and Betz, 2001). The enlargement also affects the emission reduction targets for the second commitment period, as first analysed by Wagner and Michaelowa (2005).

EU Commission, rather than just the Member States. Thus the ETS has reduced the flexibility for Member States in distributing emission reductions among sectors. On the other hand, the ETS has enhanced the opportunities for Member States to meet their EU burden-sharing commitments in a more cost-effective way.

Theoretically, the internal EU burden-sharing could be heavily impacted by the ETS, depending on the future development of the ETS. If emission allocation under the ETS is increasingly determined by the EU Commission (either by direct allocation or via strict guidance for the Member States in making allocation plans) and the scope of the ETS continues to be broadened, this will increasingly affected the EU burden-sharing among the Member States. Initially it may result in Member States anticipating the allocations under the ETS and trying to obtain compensation. Eventually, the EU burden-sharing may be stripped down to dealing only with the remaining emission allowances of the sectors not included in the ETS. In the longer term, it can be envisaged that continually extending the scope of the ETS and removing national jurisdiction would result in the EU becoming the only Party to take on new commitments under future international climate agreements, rather than the individual Member States.

Sijm et al. (2007) discusses the links between the EU-ETS and EU burden-sharing in more detail, and consider three major types of options for EU burden-sharing and ETS allocation beyond 2012:

1. *Present system,* i.e. initially sharing the overall EU emission target among its Member States and, subsequently each Member State (MS) dividing its national target between the ETS and other sectors, while the allocation of the national ETS cap to eligible installations is based on (different) MS rules.
2. *EU burden-sharing with ETS allocation at EU level,* i.e. both the top-down ETS cap and the bottom-up allocation rules are set at EU level, while the EU target for the non-ETS sectors is shared among the Member States.
3. *EU burden-sharing with an EU-wide ETS cap and MS allocation for either (a) both existing and new installations (Type 3a) or (b) existing installations only (Type 3b),* while the EU target for the non-ETS sectors is shared among the Member States.

These three types of options have different implications in quantitative terms[10] (e.g. assigned amounts of emissions and costs at the EU, national, sector or installation levels), depending on the specific burden-sharing and allocation rules applied. The three options are discussed in more detail in chapter 4 of this report. However, the analysis focuses only on the first two options. Chapter 5 uses option 1 as the starting point: more specifically, starting with an EU reduction target, the emissions are re-allocated (excluding the international aviation and marine sector) among the individual European countries using different burden-sharing approaches (next paragraph), with calculations of the national reduction targets and abatement costs (accounting for the Kyoto Mechanisms). Chapter 6 uses option 2 as its

[10] For a discussion on the effect of the three options in qualitative terms, see Sijm et al. (2007).

starting point, and first calculates the EU targets for the ETS and non-ETS sectors, based on an EU reduction target, then calculates for the EU-ETS cap according to bottom-up rules (described in chapters 4 and 6) the allocation in the ETS sector among the different sub-sectors with ETS. Finally, the non-ETS cap per Member State is calculated using different burden-sharing approaches.

Coverage of the EU-ETS scheme ─ The EU-ETS currently covers CO_2 emissions from combustion plants (>20 MW thermal input; including power generators, oil refineries, coke ovens), as well as from activities and sectors such as ferrous metals, cement clinker, pulp from timber, glass and ceramics (> threshold capacity level; including process emissions). About 45% of the EU's CO_2 emissions are covered by the EU-ETS. A greater proportion should be covered from 2013. For the period post-2012, this coverage may be changed, including the following options (Sijm et al*.,* 2007):

- *Emissions:* It has been suggested that process emissions should be excluded from the EU-ETS in order to make the designs of National Allocation Plans more transparent and simple (also because it is hard to reduce process emissions).
- *Gases:* Coverage of the EU-ETS could be expanded by including greenhouse gases other than CO_2, such as methane or perfluorcarbons (PFCs).
- *Sectors/activities:* On the one hand, a suggestion has been made to expand the present coverage of the scheme to include other sectors and/or activities (notably aviation) in order to enhance the environmental effectiveness and economic efficiency of the scheme. On the other hand, it has been proposed that small installations should be excluded from the scheme because of the high transaction costs for these installations, which contribute only a small fraction of the total emissions covered.

This report assumes (for the post-2012 EU climate regime) that the ETS sector includes all GHG emissions from the electricity and industry sector, and the non-ETS sector includes the remaining emissions. This assumption only affects the calculations for option 2, i.e. the analysis presented in chapter 6.

1.4 Post-2012 EU burden-sharing approaches

The emission reduction percentages of the European countries for the first commitment period of the Kyoto Protocol were essentially based on the political willingness of European countries themselves. There was little underpinning of the level of global or Annex I action needed. The initial proposal for allocating emission reductions within the EU-15 countries was based on the Triptych approach (section 3.7), but these figures were further renegotiated before and after the Kyoto agreements (see Phylipsen et al., 1998; Ringius, 1999). It is not yet clear how a new internal EU burden-sharing agreement would be reached. The European Council (EC, 8-9 March 2007) has asked the EU Commission 'to start a technical analysis of criteria, including socioeconomic parameters and other relevant and comparable parameters, to form the basis of a more in-depth discussion', but is unclear what will be done with this information. Given the fact that the EU has already proposed a 20% reduction target; this seems the most logical starting point for the negotiations. Again, negotiations could be based on initial proposals based on certain allocation formula, but this is not certain. In principle, two variants for differentiating future emission targets between EU Member States can be envisaged (Höhne et al., 2005):

1. In a next round of negotiations, the EU Member States start the process by indicating what individual reductions they consider feasible/acceptable for their country (pledge-based approach). This approach includes the risk that these reductions do not lead to the low emission level needed to reach the overall agreed EU total reduction (20% or 30% reduction compared to 1990 levels).
2. Alternatively, a common formula could be agreed (see also below) to differentiate between emission targets, starting from the overall reduction target objectives. This rule could lead to reduction percentages for each individual country, which could then be modified by further negotiations.

For the second variant, an allocation rule or formula would have to be selected in order to share emission allowances between the EU countries. This report focuses on this variant and considers six burden-sharing approaches.

The simplest approach would be to choose a reference year and to apply equal percentage reductions to all countries ('flat rate' or 'grandfathering') (*1. Grandfathering*). This method is simple but does not take into account structural differences between countries, historic trends and reduction potentials. It is therefore very unlikely that this will happen. Some of the other rules have been proposed by various countries during the negotiations on the Kyoto Protocol, including EU Member States (see for an overview Torvanger and Godal, 2004). Early in the negotiations France, Switzerland and the EU proposed differentiation based on convergence of per capita emissions over time (UNFCCC, 1997a) (*2. Per capita convergence*), but this was withdrawn on the advent of the agreed common EU target (Depledge, 2000). Norway and Iceland proposed burden-sharing based on multi-criteria rules containing a set of indicators. Specifically, the Norwegian proposal considers a Party's reduction of greenhouse gas emissions based on three indicators: GDP per capita, emission intensity and emissions per capita (*3. Multi-criteria*). There were also proposals from the new EU Member States. Poland supported by other East European states (Bulgaria, Estonia, Latvia and Slovenia) suggested a burden-sharing scheme based on GDP per capita as the main criterion for differentiation (*4. Ability to pay*). Instead of these rather 'simple' allocation rules, more complex allocation approaches could also be used. Here two candidates are considered: the (renewed) Triptych approach (*5. Triptych*), and an approach based on equal costs or welfare loss for all Member States (*6. Equal costs*).

From these more complex approaches, the first candidate (the *Triptych* approach) has proved its use in supporting decision-making to differentiate between the EU's internal Kyoto target between its Member States, both before and after Kyoto (COP-3) (Blok et al., 1997). In the political (negotiation) process of the EU and its Member States, the application of the Triptych approach was very successful because it resulted in increased insight among EU negotiators concerning the feasibility and comparability of emission reductions and the differences in national circumstances. On the basis of this improved understanding it was possible to come to an agreement on burden differentiation within the EU. The Triptych approach also fits in well with the sector-based approach of the ETS.

However, as shown in the evaluation of the burden-sharing arrangement for the first commitment period, it does not necessarily result in equal relative costs for all Member States (Eyckmans et al., 2002; Viguier et al., 2003). More specifically, some countries (Sweden, Belgium, the Netherlands, Spain and Portugal) have a relatively heavy burden, while others (Germany, United Kingdom and France) have a relatively light burden. This risk may be enhanced by the increase in the diversity between EU Member States. This is what the second candidate *Equal costs* approach intends to secure. This is an outcome instead of an allocation-based equity formula (Rose et al., 1998).[11] More specifically, the rule is to distribute the emission reductions in order to equalise net welfare changes across nations (net gain or loss as proportion of GDP equal for each nation).[12] It does require the use of macroeconomic or energy system modelling tools. This implies that the allocation becomes model dependent and thus would first require agreement on the tools to be used, which may be rather complicated.[13] Here, costs are assumed to mean the abatement costs, i.e. abatement costs plus emission permit sales revenues minus permit purchase costs, and the objective is to achieve the same abatement costs, as a percentage of GDP, for all countries. The FAIR model is used to calculate abatement costs.

This report is structured as follows. Chapter 2 describes the methodology of the modelling framework FAIR 2.1, at the level of individual European countries. Chapter 3 describes the six EU burden-sharing approaches analysed in this report in more detail. Chapter 4 highlights the three major types of options for EU burden-sharing and ETS allocation beyond 2012. Chapter 5 analyses the emission reductions, abatement costs and reduction measures (including the Kyoto Mechanisms) for the EU countries for the three scenarios based on the

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[11] The first five burden-sharing approaches are *allocation based,* i.e. defining equitable differentiation of commitments in terms of principles for the distribution of emission allowances or the allocation of emission burden approaches, whereas this approach is *outcome based*, i.e. defining equitable differentiation of commitments in terms of outcome, in particular the distribution of economic effects. Allocation-based approaches are preferred because they are more straightforward, transparent, and specifiable with perfect certainty. A disadvantage of outcome-based approaches is that they are dependent on complex (economic) models, the outcomes of which are usually not transparent to policy-makers. Outcome-based criteria are also subject to controversy over definition of the criteria themselves and the measure of welfare. On the other hand, the (perceived) costs and economic impacts of options for differentiation of future commitments will have an important impact on the evaluation of policy options (see chapter 4).

[12] Net welfare change (gain or loss) is equal to the sum of mitigation benefits (benefits from mitigation of greenhouse gas mitigation, such as reduced climate damage) – abatement costs + permit sales revenues – permit purchase costs.

[13] Obvious candidates would be models already widely used by the EU Commission, such as the GEM–E3 model, but instead of one common model a set of different models could also be used to check the robustness of the outcomes.

present system for EU burden-sharing and ETS allocation (option 1). Chapter 6 presents a similar analysis, but now based on *EU burden-sharing with ETS allocation at EU level* (option 2). Chapter 7 presents a comparison with other studies, the robustness of the results, including a sensitivity analysis, and the limitations of the study. Finally, the conclusions are listed in chapter 8.

2 The FAIR EU modelling framework

This chapter describes the FAIR EU modelling framework, which consists of three subsequent modelling steps:

1. The FAIR region model (including the EU as a region);
2. The FAIR EU model (including the 27 EU countries);
3. The MAC-EU tool.

The models are fed by two databases:

1. The TIMER-IMAGE baseline emissions (i.e. for the calculations presented in this report, the IMAGE/TIMER B2 baseline scenario, see Box 1) and MAC (marginal abatement cost) curves for 15 non-EU world regions (i.e. Canada, USA, Former Soviet Union (FSU), Oceania and Japan (Annex I regions); Central America, South America, the Middle East and Turkey, Northern Africa, Southern Africa, East Asia (incl. China) and South-East Asia and Western Africa, Eastern Africa and South Asia (incl. India) (non-Annex I regions))[14];
2. The LREM baseline emissions (see Box 2) and GENESIS reduction measures for the EU region and the 27 individual EU countries. The sections below describe the separate models and databases in more detail, as well as their interlinking aspects (see also Figure 2.1).

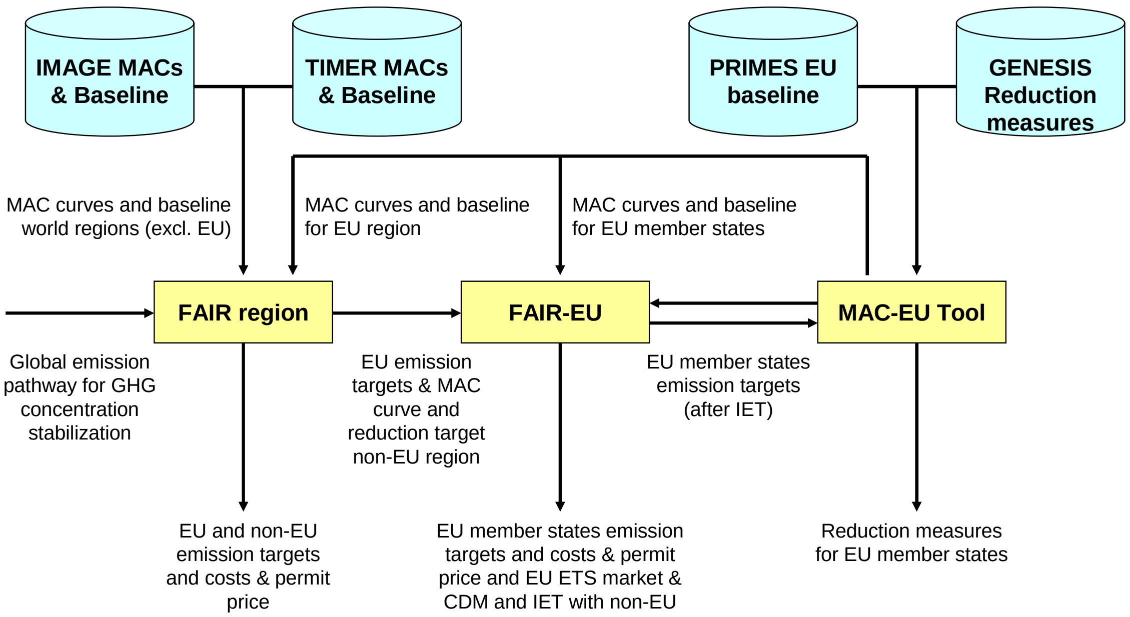

Figure 2.1: The FAIR EU modelling framework.

[14] Corresponding with the 17 IMAGE world regions, excluding OECD and Eastern Europe (IMAGE-team, 2001).

Box 1: The IMAGE/TIMER B2 baseline scenario used for the 15 non-EU world regions

The baseline scenario used for the default calculations of 15 non-EU world regions is the updated IMAGE/TIMER implementation of the IPCC-SRES B2 scenario (Van Vuuren et al., 2007a). This scenario is based on medium assumptions for population growth, economic growth and more general trends such as globalisation and technology development. In terms of quantification, the scenario roughly follows the reference scenario of the World Energy Outlook 2004 (IEA, 2004) and, after 2030, economic assumptions converge with the B2 trajectory. The population scenario is based on the UN Long-Term Medium Projection (UN, 2004). For emission and technology trends in land use, the assumptions of the Adapting Mosaic Scenario of the Millennium Ecosystem Assessment were used, as they are a reasonable representation of 'business-as-usual' assumptions for land use. GHG emissions in this scenario increase from about 45 $GtCO_2$-eq. today to more than 80 $GtCO_2$-eq. in 2050 for the set of six GHGs considered in the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) using the 100-year Global Warming Potentials from IPCC (2001). This corresponds to a medium- to high-level emission scenario compared to the IPCC SRES (Special Report on Emission Scenarios). As a result, the baseline reaches a GHG concentration of around 850 ppm CO_2-eq. by 2100.

2.1 The FAIR region model

The policy decision-support tool, FAIR 2.1 (Framework to Assess International Regimes for the differentiation of commitments) (Den Elzen and Lucas, 2005) was developed to explore and evaluate the environmental and abatement cost implications of various international regimes for differentiation of future commitments when meeting long-term climate targets such as stabilising atmospheric GHG concentrations. The FAIR 2.1 model consists of three linked models:

1. A *climate model* to calculate the climate impacts of global emission pathways for concentration stabilisation targets and baseline emission scenarios, and to determine the global emission reduction objective – based on the difference between the global emissions scenario (without climate policy) and a global emission pathway.

2. An *emission allocation model* to calculate the regional emission allowances for more than ten regimes for the differentiation of future commitments within the context of this global reduction objective (from climate model).

3. A *costs model* to calculate the regional abatement costs and abatements on the basis of the emission allowances (from the emission allocation model), the use of the flexible Kyoto mechanisms such as international emissions trading and substitution of reductions between the different gases and sources following a least-cost approach.

The model calculations are based on 17 world regions. Within the FAIR EU modelling framework, the FAIR region model was slightly adapted for this study. The OECD and Eastern European regions are replaced by the EU region. The model uses the aggregated marginal abatement costs curves and the LREM baseline scenario for this EU region from the MAC-EU tool (see section 2.3 for further details). The MAC curves from the MAC-EU tool are expressed in euro (2000€), while MAC curves for the other 15 world regions are expressed in dollars ($1995). For the case of simplicity, and as there is only a small difference between both expressions, we assumed them to be equal and no conversion factors were applied.

The main input of this FAIR region model within the framework is a global emissions pathway for stabilising greenhouse gas concentrations. The output is the emission allowances for the EU and non-EU region, as well as the aggregated marginal abatement costs curves for the non-EU region, which then forms the input for the FAIR-EU model (see next section). The model also calculates the international permit price for the world emissions trading market.

2.2 The FAIR EU model

The FAIR EU model is a special version of the FAIR region model and was developed for this study to explore and evaluate the environmental and abatement cost implications of different burden-sharing approaches for differentiating future commitments for the 27 individual EU countries. The model includes bottom-up marginal abatement costs curves for all individual EU countries, plus baseline developments for population, GDP (MER, 2000€) and emissions of the Kyoto GHGs for the period 2000–2030 under the September 2003 EU baseline scenario by DG-TREN, i.e. the LREM scenario (see section 2.3 and Box 2). The historical (1990–2000) GHG emissions are estimated based on 2000 emissions data of the LREM baseline, combined with historical greenhouse gas emission trends from the database of the International Energy Agency (CO_2 emissions) (IEA, 2005) and EDGAR (non-CO_2 GHG emissions) (Olivier et al., 2005).

The model starts by calculating the emission levels for 2010 (the central year of the Kyoto period). All Annex I European countries implement their Kyoto targets by 2010, including those Annex I countries with baseline emissions in 2010 that are much less than their Kyoto targets, i.e. countries with excess emission allowances ('hot air').[15] The non-Annex I countries Cyprus and Malta follow the baseline scenario until 2010. After the 2010 calculations the model determines the emission allowances of the individual countries in 2020, according to the rules set under the various approaches (see chapter 3). It should be noted that it is assumed that all banked excess emission allowances during the first commitment period (2008 – 2012) are fully used in a second commitment period (with 2015 as the central year) and therefore do not enter our 2020 calculations.

All calculations include emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6, excluding international aviation and marine transport. They also exclude CO_2 emissions or removals from land-use change and forestry, which is a minor source for the European countries.

The model calculates the emission allowances (before and after emissions trading) and abatement costs for the 27 EU countries, using the inputs from the FAIR region model. The model also calculates the permit price on the European emissions trading market, which corresponds in our model framework with the permit price on the world international emissions trading market (assuming there are no restrictions in emissions trading). The model also calculates the volume of traded credits both inside and outside the EU.

2.3 The MAC-EU tool

The MAC-EU tool has two functions within the FAIR EU modelling framework:

1. *Calculation of the MAC curves for the EU region and its individual EU countries*: More specifically, the tool converts the emission reduction options and costs data of the GENESIS 2.0 database (Blok et al., 2001) into the Marginal Abatement Costs (MAC) curves. This is implemented relative to the greenhouse gas emissions and activity data of the LREM baseline scenario from the PRIMES model (Mantzos et al., 2003) (Box 2). This is implemented for the EU region and individual 27 EU countries for the years 2020, for both the FAIR region and FAIR EU model, respectively.
2. *Calculation of the reduction measures needed to meet reduction targets for the EU countries.* The emission reduction targets per country, after emissions trading, as calculated using the FAIR EU model, are fed back into the MAC-EU tool to determine which measures the European countries must take to achieve those reduction targets. More specifically, the MAC-EU tool generates a list of measures required to implement reductions in a most cost-effective way, per country, per sector and per category (renewables, energy efficiency, CHP (cogeneration), et cetera).

Appendix A contains a detailed description of the MAC-EU tool, i.e. input, algorithms and output. This section briefly describes the methodology for creating the MAC curves (function 1), and briefly describes the GENESIS 2.0 database.

[15] If we assumed that the 2010 emissions of these countries are based on the lower of the Kyoto targets and the baseline emissions, these countries would have no excess emission allowances, and this would also relax the reduction targets in 2020 for the other European countries, as discussed in section 7.5.

Table 2.1: The main indicators for the year 2020 of the LREM baseline scenario from the PRIMES model (Mantzos et al., 2003)

	Population (1000)	GDP (10^6 €)	Emissions ($MtCO_2$-eq)	GDP/cap (€/cap)	Emissions/cap (tCO_2-eq/ cap)	Emissions/GDP (tCO_2-eq/ €1000)
Austria	8216	309307	87	37,647	10.6	0.281
Belgium	10572	367385	146	34,751	13.8	0.397
Denmark	5565	258802	62	46,505	11.1	0.238
Finland	5314	197769	70	37,217	13.1	0.352
France	64565	2235184	615	34,619	9.5	0.275
Germany	83056	3069240	1001	36,954	12.1	0.326
Greece	11184	249462	134	22,305	12.0	0.537
Ireland	4465	204550	74	45,812	16.5	0.360
Italy	56611	1836416	519	32,439	9.2	0.283
Luxembourg	513	41972	14	81,817	26.9	0.328
Netherlands	17404	630338	233	36,218	13.4	0.370
Portugal	10546	221773	99	21,029	9.4	0.446
Spain	40778	1084532	423	26,596	10.4	0.390
Sweden	9155	384130	85	41,958	9.3	0.221
United Kingdom	62505	2550314	676	40,802	10.8	0.265
EU-15	390449	13641174	4236	34,937	10.8	0.311
Cyprus	849	19202	11	22,617	12.6	0.556
Czech Republic	9878	115920	117	11,735	11.9	1.010
Estonia	1109	11590	16	10,451	14.8	1.412
Hungary	9069	106891	88	11,786	9.7	0.825
Latvia	2115	17761	14	8,398	6.6	0.782
Lithuania	3299	29082	29	8,815	8.9	1.010
Malta	415	8372	4	20,173	9.8	0.485
Poland	37674	429604	402	11,403	10.7	0.936
Slovakia	5370	46652	50	8,688	9.3	1.072
Slovenia	1888	35866	21	18,997	10.9	0.573
EU-10	71666	820940	752	11,455	10.5	0.917
Bulgaria	6650	30424	75	4,575	11.3	2.475
Romania	21008	104387	148	4,969	7.0	1.414
EU-2 new	27658	134811	223	4,874	8.1	1.653
EU	489773	14596925	5212	29,803	10.6	0.357

Box 2: Long-Range Energy Modelling (LREM) baseline used for the EU countries (incl. EU)

In this model, the 2000–2030 population, income and greenhouse gas emission data (see Table 2.1 for the year 2020) are based on the September 2003 EU baseline scenario of DG-TREN[16], i.e. the LREM scenario, which largely builds on the socioeconomic assumptions developed through extensive stakeholder consultation for DG TREN baseline projections 'European Energy and Transport Trends to 2030', which was developed for the European Commission (Mantzos et al., 2003). [17] These projections show how the future energy, transport and CO_2 emissions may unfold with a continuation of current trends and policies. The predictions are built on a modelling approach that encompasses both energy demand and supply. Some key assumptions:

- The population in Central and Eastern European countries is projected to decline slightly over the next 30 years, while the population in the Former Soviet Union and OECD Europe is projected to be stable over the projection period.
- World GDP is expected to grow by 2.9% per year on average between 2000 and 2030. In the OECD region as a whole GDP growth will be limited to 1.9% per year up to 2030. GDP grows by 2.9% per year in Central and Eastern European countries and by 2.9% in the Former Soviet Union.
- Between 2000 and 2030 the gross domestic energy consumption is expected to increase by 0.7% per year in OECD Europe, while the Central and Eastern European countries and the Former Soviet Union will increase by 1% and 1.7% respectively.
- CO_2 emissions increase more rapidly than primary energy use consumption, due to changes in the fuel mix of primary energy supply towards more carbon-intensive fuels. This increase in the carbon intensity of the global energy system is partly due to the low expansion of nuclear and renewable energy at the world level. It represents a structural change away from the historic trend towards 'decarbonisation'.
- CO_2 emissions will increase by 0.7% per year on average between 2000 and 2030 in OECD Europe, while CO_2 emissions in the Central and Eastern European countries and Former Soviet Union will increase by 0.9% and 1.7%, respectively.

GENESIS 2.0 – GENESIS 2.0 is a database information system that is characterised by an engineering-economic analysis of individual emission reduction measures (approximately 221 included) and cost estimates (in the year 2000 €) for 30 European countries (EU-27 countries, plus Turkey, Switzerland and Norway, which were left out of our calculations). The starting point for this GENESIS 2.0 database has been the GENESIS 1.0 database, which was developed under the framework of the Sectoral Objectives project supported by DG-ENV[18] (Blok et al*.,* 2001). For the GENESIS 2.0 database, the time frame of GENESIS 1.0 has been extended from 2010 to 2020 and 2030 and the number of countries also expanded (from EU-15 to 30 European countries).[19] Other main characteristics of the database are: 221

[16] In 2005 an update of the EU baseline was developed, which took into account higher oil price levels. Due to this, both energy price scenarios and activity levels have been changed. This updated data was not available at the time of this study and has therefore not been used.

[17] The LREM baseline scenario is almost identical to the scenario without climate change policies in the Clean Air for Europe (CAFE) programme, developed by DG Environment.

[18] See http://ec.europa.eu/environment/enveco/climate_change/sectoral_objectives.htm

[19] Ecofys is currently working on updating the data set in the project called SERPEC-CC, which is funded by DG-Research and DG-ENV. The update concerns an inventory of new measures (given the extended time frame), an update of technical and cost

reduction measures, nine sectors (i.e. households, tertiary, agriculture, waste, transport (passenger and freight), industry (iron and steel, non-ferrous metals, chemicals, building materials, food, drinks and tobacco, paper and pulp), refineries, electricity and steam production, extraction), and four groups of greenhouse gases (i.e. CO_2, N_2O, CH_4, F-gases).

The 221 reduction measures are described in the Sectoral Objectives reports, which can be found on the DG-ENV website: http://ec.europa.eu/environment/enveco/climate_change/sectoral_objectives.htm.

Compared to Sectoral Objectives no additional reduction measures have been included. The reduction measures that can make a contribution to emission reductions are characterised according to the following aspects: emission reduction potential; investment costs; operation and maintenance costs; operational benefits (e.g. energy cost savings) and lifetime. The information on the individual reductions can be used to calculate total emission reduction potentials and associated mitigation costs by sector, by country and by gas.

GENESIS calculates costs as being national costs, i.e. the costs as they are experienced by society as a whole. These costs are defined as all the additional costs that need to be made by society as a whole, compared to the reference situation where no reduction policies are in place. These include the same categories of costs as for the end-user, but exclude transfers between the government and the end-user because these transfers are a ‘zero-sum-game’ for society as a whole.

National cost-effectiveness is calculated by:

1. Taking the additional investments of a reduction measure (additional compared to the reference situation) and depreciating these investments over the economic lifetime of the reduction option, using a social discount (4%).
2. (If applicable) reducing the capital costs found under point 1 with the annual cost savings on energy or (raw) materials. Cost savings on energy are calculated using European shadow prices.
3. The sum found at point 2 is divided by the net reductions due to implementation of the emission reduction measures (the reductions compared to a reference situation), i.e. costs are expressed in euro per CO_2 emission reduced.

Calculating marginal abatement costs curves – the calculation includes the following steps:

1. Start with the base year (1990).
2. Determine the ‘frozen’ CO_2-eq. emission in the target year (2020 or 2030) by using the growth rates in the activity levels of the LREM baseline. Under the frozen efficiency assumption, no efficiency improvements are assumed in any of the sectors studied.

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characteristics of the measures already included in the database and a link to the most recent baseline scenarios of the European Commission (http://ec.europa.eu/dgs/energy_transport/figures/trends_2030_update_2005/index_en.htm).

3. Take the CO_2-eq. emission under the baseline according to the PRIMES model from the database and determine the implemented reduction potential under these scenarios (i.e. frozen efficiency minus baseline improvements). The LREM baseline emissions already include autonomous efficiency improvements, and are therefore lower than those of the frozen technology scenario, as illustrated in Figure 2.2. Therefore, some of the measures already included in the LREM baseline need to be excluded in further calculations. It would be ideal if the measures coloured in red could be specifically identified. However, this was not possible, as the documentation on the underlying assumptions of the PRIMES model was not specific enough for the reduction measures (such as overall efficiency improvement rates) already assumed in the baseline.
4. Identify those measures with the lowest marginal abatement costs, which cumulative total corresponds with the difference between 'frozen' and LREM baseline emissions ('cut-off method') and exclude these from further calculations.

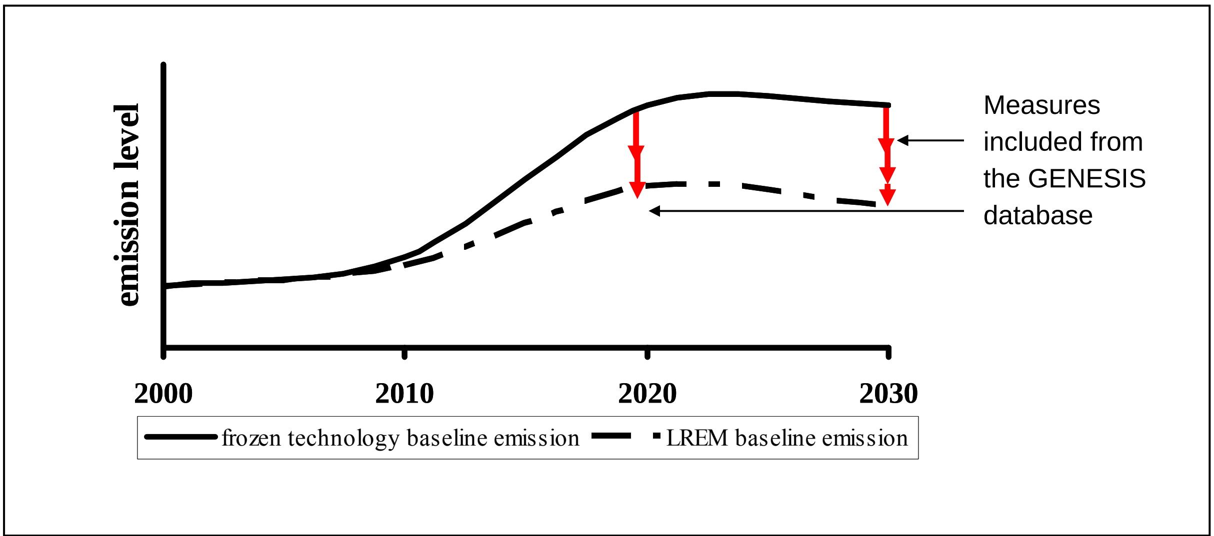


Figure 2.2: Schematic overview of the 'frozen' level and the PRIMES level.

5. Assume zero marginal costs for the reduction measures in GENESIS with negative marginal costs. More specifically, in Step 4 some of the negative cost measures of the GENESIS database are removed, but some measures remain. Here, we assume that the negative costs of these options are set to zero, based on the following arguments. The GENESIS database is rather optimistic about the 'no-regret' measures, i.e. measures with costs equal or less than zero €/tCO_2-eq. For the EU around 15% of the baseline emissions (approximately 850 MtCO_2-eq.) can be reduced in 2020 through reduction measures with costs that are equal to or less than zero. These fractions differ from country to country (see Box 3). Energy system models such as TIMER (Van Vuuren et al., 2007a) and POLES (Criqui et al., 2003; Russ et al., 2005b) do not include zero or negative cost reduction measures, as these are already implemented in the baseline. Therefore, when developing the MAC curves for this study, these

negative marginal abatement costs are not included, and zero costs are assumed. Chapter 5 explores the impact of using other marginal abatement cost curves on the outcomes.

6. The next step is to convert the remaining measures to MAC curves. Each measure is therefore linked to the corresponding LREM emission level, according to the following six sectors included in the FAIR-EU model, i.e.: CO_2, CH_4 and N_2O emissions from energy generation and industrial processes, CH_4 and N_2O emissions from agricultural processes and total F-gas emissions (HFCs, PFCs and SF_6). The relative reduction of each measure is calculated and subsequently sorted into ascending order by abatement costs, and then cumulated.
7. Finally, the MAC-EU tool creates an aggregated MAC curve for the EU region of the FAIR region model, and separate MAC curves for the individual EU countries for the FAIR EU model (see Box 3).

Uncertainties **–** The MAC curves are surrounded by many uncertainties, as briefly described below:

Energy prices: Energy prices constitute one of the main uncertainties. Capital-extensive measures are particularly sensitive to changes in energy prices. This also applies to capital-intensive measures that save a relatively large amount of energy.

Technical and costs characteristics of the measures: The measures described are compared to a reference technology. The way how we deal with the measures already included in the baseline emissions is source of uncertainty. In additional the assumptions made for the technical reduction potentials as well as the costs are uncertain.

Additional measures: The current set of measures may become outdated, since new technologies may become available that are not yet included in the data set. For example, the current version does not include biofuel measures and only a limited number of biomass measures. It also does not include nuclear as a reduction measure. The update that is currently taking place of the GENESIS database (see footnote 19) may reveal this information, which could lead to an underestimation of the technical reduction potential.

Implementation degree of the reduction measures: To calculate the remaining reduction potential of a certain measure, one needs to know its current level of implementation. These implementation levels also need to be updated, along with technical and costs characteristics.

Box 3: MAC curves for the EU countries

Figure 2.3 shows the results for six European countries and Europe as a whole for the sector CO_2 industry and energy. See Appendix A for a more detailed explanation. Several conclusions can be drawn from this graph:

A large number of the reductions are 'no-regret' measures: These are defined as measures with costs that are equal to or less than zero €/tCO_2-eq. A large potential of the measures for the EU countries are no-regret measures: 803 MtCO_2-eq. of CO_2, 37 MtCO_2-eq. of CH_4 and 29 MtCO_2-eq. of N_2O can be reduced from the baseline in 2020 with costs that are equal to zero.

The various curves are similarly shaped: The shapes of the curves of the various countries are very similar. In theory, each country has the same set of measures (e.g. affected by geography – for example for offshore wind – and industrial structure) and each measure is similarly characterised for each Member State by the following aspects, i.e. emission reduction potential; investment costs; operation and maintenance costs; fuel costs, operational benefits (e.g. energy cost savings), lifetime and discount rates, which are assumed to be the same for each country. The impact of a measure differs slightly for each country, mainly driven by the percentage of emissions to which the measure applies.

Around €60/tCO_2-eq. and €98/tCO_2-eq. large reductions are defined: The measures that cause the large reductions of around €60/tCO_2-eq. are 'Advanced heating systems: condensing boilers' and 'Carbon Capture and Storage (CCS)'. The measure that causes large reductions of around €98/tCO_2-eq. concerns the replacement of capacity by natural gas-fired combined cycles (at PRIMES price assumptions). However, the mitigation cost is strongly dependent on the relative price differences between coal and natural gas that are assumed in the scenarios.

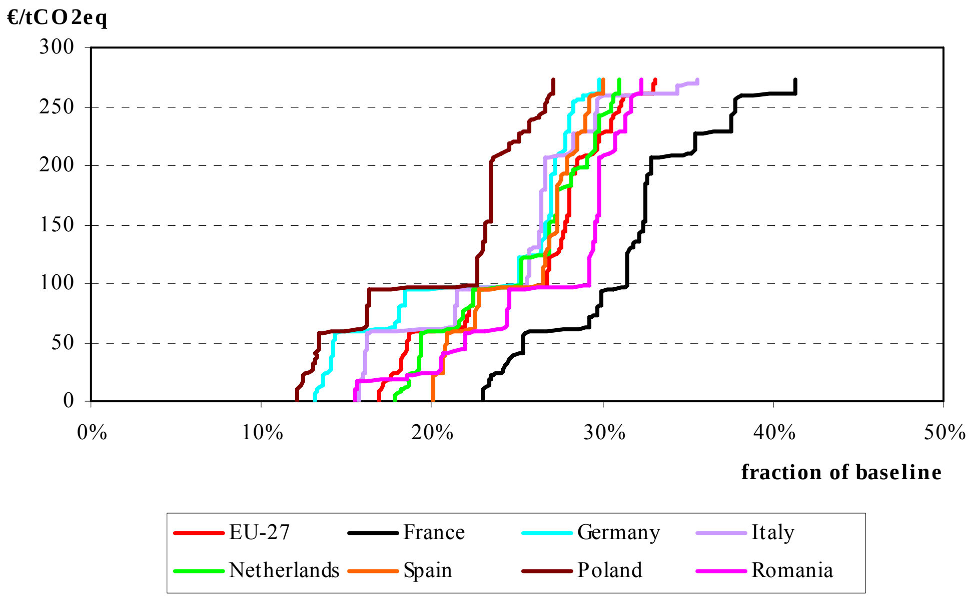


Figure 2.3: Marginal Abatement Costs (MAC) curves for six European countries for the industry energy-related CO_2 emissions in 2020.

Poland has high marginal abatement costs: As measures are characterised similarly for each Member State, the specific mitigation costs are similar. The mitigation potential of a measure differs for each Member State as this is driven by the potential application of each measure, and hence economic structure and emission profile of a country. For example, the measure 'Miscellaneous options (moderate costs tranche)' counts for 1.5% reduction in Germany, but in Poland for 'only' 0.5%. In Poland, the no-regret options cover a relatively small part of the reduction potential, which automatically makes the abatement costs of this country higher. This is also partially due to the structure of the database, as measures that are solely applicable to Poland are not included, because these were not included in the original database developed for EU-15.

3 Options for post-2012 EU burden-sharing

This chapter describes the following six EU burden-sharing approaches:

1. *Grandfathering,* i.e. applying a flat reduction rate for all EU countries to their historic emissions in a certain reference period (Kyoto targets).
2. *Per capita convergence,* i.e. differentiation of emission reductions based on equal per capita emissions in a certain convergence year (2050).
3. *Multi-criteria rule,* i.e. differentiation of emission reductions based on a mix of (i) GDP per capita, (ii) emissions per capita, and (iii) emissions per unit GDP (Equal weighting).
4. *Ability to pay,* i.e. differentiation of emission reductions based on GDP per capita.
5. *The Triptych approach,* i.e. differentiation of emission reductions based on a variety of sector and technology criteria.
6. *Equal mitigation costs,* i.e. differentiation of emission reductions based on equal mitigation costs per country (e.g. a certain percentage of GDP) (MER).

The following sections comprise short overviews of each regime (or approach), along with the relevant methodology. However, before presenting these overviews, the equity principles that play a role in the development of the regime are outlined briefly, with the aim of positioning the various regimes.

3.1 International burden-sharing regimes and their main equity principles

The international regimes considered here can be characterised on the basis of equity principles. There is no common accepted definition of equity. Equity principles refer to general concepts of distributive justice or fairness. Many different categorisations of equity principles can be found in the literature (Ringius et al., 1998; Ringius et al., 2000). Den Elzen et al. (2003) developed a typology of four key equity principles that seem most relevant for characterising various proposals for the differentiation of post-Kyoto commitments in the literature and international climate negotiations to date:

- *Egalitarian*: i.e. all human beings have equal rights to ‘use’ the atmosphere;
- *Sovereignty and acquired rights*: all countries have a right to use the atmosphere, and current emissions constitute a ‘status quo right’;

- *Responsibility/polluter pays*: the greater the contribution to the problem, the greater the user's share of the mitigation/economic burden;
- *Capability*: the greater the capacity to act or ability to pay, the greater the share of the mitigation/economic burden.

These four principles can be used to create a square that allows for positioning proposals according to their equity[20]. These equity principles can be further sequenced as being either rights-based or duty-based (Figure 3.1): responsibility and capability result in a duty to contribute to mitigation, while the egalitarian and sovereignty principles establish a right to emit.

When the scheme is used to characterise the regime proposals explored[21], we see that the *Per capita convergence* approach is a rights-based approach that is based on a combination of both the egalitarian and sovereignty principles, while ignoring the responsibility principle. *Grandfathering* is generally based on the sovereignty principle. The other approaches are duty-based approaches.

Under the *Equal costs* approach, all European countries would be limited in their economic growth. The principle of capability (ability to pay) is included, as the economic burden is defined as reduction that is related to GDP, assigning higher costs to those countries with higher GDP, i.e. a progressive reduction rate. The principle of responsibility (polluter pays) is not addressed. The *Multi-criteria* approach is mainly based on the egalitarian and capability principles. The *Ability to pay* approach's main principle is that of capability. The *Triptych approach* is based mainly on the capability to act, but also encompasses elements of the egalitarian principle via the convergence in per capita domestic emissions.

[20] Some typologies or proposals also mention the criterion of opportunity (to mitigate), which is related to the cost-effectiveness of mitigation. This criterion should not be compared to the capability criterion nor the responsibility criterion, as those with cost-effective mitigation options do not need to be the most capable to act, or be responsible for the problem. With emissions trading the relevance of this criterion as such has diminished.

[21] This work is based on Den Elzen et al. (2003) and Höhne et al. (2003).

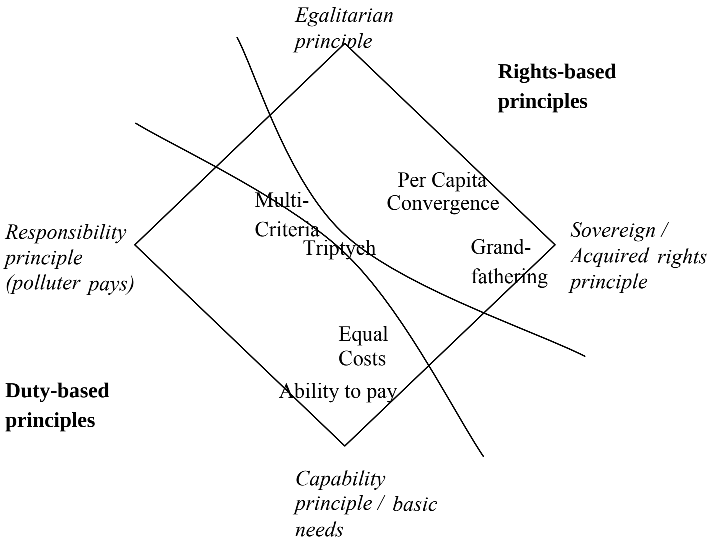


Figure 3.1: Equity principles and proposals for differentiation of commitments.

3.2 Grandfathering

The Grandfathering approach distributes the emission allowances according to the present regional emission levels ('flat rate'). In the European context this means that all Member States would have to reduce emissions by a uniform rate that is equal to the common target (here 20% in 2020). The rationale behind this approach would be the idea of sovereign states with equal bargaining power negotiating over the allocation. The principle finally results in a protection of rights that have been established by usage or custom, and is generally based on the sovereignty principle. Regardless of any philosophical considerations, the sovereignty rule can be perceived as the simplest form of allocating allowances, which makes it worth analysing.

3.3 Per capita convergence

During the Ad-hoc Group on the Berlin Mandate (AGBM) process (1996) for negotiating Annex I Kyoto targets, France proposed a formula for Annex I targets in 2010 based on eventually converging global per-capita emissions by 2100. In 1997 the EU also proposed that emission paths should eventually converge to similar per capita levels, without specifying a timeframe or level. The Global Commons Institute presented the 'Contraction and Convergence' (C&C) approach in 1996 (Meyer, 2000), where emission rights are redistributed at the global level based on a convergence of per capita emissions under a contracting global emission profile within a predefined time. The C&C approach constitutes a redistribution of emission rights over time based on sovereignty to an equal per capita allocation. All Parties would participate immediately after 2012, but a (top-down) global emissions ceiling would need to be established first.

This approach can also be applied at the EU level, assuming that all EU Member States agree on a future European overall emission profile that comes out of an international agreement on post-2012 commitments. For the analysis, we assume a convergence year of 2050 (convergence on the medium term).

3.4 Multi-criteria

During the AGBM process Norwegian and Icelandic proposals overlapped to a large extent. They both comprise multi-criteria rules containing indicators for ability to pay (GDP per capita), equity (emissions per capita), and 'energy efficiency' (emissions per unit of GDP). Deviation from the average value (of the group of countries) of one or more of these indicators generates a burden above the average percentage emission reduction required in the group (Torvanger and Godal, 2004). Specifically, the Norwegian proposal (UNFCCC, 1996) considers a Party's percentage reductions of greenhouse gas emissions as a linear function of three indicators: CO_2-eq. emissions per unit of GDP (indicator for emission intensity), GDP per capita, and CO_2-eq. emissions per capita. The formula for the country's reduction burden, measured as the relative change in emissions compared to 1990 levels ($R_{country}$), is given as:

$$R_{country} = A\,[x * (EM_{country}/GDP_{country})/(EM_{EU}/GDP_{EU}) + y * (EM_{country}/POP_{country})/(EM_{EU}/POP_{EU}) + z * (GDP_{country}/POP_{country})/(GDP_{EU}/POP_{EU})] \quad (1)$$

where A is an appropriate scalar, which is typically negative to secure the aggregate total reduction level. $POP_{country}$, $GDP_{country}$ and $EM_{country}$ represent the population, GDP and emissions. The factors x, y and z are weights that add up to one. In the original proposal these weights were subject to negotiation, but in later proposals and in our calculations they were equalised to one-third. To emphasise that we have assumed an equal weighting of all criteria, we refer to the multi-criteria (EQ) throughout this report.

3.5 Ability to pay

The common feature of the proposals put forward by Estonia, Poland, the Russian Federation, Korea, and Poland is the main focus on GDP per capita as an important indicator for distributing commitments (see Torvanger and Godal, 2004). GDP per capita can be interpreted as a proxy variable for *ability to pay*. In addition, some of these proposals, but not all, include a reference to emissions per capita and/or contribution to global emissions. The Poland et al. proposal (UNFCCC, 1997b) was prepared by Bulgaria, Estonia, Latvia, Poland and Slovenia, and suggests that the emission targets for each Annex I Party should be somewhat flexible and based on the following criteria: GDP per capita; contribution to global emissions; and emissions per capita and/or emission intensity of GDP. As the proposal does not define the exact key for burden-sharing, but stresses that income is the key criterion for burden-sharing, we hereby assume that per capita GDP forms the key for the reductions.

The approach therefore becomes similar to *ability to pay*, as earlier proposed by Jacoby et al. (1999). The distribution of reductions compared to 1990 levels ($R_{country}$) follows the relative GDP per capita compared to the average of the EU, scaled to achieve the overall reduction level according to:

$$R_{country} = A\ [(GDP_{country}/POP_{country})/\ (GDP_{EU}/POP_{EU})] \qquad (2)$$

where A is an appropriate scalar, which is typically negative to secure the aggregate total reduction level. It thereby becomes a special case of the multi-criteria rule, where weights x and y are set to 0 and z becomes 1.

3.6 Equal costs

Equal costs aim to set targets in such a way that the economic burden (relative to GDP) is equally distributed over all countries. This could be extended to include mitigation and adaptation costs, although calculating the costs of adaptation would be more difficult than calculating the costs of mitigation. Such a concept could be implemented in various ways, e.g. choosing emission reduction targets so that all participating countries have the same percentage reduction in GDP (Babiker and Eckaus, 2002; Rose et al., 1998).

In our implementation of the approach we assume costs to be defined as the mitigation costs, i.e. abatement costs plus emission permit sales revenues minus permit purchase costs, which are calculated with the FAIR model. We aim at the same abatement costs as a percentage of GDP for all countries. It should be noted that these costs only represent the direct cost effects based on MAC curves but not the various rebound effects via the economy or impacts of carbon leakage. These costs also do not include the mitigation benefits, i.e. mitigation benefits from greenhouse gas emission reduction, such as reduced climate damage. When implementing this approach, we use an iterative process to calculate the emission targets for the individual countries, such that their abatement costs as a percentage of GDP are equal to the EU average.

Rose et al. (1998) use a different definition of mitigation costs, which also includes the mitigation benefits. Babiker and Eckaus (2002) implement this approach as equal reductions in welfare across all countries, and use the macroeconomic model MIT EPPA for the welfare calculations.

In this context, it is important to note that the literature shows different methods being used to calculate the costs of climate policy. On the one hand, (top-down) general equilibrium models are used to assess the macroeconomic changes as a result of climate policy (reported as consumption or welfare losses); on the other hand, system engineering partial (bottom-up) equilibrium models are used to estimate the increase in energy system costs or abatement costs, as we do here. Both methods have their strengths and weaknesses. The strength of the abatement costs approach is that it is relatively simple, flexible and focuses on the direct cost factor – additional costs for energy and abatement technology – which is also a good proxy for the total direct costs of climate policy. Macroeconomic costs are more comprehensive (as they also capture indirect effects within the economy) but are also much more uncertain. In fact, many of the factors not included in abatement costs approaches (such as the impact of various investment patterns and recycling of tax revenues) are examples of such uncertainties, and in various macroeconomic models can lead to both higher and lower overall costs, depending on model assumptions. In conclusion, macroeconomic costs are more comprehensive – but also more uncertain, and abatement costs still form a good proxy for the total direct costs of climate policy. For a further discussion on the various cost measures, see Den Elzen et al. (2007b).

3.7 The Triptych approach

The Triptych approach is a sector- and technology-oriented approach that allows different national circumstances to be taken into account. The Triptych approach was originally developed at Utrecht University and has been used to support decision-making when differentiating between the EU's internal Kyoto target among its member states, both before and after Kyoto (COP-3) (Blok et al., 1997; Phylipsen et al., 1998; Ringius, 1999). The *Original Triptych* approach only comprised energy-related CO_2 emissions and highlighted three sectors:

1. internationally orientated, energy-intensive sectors of industry (or heavy industry),[22]
2. the domestic sector[23] and
3. the electricity power sector.

The initial selection of these categories was based on a number of differences in national and sectoral circumstances that were considered during the negotiations to be relevant to emission reduction potentials. These included differences in economic structure and the competitiveness of internationally oriented industries, in the standard of living and in the fuel mix for the generation of electricity. The emissions of the three categories are treated differently in that a reasonable emission allowance is calculated for each category, while relevant national and sectoral circumstances are also taken into consideration. The methodology derives these allowances for each sector using uniform rules applied equally to

[22] Iron and steel, chemicals, pulp and paper, non-metallic minerals, non-ferrous metals and the energy transformation sector, including petroleum refining, the manufacture of solid fuels, coal mining, oil and gas extraction and any energy transformation other than electricity production.

[23] The domestic sectors comprise various segments: not only the residential sector (households), but also the commercial sector, transportation, and light industry are included in this category, as are CO_2 emissions relating to combustion in agriculture and during the production of fossil fuels.

all countries, and the sum of the emission allowances for the categories forms the national allowance for each country. Only one national target per country is proposed – no sectoral targets – so that countries are given more flexibility to pursue cost-effective emission reduction strategies.

Over the years, the Triptych approach used for the EU has been extended to cover the global scale and include more sectors and non-CO_2 greenhouse gases (CH_4, N_2O, HFCs, PFCs and SF_6), at the level of world regions (Groenenberg, 2002). The *Triptych 6.0* approach (Phylipsen et al., 2005) was the first attempt to extend the calculations at the level of countries, for the various sectors, which are added to obtain a national target (Höhne et al., 2005). Unfortunately, this approach still includes a number of shortcomings, mainly due to the use of regional data rather than country-specific data, assuming a uniform structural change factor for all countries, and the use of regional economic data for the physical production growth in the industry. A revised Triptych approach (*Triptych 7.0*) that addresses these shortcomings is described by Den Elzen et al. (2007a) in detail, and briefly here.

The *industrial sector* consists of the manufacturing industry and construction. Due to the lack of available data, the industrial sector is handled in its entirety – i.e. energy-intensive and light industries are not treated differently. The allowable GHG emissions are calculated on the basis of: (i) a realistic growth of energy consumption in the industry, and (ii) the improvements of energy intensity (energy used per unit of production), using the methodology of Groenenberg et al. (2004). The growth rates are based on energy consumption in industry taken from the LREM baseline scenario (Mantzos et al., 2003), so that they also account for structural changes in the industrial sector, as well as autonomous baseline energy efficiency improvements. The improvement rates in energy intensity for all regions are calculated by a convergence in energy efficiency levels, expressed as an aggregated Energy Efficiency Indicator (EEI) over time (Phylipsen et al., 1998).[24] Here, we have used the most recent updated EEI values based on the work of Kuramochi (2006) (see Table 3.1). The improvement rates for energy efficiency can now be calculated from the linear convergence trajectories for the aggregated (2000) EEI values to a final convergence level in a year of convergence (Table 3.2). This final convergence level is a fraction of the indicator value under the best current practices or best available technologies. The convergence level for the EEI was based on bottom-up studies of thermodynamic minimal energy requirements (Groenenberg, 2002). Groenenberg established a central estimate of 0.7 (around 30% below the present best practices) in 2050 with a range of [0.5-0.8]. Here, for the EU 20% reduction objective, we have assumed a convergence to the best present practices (thus EEI = 1) already by 2030.

[24] This index is defined as the ratio between the specific energy consumption (SEC) (energy consumption per tonne of product) for each region, divided by a reference SEC level. The reference SEC is equal to the SEC with best current practices or best available technologies. For example, an EEI of 105 in a region means that the average SEC is 5% higher than the reference level, so that 5% of energy could be saved in the given sector structure by implementing the reference level technology.

Table 3.1: The Energy Efficiency Indices (EEIs) at European country level, based on the work of Kuramochi (2006).

	EEI		EEI
Austria	1.3	Lithuania	2.2
Belgium	1.4	Luxembourg	1
Cyprus	1.5	Malta	1.5
Czech Republic	2.1	Netherlands	1.4
Denmark	1.7	Poland	2.1
Estonia	2.2	Portugal	1.5
Finland	1.3	Slovakia	1.9
France	1.3	Slovenia	2
Germany	1.3	Spain	1.5
Greece	1.5	Sweden	1.5
Hungary	1.7	United Kingdom	1.5
Ireland	1.4	Bulgaria	2.6
Italy	1.4	Croatia	2
Latvia	2.2	Romania	2.3
		Iceland	1.5

The *domestic sector* emissions depend on the population growth and a convergence of per capita domestic emissions to a same convergence level by a particular convergence year (e.g. 2040). This level includes a convergence of the standard of living (e.g. the number of cars or appliances owned) and a reduction in existing differences in energy efficiency of devices, buildings and vehicles. The default calculations for this study use the central estimate by Groenenberg (2002) of 1.7 tCO_2-eq. per capita per year.

When calculating the future power sector emissions we assume a *growth in the electricity consumption* (from the LREM baseline), *convergence of emissions per kWh per fuel*, a *decrease in coal and oil percentages* in the fuel mix and *electricity consumption efficiency improvement (demand).* This methodology makes the calculation of emissions from the electricity sector simpler and more concise. It leaves more freedom for the countries to decide how they would like to fulfil their share of CO_2-free energy, with renewables, nuclear energy and CCS. The three aspects are the same for all countries:

1. *Convergence of emissions per kilowatt hour per fuel*: The emissions per fuel converge (in CO_2 per kilowatt hour) for each fuel by a differentiated year (see Table 3.2).
2. *Decrease in the coal and oil percentages in the fuel mix*: The coal and oil percentages in the mix of fuels used decrease linearly compared to the 2004 levels (for example, by 30% up to 2030 and by 75% up to 2050). A significant proportion of this reduction can be achieved via CCS, particularly for meeting the stringent climate targets, and by renewables. Accordingly, countries with high numbers of coal- and oil-fired power stations need to reduce to a greater extent than those that currently have a low numbers of such plants.
3. Annual *electricity consumption efficiency improvement* (compared to the baseline electricity consumption): This is due to their convergence trajectories (for example, by 1.5% per year) (see section 3.2). This factor of decreasing demand from the industry and domestic sector is also included in the Global Convergence Triptych approach developed by Groenenberg et al. (2004).

The following formula illustrates the calculation of emission reductions during the first reduction phase for EU countries for the year 2030, under the 30% EU reduction with a 1.5%/year decrease in electricity consumption and reduction in coal and oil by 60% (compared to 2004 levels):

$$\begin{aligned}
CO_2 \text{ emissions}_{2030} &= \frac{\text{elec.consum}_{\text{total 2030}}}{\text{elec.consum}_{\text{total 2004}}} \times (1-1.5\%)^{(2030-2004)} \times \\
&(\text{elec.consum}_{\text{coal 2004}} \times 600 \frac{\text{g } CO_2}{\text{kWh}} \times (1-60\%) + \\
&\text{elec.consum}_{\text{oil 2004}} \times 450 \frac{\text{g } CO_2}{\text{kWh}} \times (1-60\%) + \\
&\text{elec.consum}_{\text{gas 2004}} \times 300 \frac{\text{g } CO_2}{\text{kWh}})
\end{aligned} \quad (3)$$

Emissions from *fossil fuel production* can be drastically reduced. We assume the baseline emissions from this sector to be scaled with the ratio baseline emissions and Triptych emissions from the three energy-consuming sectors. An additional reduction factor further reduces the emissions, reaching its maximum reduction in the convergence year.

Emissions from *agriculture* are assumed to be reduced by a certain percentage below the baseline emissions within a (differentiated) convergence period. Two groups of countries are distinguished: Annex II EU countries (countries with a higher GDP/cap) need to achieve greater reductions than the other EU countries with a lower GDP/cap.

Emissions from *waste* are substantial, but there are many emission reduction options available (e.g. capture of methane from landfills). Emissions from the waste sector are assumed to converge to a per capita level in a convergence year. The latter is based as a fraction of the global per capita emissions in the base year, using the reduction potentials based on Lucas et al. (2006).

Table 3.2 presents the parameters chosen for the EU 20% reduction cases (EU 20% with CDM and without CDM) and 30% reduction case (EU 30% in a multilateral regime) of this report. These parameter assumptions for the 20% and 30% reduction cases are based on the assumptions made under the Medium and Strong technology scenarios, described in detail in Den Elzen et al. (2007a), i.e.:

- EU 20% unilateral with/without CDM: Early convergence (in 2030) to high technology standards with a large coalition. Main assumption: early convergence to the present (2004) level of the best performing European country (such as CO_2 emissions per kilowatt hour per fuel type) in 2030, followed by common convergence to the lowest technical sectoral target in 2050 for the European countries (see Table 3.2).

- EU 30% in multilateral regime: Medium convergence (in 2050) to high technology standards, and a delayed convergence for the developing countries. Main assumption: starting in 2010, European countries implement a convergence trajectory to the present (2004) level of the best performing European country in 2050.

Two additional changes have been made compared to the original parameter assumptions of these scenarios, to obtain the overall EU reduction of 20% and 30%. For both the EU 20% and 30% reduction cases the annual per capita domestic convergence level has been set at 1.7 tCO_2 per capita, rather than the lower values of 1.25 and 1.5, as assumed in the strong and medium scenario respectively. The reduction in the percentage of coal and oil in the convergence has been set at 45% and 85%, rather than 60% and 95%.

Table 3.2: Parameter choices for the Triptych 7.0 cases aiming at 20% and 30% reduction for the EU.

	Variable	**EU 20% unilateral with/without CDM**	**EU 30% in multilateral regime**	
Sector	Convergence year (all sectors)	**2050**	**2030**	**2050**
Power	Convergence and reduction level of GHG emissions [gCO_2/kWh]			
	Coal	600	600	400
	Oil	450	450	300
	Gas	300	300	250
	Reduction of share of coal and oil			
	Coal	85%	45%	90%
	Oil	85%	45%	90%
	Energy efficiency improvements rate for the production after 2010	1.5%/yr	2.0%/yr	
Industry	Convergence level of Energy Efficiency Indicator	0.7	1.0	0.6
Domestic	Domestic convergence level – per capita emissions in tCO_2/cap/yr	1.7	1.7	1.25
Fossil fuel production	% total emissions below baseline in convergence year	90%	90%	95%
Agriculture	Reduction below baseline emissions – high GDP/cap	50%	40%	50%
	– low GDP/cap	30%	30%	50%
Waste	Waste convergence level – reduction below global base year per capita emissions	90%	90%	90%

4 Options for post-2012 EU burden-sharing and ETS allocation

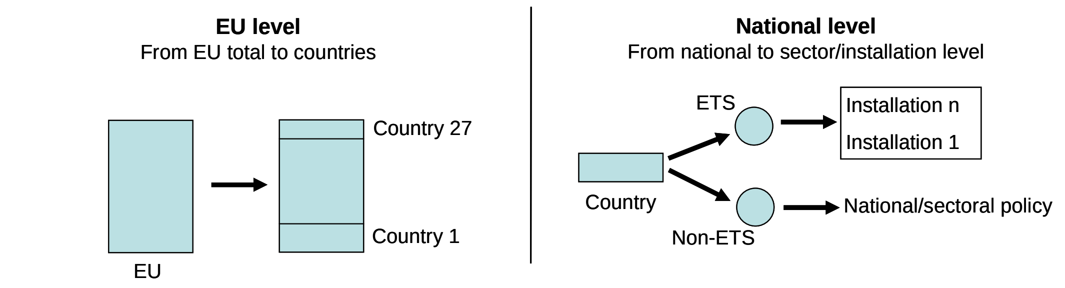
This chapter briefly describes a few options for post-2012 EU burden-sharing and ETS allocation, based on the work of Sijm et al. (2007).

4.1 Three major types of options

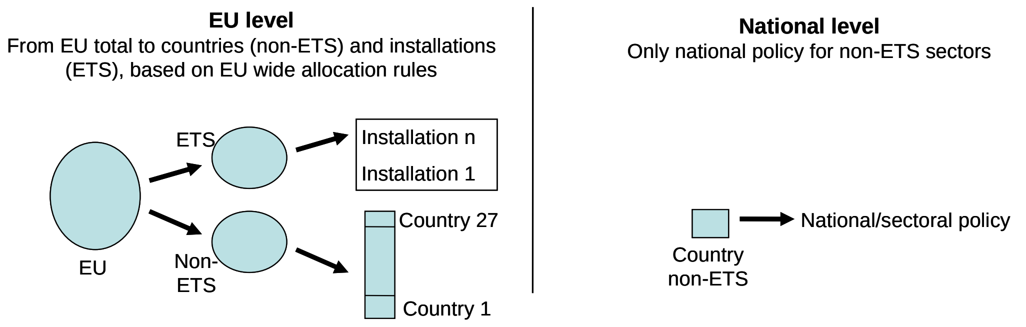
Sijm et al. (2007) discussed three options for the future EU burden-sharing system and ETS (Figure 4.1) i.e.:

1. *Present system*. The present system (up to 2012) is initially characterised by sharing the post-2012 reduction targets (i.e. the EU assigned amount of GHG emissions) among the Member States and, subsequently, each Member State divides its national target (including eventual purchases of JI/CDM credits) between the ETS and non-ETS sectors. Finally, while national/sectoral policies are implemented in order to achieve the target for the non-ETS sectors at the Member States' level, the assigned amount of emission allowances for the ETS sectors is distributed further at the installation level via national allocation rules (subject to the allocation guidelines and judgement by the European Commission). In principle, this option of EU burden-sharing and ETS allocation can also be used for the post-2012 period (with further guidelines and harmonisation of allocation rules by the EC). In short, with regard to the EU-ETS allocation process (i.e. setting the top-down cap and the bottom-up allocation rules) this option is characterised by a high level of decision-making at the Member State level.
2. *EU burden-sharing with ETS allocation at EU level*. This option is characterised by the:
   (1) Distribution of EU-assigned amounts of GHG emissions between the ETS and other sectors (i.e. setting an overall, EU-wide cap for the ETS);
   (2) Allocation of the cap to eligible installations based on EU uniform allocation rules; and
   (3) Distribution of the EU emission target for the non-ETS sectors among individual Member States (based on a corresponding EU burden-sharing agreement for post-2012).

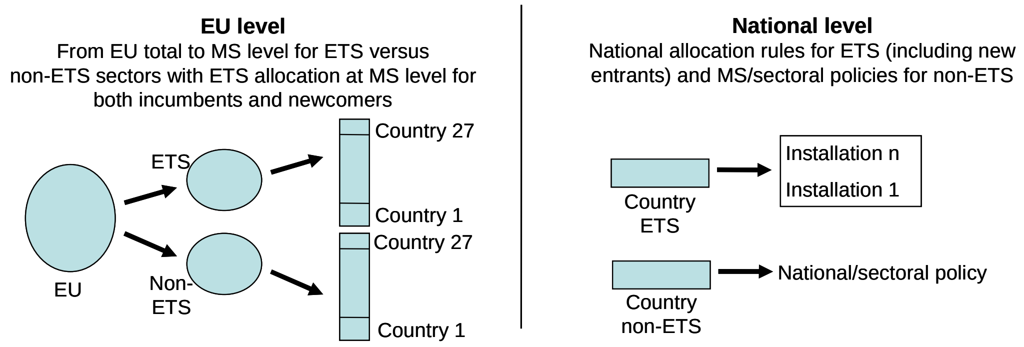
Option 1: Present system: EU burden-sharing with ETS allocation at national level



Option 2: EU burden-sharing with ETS allocation at EU level



Option 3a: EU burden-sharing with EU-wide ETS cap and MS allocation for all installations



Option 3b: EU burden-sharing with EU-wide ETS cap and MS allocation for incumbents only

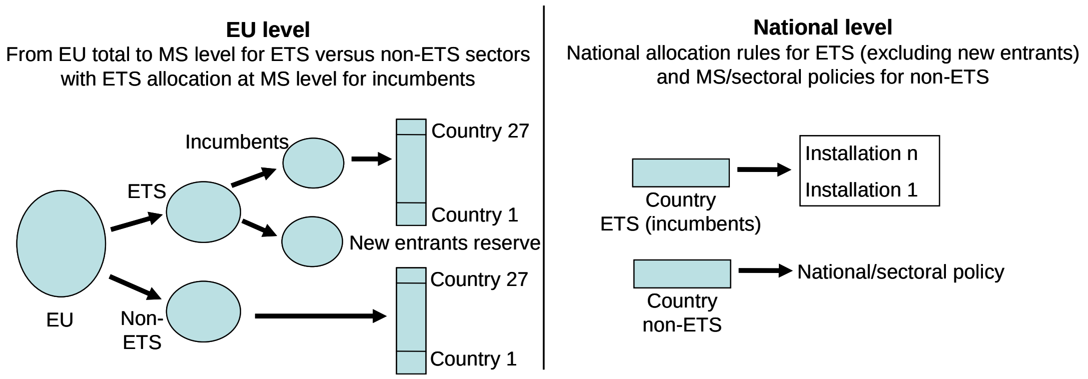


Figure 4.1: Options for EU burden-sharing and ETS allocation post-2012.

Source: Sijm et al. (2007)

In short, with regard to the EU-ETS allocation process, this option is characterised by a high level of decision-making at the EU level. In principle, there is also another (version of this) option conceivable, in which not only the ETS target and allocation rules are set at the EU level, but also the achievement of the target for the non-ETS sectors is implemented or harmonised at the EU level, e.g. via harmonised energy efficiency and renewables policies, CO_2 technology standards for cars, etc. Although it may take some time before this option is realised, it would imply that an EU burden-sharing agreement among its Member States will no longer be needed to achieve the overall EU mitigation target.

3. *EU burden-sharing with EU-wide ETS cap and MS allocation for (a) both existing and new installations (Type 3a) or (b) existing installations only (Type 3b)*. In terms of centralising or harmonising EU decision-making on ETS allocation issues, option types 3a and 3b are less extreme than option type 2 (actually, they can be regarded as 'intermediate' or 'transfer' options between types 1 and 2). Similar to type 2, under these options the overall EU emission target is first divided between the ETS and the other sectors of the EU, while the assigned amount of emissions to the non-ETS sectors is further distributed among the Member States, based on a corresponding burden-sharing agreement. However, in contrast to type 2, the EU-wide ETS cap is not allocated straight to the eligible installations (based on EU-wide allocation rules), but first distributed among the Member States, which are free to further allocate their national ETS cap to their eligible installations according to their own rules (within certain guidelines set by the European Commission). In addition, the major difference between option types 3a and 3b is that in option 3a the national allocation system refers to all eligible installations (i.e. both incumbents and newcomers), whereas in type 3b it applies only to existing installations, while newcomers obtain their allowances from an EU-wide reserve based on EU-harmonised allocation rules.

This report only focuses on quantifying the first two major options.

Sijm et al. (2007) discuss the pros and cons of those options[25], and concluded that option 1 is characterised by a high level of decision-making at the Member State level, whereas option 2 is characterised by a high level of decision-making at the EU level. Centralising or harmonising the process of setting the ETS cap and the allocation rules for eligible installations throughout the EU as in option 2 may appear an attractive option as it reduces competitive distortions and other adverse effects due to a national-oriented allocation process, but it implies a significant transfer of decision competence from the national to the EU level (compared to the present allocation process). Member State governments are likely to be rather reluctant to transfer a major part of their allocation decision competence to the EC level, as allocation decisions may have significant distributional and competitive effects at the national, sectoral and firm levels.

[25] See also Sijm (2006) for a discussion of the pros and cons of allocation options for ETS for the period beyond 2012.

4.2 Quantitative aspects

The implications of the option types mentioned above, in quantitative terms – for example, in terms of costs or assigned amounts of emission allowances at the EU, national, sector or installation level – depends on a variety of other aspects and choices to be made. For instance, first of all such implications depend on the overall reduction target adopted by the EU as a whole. For the year 2020, the EU has proposed a reduction target of 20–30% (compared to the 1990 reference level), depending on the outcomes of the international post-Kyoto negotiations. Subsequently, the quantitative implications also depend on the approach or methodology used for distributing the EU-assigned amount of emission allowances at the national or sector level, as discussed below for the various types of options for EU burden-sharing and ETS allocation (post-2012).

Option type 1

For option 1, the allocation of the EU-assigned amount of emissions (post-2012) to the 27 Member States can be based on different approaches, including the six burden-sharing approaches as discussed in the previous chapter, i.e.:

1. G*randfathering;*
2. *Per capita convergence*;
3. *Multi-criteria;*
4. *Ability to pay*;
5. *Triptych approach;*
6. *Equal costs approach*.

Subsequently, each Member State can allocate its national target amount of emissions between the ETS and non-ETS sectors (based on sector climate policy targets and evaluation criteria), while the national cap for the ETS sector is further allocated at the installation level, based on national allocation rules and EU guidelines.

Option type 2

For option 2, setting an EU-wide target for the ETS as a whole (versus the other sectors) can be based on different approaches, including:

1. *Marginal abatement costs* of ETS versus non-ETS sectors, i.e. the EU-wide reduction commitments are divided between the ETS and non-ETS sectors, based on equal estimates of the marginal abatement costs and potentials of these sectors, in order to equalise these costs between the ETS and other sectors of the EU and, hence, to minimise the social costs of the mitigation commitments.

2. *Simple grandfathering,* i.e. allocation based on historic emissions of ETS versus non-ETS sectors over a certain reference period, adjusted for new entrants and other changes in sector coverage, and corrected by a uniform ('flat') reduction rate in order to meet the overall EU mitigation target.
3. *Advanced grandfathering,* i.e. allocation based on historic emissions of ETS versus non-ETS sectors over a certain reference period, adjusted by specific allocation rules for the ETS versus non-ETS sectors, such as accounting for sector differences in growth rates (including new entrants), trends in carbon intensity improvements and abatement costs, and corrected by a (uniform/differentiated) reduction rate in order to meet the overall EU mitigation target. Here, we use the Triptych rules as a proxy, which accounts for carbon intensity improvements in the industrial and electricity sector (ETS) and convergence in the per capita domestic emissions (non-ETS).

Subsequently, the EU-wide cap for the ETS as a whole is allocated straight to the eligible installations throughout the system, based on EU-wide allocation rules. In contrast, the EU-wide target for the non-ETS sector is first shared among the Member States, which can be based on a variety of burden-sharing approaches, including those described in chapter 3.

Finally, each Member State is free to further subdivide its national target for the non-ETS sectors and to set its domestic/sector policies to achieve this target (including MS purchases of JI/CDM credits).

5 Model analysis of EU burden-sharing according to the present system

This chapter uses option 1 (as described in the previous chapter) as a starting point, i.e. starting with an EU reduction target, we re-allocate the emissions among the individual European countries using different burden-sharing approaches (next paragraph), and calculate the national reduction targets and abatement costs (accounting for the Kyoto Mechanisms).

5.1 Global background

The analysis focuses for the international context on three scenarios based on different assumptions for the participation of world countries and the EU reduction objective, i.e.:

1. '***EU 20% unilateral without CDM***': There is insufficient political will for a collaborative international post-2012 agreement. The EU implements its 20% reduction target. All other countries implement hardly any climate policy and do not take on reduction commitments beyond 2012. Emission allowances are traded freely between the EU Member States through the ETS. This case assumes no availability of JI and CDM beyond 2012.
2. '***EU 20% unilateral with CDM***': This case is similar to 'EU 20% unilateral without CDM', but now includes the availability of international flexibility mechanisms JI and CDM beyond 2012.
3. '***EU 30% in a multilateral regime***' The negotiations succeed in forming a coalition that adopts emission reduction targets, including not just the Annex I countries, but also all advanced developing countries (ADCs) such as China, Mexico, South Korea and Brazil (see below). The EU adopts a 30% reduction target and other Annex I countries and ADCs adopt comparable reduction efforts by 2020. Emissions trading is only allowed within the coalition. Furthermore there is the availability of JI and CDM beyond 2012 as an emission reduction option in countries with no restrictions on emissions, such as India.

The following section describes the scenarios in more detail. This section briefly describes the quantification of these scenarios, particularly the international context. The '***EU 20% unilateral without CDM***' and '***EU 20% unilateral with CDM***' scenarios assume that the EU unilaterally implements the 20% reduction target, whereas the other Annex I countries that participate in the Kyoto Protocol implement their Kyoto targets during the first commitment period (2008–2012), and follow their baseline after 2012. However, this does not mean that in the absence of an international agreement on an inclusive climate change regime, the EU should keep the EU-ETS linked to the global carbon market, in particular to the Kyoto Protocol's JI and CDM schemes, as is assumed in the '*EU 20% unilateral with CDM*' scenario.

In the '***EU 30% in a multilateral regime***' scenario, the EU undertakes an emission reduction target of 30% by 2020 compared to 1990, other developed countries commit themselves to comparable emission reductions, and economically more advanced developing countries also contribute adequately according to their responsibilities and respective capabilities. This raises the question of what could constitute comparable efforts by other Annex I countries and advanced developing countries (with a similar level of development) in the post-2012 period up to 2020.

The assumptions on reductions for 2020 were chosen for this study in such a way (Table 5.1) as to be politically acceptable to all Parties if possible, and are very much in line with the 'political willingness' scenario developed as part of the study on the South-North dialogue proposal (Den Elzen et al., 2007c). The latter scenario represents an assessment made by a number of the research institutes involved in the South–North Dialogue proposal on emissions constraints that might be considered politically acceptable. For Annex I countries, the basic assumption for the '*EU 30% in a multilateral regime*' scenario is that their overall emission target would be at 20% below 1990 levels in 2020, which is halfway between the 15–30% range for the Annex I reduction target below 1990 levels, as formulated earlier by the European Council (2005). As the EU-25 would be able to accept a -30% target, the rest of Annex II would only have to decrease to -15% so that the Annex I as a whole would attain -20%. The USA is assumed to reach its national emission intensity target in 2010 and would have to reduce emissions drastically afterwards in order to attain its target of -15%. Whether the USA will take any stronger action after the first commitment period (2008-2012) is of course highly uncertain. There are, however, a number of reasons to assume that the US will join a post-2012 regime, whatever it may be called. Avoiding future disasters like what happened after Hurricane Katrina may play a part in this, but also the high oil prices and the motivation of the military to become less independent for fossil fuel imports. In general, the Annex I regions show similar and comparable reductions of around 35–45% compared to the baseline emissions.

East Asia (China) is assumed to reduce emissions 15% below baseline emissions and would still be allowed to increase their emissions substantially (about 130% above 1990 levels). The emissions by ADCs could grow until 2010, but would then have to be reduced by 25% below baseline levels. This still implies a growth in their emissions, compared to 1990-levels. The other developing countries do not need to reduce their emissions, as they do not participate.

Note that this scenario does not make any assumption about which future emission or concentration levels should be reached, but the short-term 2020 reduction efforts are such that the long-term temperature 2°C target is expected to remain feasible.[26]

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[26] For a discussion on alternative concentration overshoot strategies, that still meet long-term temperature targets, but under lower costs compared to concentration stabilisation strategies, see den Elzen et al. (in press).

Table 5.1: Assumed reduction levels for the 'EU 30% in a multilateral regime' scenario. Source: adapted from Den Elzen et al. (2007c).

Region	Configuration	% in 2020
Annex II	EU-25: reduce below 1990 level	30%
	Canada, Japan: reduce below 1990 level	20%
	USA and others: reduce below 1990 level	15%
Annex I but not Annex II	FSU: reduce below 1990 level	20%
Advanced developing countries	Central America and South America, Middle-East: Reduce below baseline emissions	25%
	East Asia (incl. China): Reduce below baseline emissions	15%
Other developing countries	Northern Africa, Southern Africa, Western Africa, Eastern Africa, Southeast Asia and Southern Asia (incl. India): Follow baseline emissions	

Table 5.2 presents the overall emission reduction objective and costs for the three global scenarios for the EU as a whole, as well as their percentage of emission reduction acquired through domestic abatement within and outside the EU, and the international market equilibrium permit price for the world permit trading market (in our calculations these are equal to the price on the European permit trading market). The table also shows the reductions compared to 1990 level, plus baseline emissions for the world and the global costs as a percentage of GDP.

Table 5.2: Main indicators in 2020 for the three scenarios.

	EU 20% unilateral without CDM	EU 20% unilateral with CDM	EU 30% in a multilateral regime
EU			
1990 emissions ($MtCO_2$-eq.)	5036	5036	5036
Baseline emissions ($MtCO_2$-eq.)	5212	5212	5212
Reduction target (% compared to 1990 level)	-20%	-20%	-30%
Domestic emissions (% compared to 1990 level)	-20%	-15%	-19%
Internal reduction (%)	100	77	66
Permit price (€/tCO_2-eq.)	96	23	74
Costs (%-GDP)	0.13	0.05	0.38
Global			
Global reduction compared to baseline (%)	-2%	-2%	-22%
Global reduction compared to 1990 levels (%)	+53%	+53%	+23%
Global costs (%-GDP)	< 0.0001%	< 0.0001%	0.37%

Box 4: Which scenarios provide the highest likelihood of achieving the 2°C target?

Figure 5.1 compares the 2020 greenhouse gas emissions shown by the three scenarios (Table 5.2) with 'ranges' of interrelated sets of emission pathways ('emission envelopes'). These emission envelopes show the range within which the emissions for this century must remain, in order to achieve the stabilisation levels for greenhouse gases of 450, 550 and 650 ppm CO_2-eq. (Den Elzen et al., 2007b). The top of the envelope is mainly determined by the fact that further postponement of reductions will mean that the intended concentration levels in the atmosphere will no longer be feasible. The emission pathways that in the short term (2020-2030) are found at the top of the envelope, the so-called 'delayed response' pathways, will switch to the bottom of the envelope after a period of maximum emission reduction (2% per year for 650 ppm, 2.5% for 550 ppm, and 3% for 450 ppm). The reverse is true for pathways that start at the bottom of the envelope, the so-called 'early action' pathways.

The figure shows that if the world fails to reverse the increase in emissions before 2025 and to let these fall sharply afterwards, it will not be possible to achieve low concentration levels within a reasonable timeframe. A temperature increase of over 2°C is then very likely. In order to achieve the 2°C target with over 50% certainty (assuming the probabilistic density function for the climate sensitivity[27] of Wigley and Raper (2001), we need to stabilise GHG concentrations at 450 ppm CO_2-eq. (Den Elzen and Meinshausen, 2005; 2006a; 2006b; Hare and Meinshausen, 2006). The 'EU 30% in multilateral regime' scenario leads to increase in the global GHG emissions (excluding land-use related CO_2 emissions) by 23% compared to 1990 levels, which strongly resembles the 450 ppm CO_2-eq. scenario, and is therefore likely to meet the 2°C target. In the scenarios 'EU 20% unilateral without CDM' and 'EU 20% unilateral with CDM' scenario the rise of emissions up to 2020 is so substantial that it becomes very unlikely that the temperature increase can be limited to 2°C.

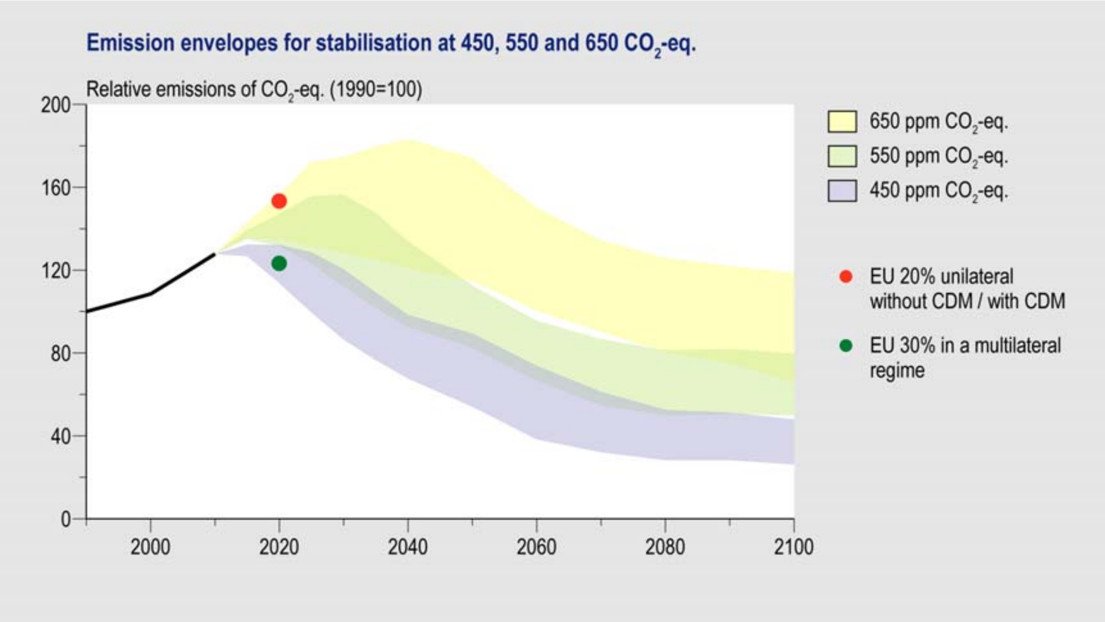

Figure 5.1: Emission reductions of the three scenarios compared to the emission envelopes for stabilisation of concentrations and the chance of achieving the EU climate target, based on Den Elzen et al. (2007b).

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[27] Climate sensitivity summarises the key uncertainties for long-term climate projections and is expressed as the expected warming of the earth's surface for a doubling of pre-industrial CO_2 concentrations. This study uses the probabilistic density function for the climate sensitivity by Wigley and Raper (2001) to match the conventional IPCC 1.5–4.5°C uncertainty range as being a 90% confidence interval of a lognormal PDF.

Including CDM (comparing 'EU 20% unilateral with CDM' and 'EU 20% unilateral without CDM') significantly increases the amount of cheap emission reductions on the EU trading market, which mainly affects the permit price[28], lowers the domestic abatement to -15% compared to 1990 levels, and also significantly lowers the overall costs for the EU as a group.

Increasing the reduction objective to 30% in a multilateral regime leads to almost the same internal domestic abatement for the EU as in the 'EU 20% unilateral without CDM' scenario. However, the additional reduction effort to meet the 30% reduction is bought outside the EU through CDM and IET. The extra permits are bought against a permit price of €66/tCO_2-eq. This price is much higher than in the 'EU 20% unilateral with CDM' scenario as a result of the higher demand for permits from a large coalition of Annex I and more advanced developing countries with a comparable reduction effort. The 19% compared to 1990 levels for internal domestic abatement combined with the extra 11% compared to 1990 levels bought on the international permit trading market for €66/tCO_2-eq. results in much higher costs for the EU as a group than both EU 20% scenarios.[29] [30]. (Costs for the internal domestic abatement are comparable to the 'EU 20% unilateral without CDM' scenario.)

The environmental impact in terms of global emission reductions of the unilateral EU reduction of 20% is very limited, with only 2% reduction compared to the baseline emissions in 2020. However, the impact of a broad participation in the EU multilateral 30% regime is considerable: it lowers the GHG emissions compared to the baseline emissions to 22%, which represents an increase of 23% compared to the 1990 levels (see Box 4).

The rest of this chapter focuses on EU internal burden-sharing. Sections 5.2 through 5.4 describe the emission reduction targets and abatement costs for the EU countries for all three scenarios, while section 5.5 describes the countries' reduction measures in more detail. Although the countries' abatement costs and emission reduction targets are fully dependent on the regime approach, the countries' reduction measures are not.

5.2 The 'EU 20% unilateral without CDM' scenario

International context – This scenario assumes that despite intensive negotiations, the developed and the larger, fast-developing countries fail to achieve post-2012 climate agreements on GHG reduction targets. This leads to an impasse, as no follow-up agreements are made for the post-2012 period. This scenario shows similar world developments to that

[28] The price of 23 €/tCO_2-eq. is somewhat lower than the permit price of 35 €/tCO_2-eq. under a similar scenario of the POLES energy model (see EU staff working paper: http://ec.europa.eu/environment/climat/pdf/ia_sec_8.pdf).

[29] A similar pattern of increase in the GDP impact for the EU 30% in a multilateral regime scenario was found for the macro-economic model GEM-E3 (see EU staff working paper. An opposite pattern, i.e. a decrease in the GDP impact, was found for the scenario analysis with the macro-economic model WorldScan, as described in Boeters et al. (2007).

[30] Section 7.5 presents the impact of using the marginal abatement costs curve for the EU of the TIMER model instead of the GENESIS database.

described in the IMPASSE scenario developed by Boeters et al. (2007). Here, we assume that the EU adopts the 20% internal reduction target unilaterally, as agreed by the EU. In this way, the EU tries internally to keep its emissions trading system alive – in expectation of better times. Thus one hopes that later, when climate policy ranks higher on the international policy agenda, it will be relatively easy to switch over to stricter emission restrictions.

Model implementation – We assume that the EU unilaterally adopts its 20% reduction target. Emission allowances are allocated according to the six burden-sharing approaches. CDM is not assumed in this scenario (the 'EU 20% and unilateral with CDM' scenario shows the effect of allowing CDM) and there is no trade in emission credits outside the EU's internal trading market. Table 5.3 shows the resulting emission allowances for the individual EU Member States, according to the six EU burden-sharing regimes, compared to the 1990 and baseline levels.[31] Under an allocation approach, the countries that achieve the highest and lowest reductions compared to the 1990 emissions are indicated by red and green cells respectively (Table 5.3a). Table 5.3b shows the countries with reductions compared to the baseline emissions amounting to twice the EU average (about 23%) as red cells, and those with excess emission allowances ('hot air') as green cells. Table 5.4 shows the emissions traded on the international EU internal trading market and abatement costs as a percentage of GDP for the individual EU countries. Table 5.4a shows the countries with net gains as green and countries with net costs (twice the EU average) as red. Table 5.4b shows the countries that are net buyers and net sellers (red and green, respectively). Figure 5.2 shows the reduction targets for the eight largest EU emitters, which together represent around 75% of the total 2000 EU emissions, for all regimes (except *Grandfathering,* which was excluded for reporting reasons). Figure 5.3 shows the abatement costs and emissions trading for the eight largest EU emitters. Note, the banked excess emission allowances of the Kyoto period are not available for meeting the domestic target or for selling on the EU's internal market.

Emission allowances – The 2020 emission targets are calculated by the rules set under the different approaches and the initial emissions in the starting-year (2010). The initial emissions are assumed to be equal to the Kyoto targets[32] as agreed in the internal EU burden-sharing agreement, except for the non-Annex I European countries, Cyprus and Malta, which follow their baseline emissions. This assumption favours those Annex I countries with baseline emissions in 2010 that are much lower than their Kyoto targets, i.e. countries with excess emission allowances ('hot air'). In our analysis this applies to the Czech Republic, Bulgaria and Romania, as for almost all regimes (except *Equal costs* and *Multi-criteria (EQ)*) these countries will also have excess emission allowances in 2020.

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[31] For a detailed overview of emissions and underlying drivers for the period (1990-2004), as well as a summary of the policies for the main European countries, please refer to the factsheets in the Ecofys report 'Factors underpinning future action' (Höhne et al., 2006). For a comparison of the results of the Ecofys study and this study, see section 7.2.

[32] Section 7.5 discusses the impact of choosing the baseline (2010) emissions instead of the Kyoto targets as the initial emissions..

Table 5.3: Reduction targets (%) in 2020 compared to 1990 levels (a) and baseline levels (b) for the 'EU 20% unilateral without CDM' scenario. The red cells in upper part Table 5.3a (1990-levels) indicate the regime with the highest reduction and the green cells indicate those with the lowest reductions. The red cells in lower part Table 5.3b (baseline) indicate reductions of twice the EU average and the green cells indicate excess emission allowances.

(a) 1990-levels	Kyoto target	Grand-fathering	Per capita convergence	Multi-Criteria	Ability to pay	Triptych	Equal costs
Austria	-13	-20	-19	-14	-26	-20	-7
Belgium	-7.5	-20	-23	-17	-25	-18	-12
Denmark	-21	-20	-32	-17	-34	-23	-35
Finland	0	-20	-20	-19	-27	-9	-19
France	0	-20	-9	-14	-24	-10	-14
Germany	-21	-20	-33	-16	-26	-35	-26
Greece	+25	-20	5	-17	-14	6	13
Ireland	+13	-20	-12	-22	-33	11	-8
Italy	-6.5	-20	-14	-13	-22	-15	-10
Luxembourg	-28	-20	-45	-13	0	-40	-2
Netherlands	-6	-20	-21	-17	-26	-10	-11
Portugal	+27	-20	22	-12	-13	28	46
Spain	+15	-20	5	-13	-17	16	18
Sweden	+4	-20	-5	-14	-30	-17	-20
United Kingdom	-12.5	-20	-25	-16	-28	-23	-29
EU-15	-8	-20	-19	-15	-25	-18	-16
Cyprus	*	-20	-3	-12	-15	20	61
Czech Republic	-8	-20	-29	-34	-7	-33	-45
Estonia	-8	-20	-28	-33	-6	-22	-37
Hungary	-6	-20	-20	-21	-7	-22	-27
Latvia	-8	-20	1	-13	-5	-2	-1
Lithuania	-8	-20	-7	-16	-5	-14	11
Malta	*	-20	-8	-11	0	-8	-4
Poland	-6	-20	-21	-25	-6	-18	-22
Slovakia	-8	-20	-21	-27	-5	-39	-29
Slovenia	-8	-20	-18	-14	-13	-16	-6
EU-10	-8	-20	-22	-26	-7	-23	-27
Bulgaria	-8	-20	-30	-74	-3	-45	-54
Romania	-8	-20	-22	-46	-3	-35	-50
EU-2 new	-8	-20	-25	-55	-3	-39	-51
EU	-8	-20	-20	-20	-20	-20	-20
(b) Baseline							
Austria	-24	-36	-36	-31	-41	-36	-26
Belgium	-13	-29	-32	-27	-34	-27	-22
Denmark	-15	-12	-25	-8	-27	-15	-28
Finland	6	-20	-19	-19	-27	-8	-19
France	-11	-34	-25	-29	-37	-25	-29
Germany	-11	-14	-28	-10	-20	-30	-20
Greece	-9	-44	-26	-42	-40	-26	-21
Ireland	-6	-35	-28	-36	-45	-9	-25
Italy	-17	-31	-25	-25	-32	-27	-22
Luxembourg	-31	-29	-51	-23	-12	-47	-13
Netherlands	-16	-32	-33	-30	-37	-24	-25
Portugal	-20	-56	-33	-52	-52	-30	-20
Spain	-19	-48	-32	-44	-46	-25	-23
Sweden	-2	-37	-25	-32	-44	-34	-37
United Kingdom	-4	-17	-23	-13	-26	-21	-27
EU-15	-12	-28	-27	-24	-32	-26	-24
Cyprus	-43	-59	-51	-55	-57	-39	-18
Czech Republic	42	24	10	2	43	3	-16
Estonia	0	-8	-17	-23	8	-10	-28
Hungary	6	-12	-12	-13	1	-15	-20
Latvia	-15	-40	-24	-34	-28	-26	-25
Lithuania	-24	-45	-36	-42	-35	-41	-24
Malta	-18	-38	-29	-31	-22	-28	-25
Poland	11	-13	-15	-19	2	-11	-15
Slovakia	20	-8	-10	-16	9	-30	-19
Slovenia	-22	-34	-32	-29	-28	-31	-22
EU-10	12	-10	-12	-17	5	-13	-17
Bulgaria	63	35	19	-56	65	-6	-23
Romania	58	28	25	-13	56	4	-20
EU-2 new	59	31	23	-27	59	0	-21
EU	-10	-23	-23	-23	-23	-23	-23

*: Non-Annex II; **: No limit specified. Country had not ratified the Convention when the Kyoto Protocol was adopted

The following section discusses the different regimes. For countries with a relatively high reduction target under Kyoto (such as Germany with -21%), the 2020 reduction targets are in contrary, significantly higher than the reduction targets of countries with a growth target under Kyoto (such as Spain with +15%) (Figure 5.2). This does not imply that the reduction targets compared to the baseline are also higher, as Figure 5.3 shows.

The results for *Grandfathering* show that uniform reduction targets of -20% for all countries seem somewhat in contrast with the more differentiated reduction targets, as adopted in the EU internal burden-sharing agreement. It leads to high reductions (compared to baseline levels) for EU Member States that had growth targets under the Kyoto Protocol compared to 1990 levels (Greece, Portugal, Spain and Ireland, but also Cyprus). Their reductions compared to baseline levels can be twice as much as the EU average (see red cells in Table 5.3b). On the other hand, for countries with Kyoto targets higher than 20% compared to 1990 levels, this would imply a growth target compared to this Kyoto target (Denmark, Germany and Luxembourg). Furthermore, the approach leads to substantial excess emission allowances for the Czech Republic, Bulgaria and Romania (see green cells in Table 5.3b).

Our interpretation of the *Ability to pay* approach leads to excess emission allowances for the Eastern European countries, i.e. Czech Republic, Estonia, Hungary, Poland, Slovakia, Bulgaria and Romania (green cells Table 5.3b), sometimes of around 50–60% of their baseline emissions. Evidently this results in high reduction targets for all EU-15 countries (in general the highest reductions compared to the other regimes, see red cells), in particular for Ireland, Portugal, Denmark, the Netherlands and Sweden.

The *Per capita convergence* approach, as one might expect, favours the countries with low per capita emissions, such as France and Sweden, and results in excess emission allowances for the Czech Republic, Bulgaria and Romania (although much less than in the *Ability to pay* approach). Furthermore, this regime leads to relatively high reduction targets for EU-10 countries with relatively high per capita emissions, such as Cyprus, Estonia, Hungary, Poland, Slovakia and Slovenia.

The *Multi-criteria (EQ)* approach leads to relatively low reductions for the EU-15 countries with low emission intensities, in particular Denmark, Germany and the United Kingdom. However, the approach leads to relatively high reduction targets for the EU-10 and Bulgaria and Romania.

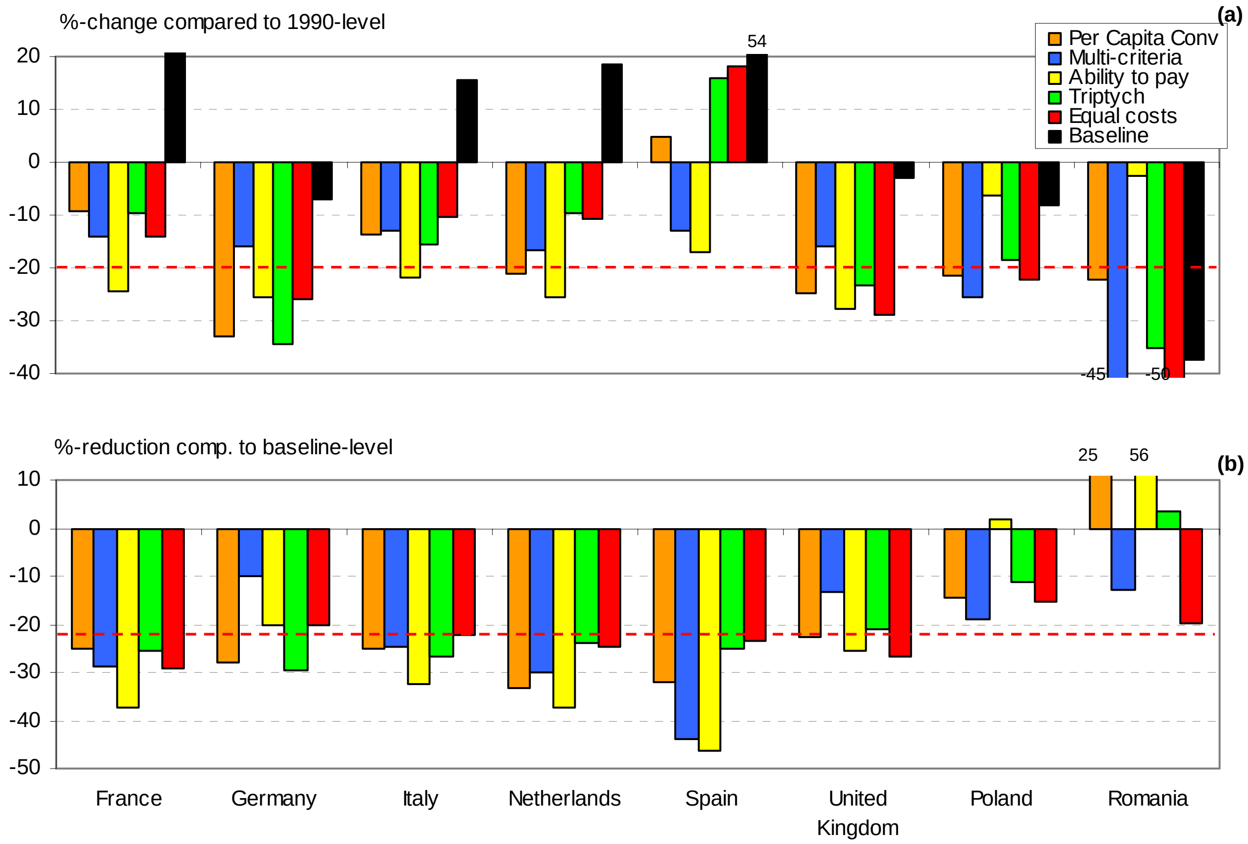

Figure 5.2: Emission allowances compared to 1990 levels (a) and emission allowances compared to baseline levels (b) for 2020, for the eight largest EU emitters under the 'EU 20% unilateral without CDM' and the 'EU 20% unilateral with CDM' scenarios. The dotted line represents the EU average.

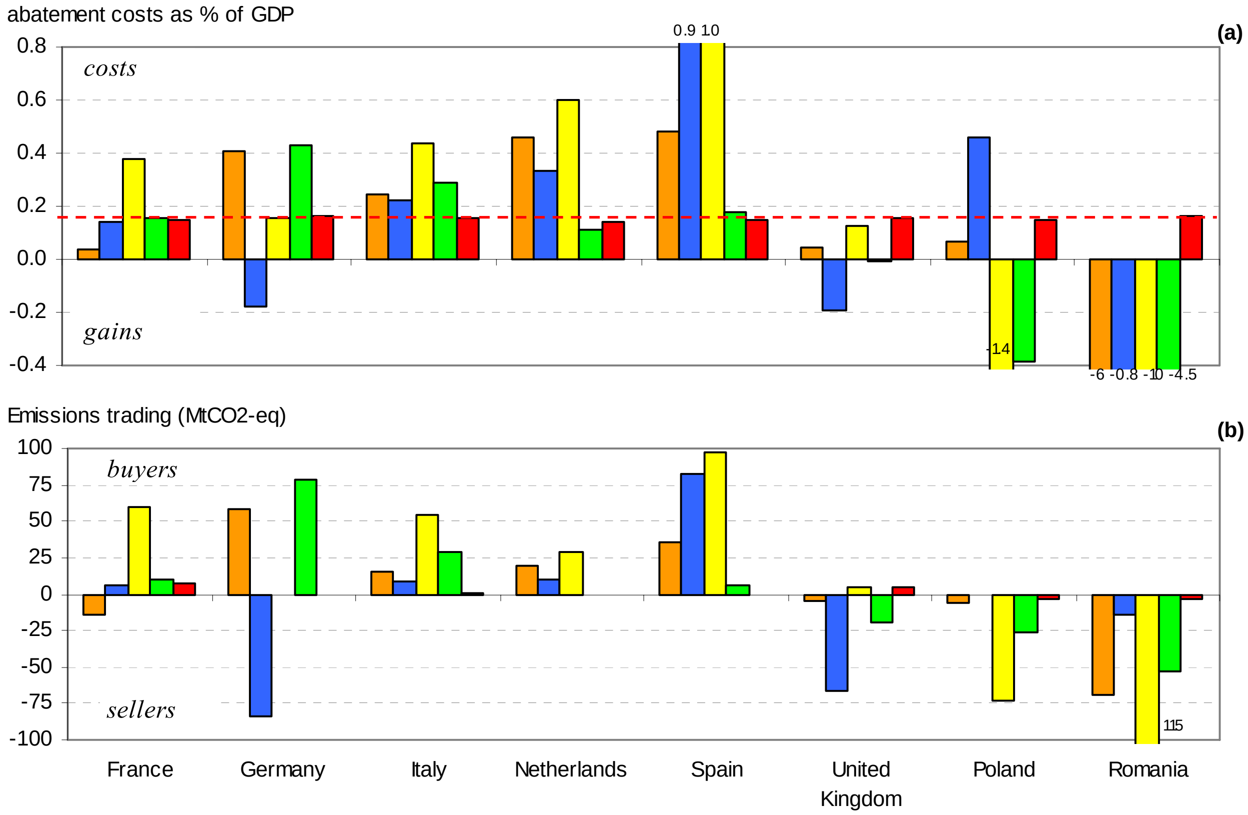

Figure 5.3: Abatement costs as %-GDP (a) and emissions trading (b) for 2020, for the eight largest EU emitters under the 'EU 20% unilateral without CDM' scenario. The dotted line represents the EU average.

The *Triptych* approach leads to low reduction targets (in general less than 10%) compared to the baseline for most EU-10 countries and Bulgaria, and low excess emission allowances for the Czech Republic and Romania. The approach allows emission growth (compared to 1990 levels) for Greece, Ireland, Spain and Portugal. It avoids extreme reduction targets, which is illustrated by the small number of countries with reductions that are twice the EU average (see red cells in Table 5.3b). The reductions for the high-income European countries are somewhat higher, but still lower compared to their reductions under the *Ability to pay* and *Equal costs* approach. The only exception is Germany, for which the *Triptych* approach leads to the highest reduction targets, due to their lower industrial growth projections and their relatively high per capita domestic emissions.

The *Equal Costs* approach leads to some fairly different reduction targets compared to the other approaches. In general Greece, Portugal and Spain are allowed to expand their emission levels in the present Kyoto agreement, and also under the *Equal Costs* approach. For some EU-15 countries this approach leads to the lowest reduction targets compared to the other approaches, while for the United Kingdom only this approach leads to the highest reductions. For the EU-10 countries, the approach leads to the highest reductions. The same holds for Romania and Bulgaria, as these countries have to give up their excess emission allowances from which they benefit in most other approaches. Therefore this approach may meet considerable resistance from these countries. It should again be noted that the results depend strongly on the marginal abatement costs assumptions.

Emissions trading - Emissions trading is determined by a country's reduction objective, as well as their abatement potential and costs. The dependency on the reduction objective makes emissions trading dependent on the regime, as illustrated in Table 5.4. This table also illustrates the emission levels after emissions trading and the domestic abatement (excluding surplus emission allowances). Due to the least-cost approach, the reductions are made in the country where they are most cost-effective. Therefore, the emission levels after trading are the same for the six regime approaches analysed. The emission allowances (before emissions trading) can be calculated as the emission levels after emissions trading minus the emissions bought on the EU emissions trading market, or the emission levels after emissions trading plus the emissions sold on the EU emissions trading market. The baseline emissions are not given here, but in Table 2.1 in chapter 2, although these can be calculated by as the sum of the emission levels after emissions trading plus the domestic abatement.

Comparing the domestic abatement and emission credits bought on the international world and EU internal emissions market by countries (buyers: red cells), provides an insight into the fractions of the domestic and external abatement of countries. For example, for the EU-15 countries, the domestic abatement exceeds the external abatement. As the domestic abatement does not include excess emission allowances ('hot air'), the traded emission credits for some countries (sellers: green cells) with excess emission allowances may exceed the domestic abatement.

Table 5.4: Emissions trading (MtCO2-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the EU 20%unilateral without CDM scenario. The green cells (a) indicate the sellers on the emissions trading market; and red cells indicate the buyers. The green cells indicate gains; red cells indicate costs of over twice that of the EU average. For comparison, the domestic abatement and emissions after emissions trading are also given here.

(a) Emissions trading	*Emissions after trading**	Domestic abate-ment**	Grand-fathering	Per capita conver-gence	Multi-Criteria	Ability to pay	Triptych	Equal costs
Austria	65	22	9	9	5	14	10	0
Belgium	110	35	7	12	4	15	5	0
Denmark	47	15	-8	0	-10	0	-4	0
Finland	57	12	1	1	1	6	-6	1
France	442	172	36	-14	5	60	11	7
Germany	816	185	-45	58	-84	0	79	0
Greece	103	31	28	5	25	24	2	0
Ireland	53	20	5	0	6	14	-5	-1
Italy	399	120	40	16	8	55	29	0
Luxembourg	12	2	2	5	2	0	4	0
Netherlands	173	60	16	19	10	29	0	0
Portugal	78	21	35	13	31	32	12	0
Spain	320	103	101	36	83	98	6	0
Sweden	57	28	3	-7	-1	10	1	3
United Kingdom	518	158	-40	-4	-67	5	-19	4
EU-15	3250	986	190	148	18	361	123	15
Cyprus	8	2	4	3	4	4	2	0
Czech Republic	97	20	-48	-31	-22	-71	-25	-2
Estonia	11	5	-4	-2	-1	-6	-3	0
Hungary	69	19	-8	-8	-7	-20	-8	-1
Latvia	10	4	1	0	1	0	0	0
Lithuania	21	8	5	2	4	2	4	0
Malta	3	1	0	0	0	0	0	0
Poland	336	67	-14	-6	0	-72	-26	-4
Slovakia	39	11	-6	-6	-2	-15	5	-1
Slovenia	15	5	1	1	1	1	1	0
EU-10	610	143	-69	-46	-24	-177	-49	-9
Bulgaria	55	20	-47	-34	19	-69	-21	-3
Romania	115	33	-74	-69	-14	-115	-53	-3
EU-2 new	170	53	-121	-103	6	-183	-74	-6
Outside EU	0	0	0	0	0	0	0	0
(b) Abatement costs								
Austria			0.44	0.43	0.29	0.58	0.47	0.15
Belgium			0.41	0.53	0.31	0.59	0.33	0.15
Denmark			-0.23	0.08	-0.31	0.12	-0.11	0.15
Finland			0.17	0.16	0.14	0.42	-0.21	0.15
France			0.28	0.04	0.14	0.38	0.16	0.15
Germany			-0.04	0.41	-0.17	0.15	0.43	0.15
Greece			1.41	0.45	1.30	1.17	0.27	0.15
Ireland			0.52	0.27	0.58	0.90	-0.09	0.15
Italy			0.40	0.24	0.22	0.44	0.29	0.15
Luxembourg			0.68	1.38	0.48	0.10	0.92	0.15
Netherlands			0.43	0.46	0.33	0.60	0.11	0.15
Portugal			1.75	0.71	1.56	1.56	0.67	0.15
Spain			1.11	0.48	0.94	1.03	0.18	0.15
Sweden			0.15	-0.12	0.05	0.31	0.08	0.15
United Kingdom			-0.09	0.05	-0.19	0.13	-0.01	0.15
EU-15			0.27	0.25	0.14	0.39	0.21	0.15
Cyprus			2.43	1.94	2.20	2.26	1.29	0.15
Czech Republic			-3.77	-2.32	-1.56	-5.63	-1.76	0.15
Estonia			-2.58	-1.23	-0.46	-4.73	-2.51	0.15
Hungary			-0.49	-0.50	-0.42	-1.59	-0.48	0.15
Latvia			1.29	0.07	0.87	0.41	0.36	0.15
Lithuania			2.28	1.37	1.98	1.23	1.91	0.15
Malta			0.77	0.33	0.44	0.03	0.24	0.15
Poland			-0.08	0.07	0.46	-1.43	-0.38	0.15
Slovakia			-0.99	-0.83	-0.18	-2.74	1.61	0.15
Slovenia			0.84	0.73	0.57	0.49	0.70	0.15
EU-10			-0.52	-0.29	0.12	-1.85	-0.32	0.15
Bulgaria			-13.92	-9.84	8.34	-20.81	-5.51	0.15
Romania			-6.51	-5.97	-0.83	-10.24	-4.49	0.15
EU-2 new			-8.18	-6.84	1.24	-12.62	-4.72	0.15
EU			0.15	0.15	0.15	0.15	0.15	0.15

* The emission allowances (before emissions trading) can be calculated as the emission levels after emissions trading minus the emissions bought on the EU emissions trading market, or the emission levels after emissions trading plus the emissions sold on the EU emissions trading market. ** Excluding surplus emission allowances.

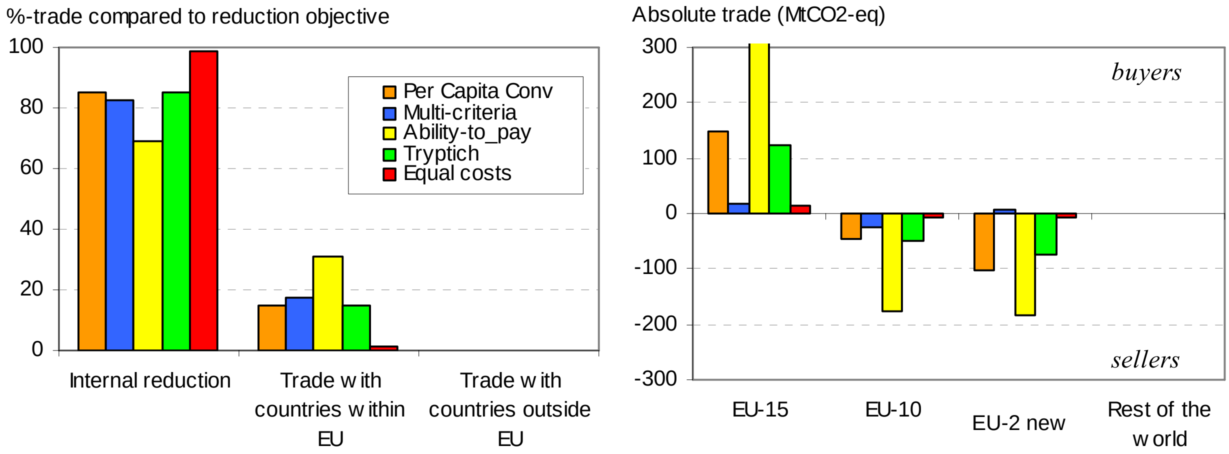

Figure 5.4: Percentage of emission reductions taken domestically, traded within the EU and traded with countries outside the EU (left), plus the total amount of emissions traded ($MtCO_2$-eq.) with the different groupings and the rest of the world (right) for 2020 for the 'EU 20% unilateral without CDM' scenario.

There are excess emission allowances for Bulgaria and Romania in all regimes except for *Multi-criteria* and *Equal costs*, while the Czech Republic has excess emission allowances for all regimes except *Equal costs*. Furthermore, several EU-10 countries have excess emission allowances for the *Ability to pay* approach. The excess emission allowances can result in high gains on the EU internal emissions trading market. On the contrary, Portugal and Cyprus have reduction targets that are twice the EU average under the *Grandfathering*, *Multi-criteria* and the *Ability to pay* approaches. Here, large reduction objectives can result in high costs, as most of these countries are not able to implement all reductions domestically.

Overall, the EU-15 countries are net buyers on the market, while the EU-10 and EU-2 new countries are net sellers (Table 5.4a and Figure 5.4). The largest supplier is Romania, but also those in Bulgaria, the Czech Republic and Poland, are large suppliers in almost every regime (except for the *Equal costs* approach), mainly because these countries still have excess emission allowances in 2020, which they sell on the EU emissions trading market. Spain is the largest overall buyer. Although most EU-15 countries are buyers, Germany, the United Kingdom and, to a lesser extent, Denmark can also be sellers as in four out of six regimes their reduction targets compared to the baseline emissions are below the EU average reduction. Overall, the *Ability to pay* regime results in the largest emissions trading, while *Equal costs* shows the least emission reductions traded on the EU internal emissions trading market.

Abatement costs – The national total abatement costs, as a percentage of GDP (Table 5.4b), differ per country and per regime. The EU-15 shows net costs for almost all countries and regimes. Denmark, Finland, France, Sweden and the United Kingdom also show the lowest costs (always less than twice the EU average) and sometimes even gains, while Portugal and

Greece show costs that are over twice the EU average for every regime. Most EU-10 countries show net gains for the six regimes. An exception is Cyprus with costs that are always more than 1% of its GDP. Lithuania and Slovenia also show high costs for several regimes. The EU-2 new countries almost always show very large gains, even up to 21% of Bulgaria's GDP (under the *Ability to pay* approach), which is a result of the lower reduction target combined with its excess emission allowances. Finally, the *Triptych* approach not only results in the most equally spread distribution of reduction efforts for all six regimes explored , but this also holds for the costs also the costs are the most balanced result into the and abatement costs among all European countries, with medium costs for the EU-15 countries (except for Portugal and Luxembourg) and lower costs and even gains for the EU-10 countries (except for Cyprus), Bulgaria and Romania. On the contrary, *Grandfathering* and the *Ability to pay* approach produces the most extreme results, with very high gains for the EU-2 new countries (up to 14% of their GDP), and high costs for Lithuania and Cyprus, but also for Portugal and Greece, and even for Ireland and Spain.

5.3 The EU 20% unilateral with CDM scenario

International context – This is similar to the 'EU 20% unilateral without CDM' case, but now with the availability of international flexibility mechanisms JI and CDM beyond 2012.

The resulting emission allowances for the individual EU Member States according to the six EU burden-sharing regimes are the same as the 'EU 20% unilateral without CDM' scenario (section 5.2), except the emission allowances for the *Equal costs* case. However, the accompanying emissions trading and abatement costs as percentages of GDP are different, as this scenario also allows emissions trading with countries outside the EU. Table 5.5 shows the emissions traded on the international market and abatement costs as percentages of GDP for the individual EU Member States. Table 5.5a shows the countries with net gains (in green) and countries with net costs that are twice the EU average (shown in red). Table 5.5b shows the countries that are net buyers and net sellers, in red and green, respectively. Figure 5.5 shows the abatements costs and emissions trading for the eight largest EU emitters and regimes.

Emissions trading – Compared to the 'EU 20% unilateral without CDM' scenario, emissions after trading are higher (3511 versus 3250 $MtCO_2$-eq.) and total internal reduction is substantially lower, as a large amount of cheap emission reductions are in this scenario achieved via CDM outside the EU (about 23%) (Figure 5.6). The lower permit price on the emissions trading market and the reductions achieved via CDM also results in a decreased amount of emissions being traded within the EU (compare Figure 5.4 and Figure 5.6). However, the emissions trading per country also shows the same trends as in the 'EU 20% unilateral without CDM' scenario. The *Ability to pay* approach again shows the most trading within the EU, while for the *Equal costs* approach internal trading is again almost zero and trading takes place almost exclusively with countries outside the EU.

Table 5.5: Emissions trading ($MtCO_2$-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the 'EU 20% unilateral with CDM scenario. The green cells (a) indicate the sellers on the emissions trading market; red cells indicate the buyers. The green cells indicate gains; red cells indicate costs that are more than twice those of the EU. For comparison, the domestic abatement and emissions after emissions trading are also given here.

(a) Emissions trading	*Emissions after trading**	Domestic abate-ment**	Grand-fathering	Per capita conver-gence	Multi-criteria	Ability to pay	Triptych	Equal costs
Austria	72	15	16	16	12	21	17	6
Belgium	122	24	19	23	15	26	16	8
Denmark	50	12	-5	3	-7	5	-1	6
Finland	61	9	5	4	4	10	-3	4
France	485	129	79	22	48	101	51	49
Germany	866	135	5	143	-37	66	153	69
Greece	112	22	37	13	35	32	9	6
Ireland	60	13	12	7	14	20	0	4
Italy	443	76	83	53	51	91	64	43
Luxembourg	13	1	3	6	2	1	4	1
Netherlands	189	44	32	33	26	43	12	13
Portugal	84	15	40	17	36	36	17	5
Spain	347	76	128	59	109	120	27	25
Sweden	61	24	7	-3	3	14	5	9
United Kingdom	547	129	-12	21	-39	44	9	56
EU-15	3511	725	451	418	272	627	378	303
Cyprus	9	2	5	4	4	5	3	0
Czech Republic	103	15	-43	-26	-17	-65	-19	0
Estonia	12	4	-3	-1	0	-5	-3	0
Hungary	74	15	-4	-4	-3	-16	-4	2
Latvia	11	3	3	0	2	1	1	0
Lithuania	23	6	7	5	6	4	6	0
Malta	3	1	1	0	0	0	0	0
Poland	353	49	3	8	27	-57	-11	9
Slovakia	43	7	-3	-3	1	-12	9	1
Slovenia	17	3	4	3	3	3	3	1
EU-10	648	104	-30	-13	24	-143	-13	13
Bulgaria	60	15	-42	-30	27	-64	-16	-3
Romania	123	24	-66	-61	-6	-107	-45	0
EU-2 new	183	39	-108	-91	21	-171	-60	-3
Outside EU			-313	-313	-313	-313	-313	-313
(b) Abatement costs								
Austria			0.12	0.12	0.09	0.15	0.12	0.05
Belgium			0.12	0.14	0.10	0.16	0.09	0.05
Denmark			-0.03	0.03	-0.05	0.04	-0.01	0.05
Finland			0.06	0.05	0.05	0.11	-0.03	0.05
France			0.08	0.03	0.05	0.10	0.05	0.05
Germany			0.01	0.10	-0.02	0.05	0.10	0.05
Greece			0.32	0.11	0.31	0.27	0.07	0.05
Ireland			0.14	0.08	0.15	0.22	0.00	0.05
Italy			0.10	0.06	0.06	0.11	0.07	0.05
Luxembourg			0.16	0.31	0.12	0.03	0.20	0.05
Netherlands			0.12	0.12	0.10	0.15	0.05	0.05
Portugal			0.39	0.17	0.36	0.35	0.15	0.05
Spain			0.26	0.12	0.23	0.24	0.05	0.05
Sweden			0.04	-0.01	0.02	0.08	0.03	0.05
United Kingdom			0.00	0.02	-0.03	0.04	0.01	0.05
EU-15			0.08	0.07	0.05	0.10	0.06	0.05
Cyprus			0.55	0.44	0.51	0.52	0.29	0.05
Czech Republic			-0.72	-0.42	-0.26	-1.14	-0.27	0.05
Estonia			-0.43	-0.15	0.03	-0.90	-0.39	0.05
Hungary			-0.07	-0.07	-0.05	-0.31	-0.06	0.05
Latvia			0.36	0.09	0.28	0.17	0.15	0.05
Lithuania			0.55	0.35	0.50	0.33	0.45	0.05
Malta			0.20	0.10	0.13	0.04	0.08	0.05
Poland			0.02	0.05	0.15	-0.27	-0.04	0.05
Slovakia			-0.14	-0.11	0.04	-0.52	0.40	0.05
Slovenia			0.24	0.21	0.19	0.16	0.20	0.05
EU-10			-0.06	-0.02	0.08	-0.35	-0.01	0.05
Bulgaria			-2.65	-1.81	2.22	-4.19	-0.78	0.05
Romania			-1.28	-1.18	-0.05	-2.11	-0.79	0.05
EU-2 new			-1.59	-1.32	0.46	-2.58	-0.79	0.05
EU			0.05	0.05	0.05	0.05	0.05	0.05

* The emission allowances (before emissions trading) can be calculated as the emission levels after emissions trading minus the emissions bought on the EU emissions trading market, or the emission levels after emissions trading plus the emissions sold on the EU emissions trading market. ** Excluding surplus emission allowances.

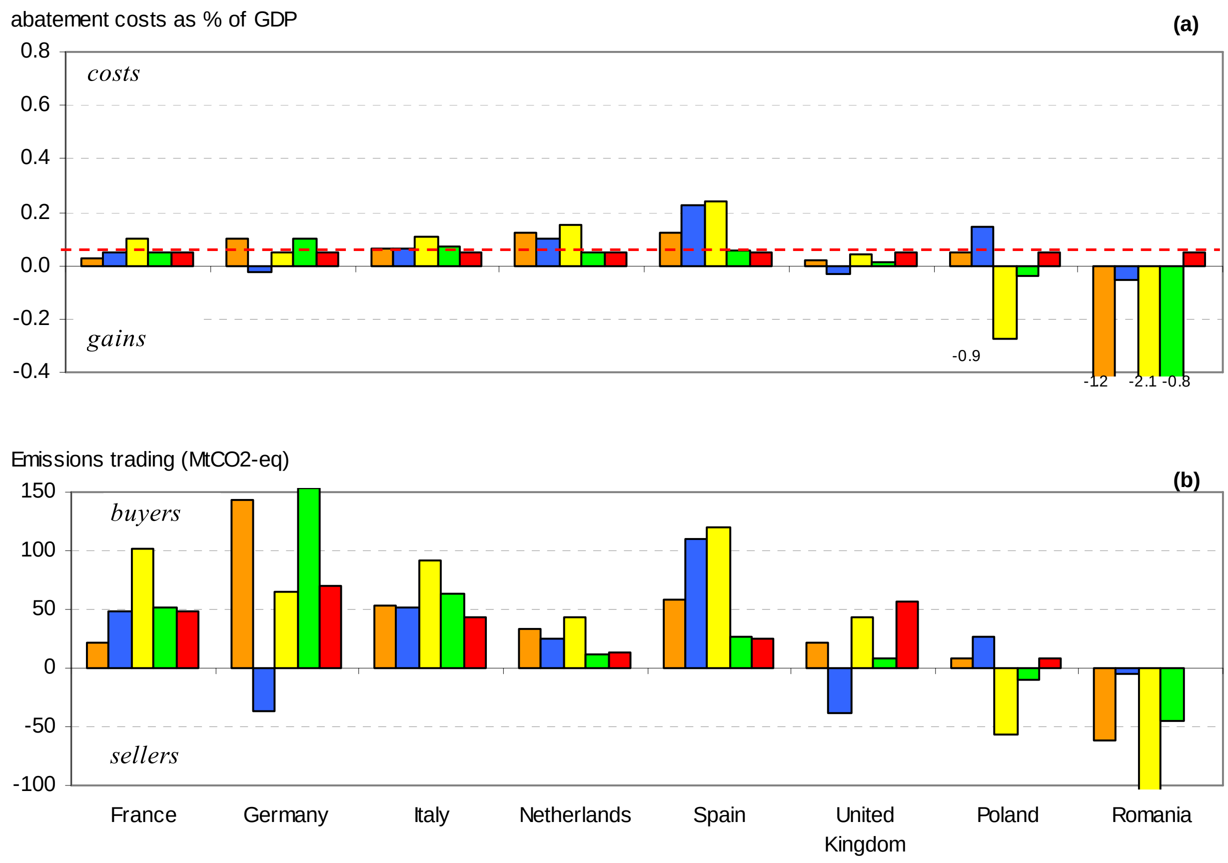

Figure 5.5: Abatement costs as %-GDP (a) and emissions trade (b) for 2020 for the eight largest EU emitters for the 'EU 20% unilateral with CDM' scenario. The dotted line represents the EU average.

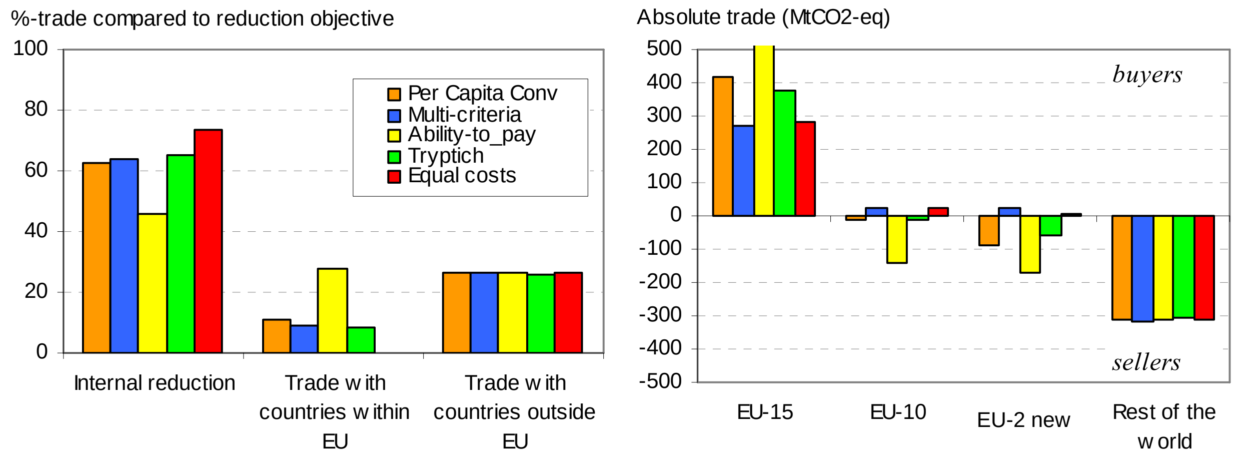

Figure 5.6: Percentage of emission reductions taken domestically, traded within the EU and traded with countries outside the EU (left), plus the total amount of emissions traded (MtCO$_2$-eq.) with the different groupings and the rest of the world (right) for 2020, for the 'EU 20% unilateral with CDM' scenario.

Abatement costs - The abatement costs also show similar trends as in the 'EU 20% unilateral without CDM' scenario, although these are generally much lower (Table 5.5). Gains for EU-10 and EU-2 new countries (now up to 4% of GDP for Bulgaria), while especially Cyprus, but to a lesser extend also Lithuania and Slovenia, are confronted with considerable costs, higher than twice the EU average. Portugal again shows costs that are more than twice the EU average for every regime. Again, the *Triptych* approach not only results in the most balanced sharing of emission reductions, but also the costs are the most balanced of all six regimes explored, with medium costs for the EU-15 countries (except for Portugal and Luxembourg) and gains for the EU-10 (except for Cyprus) and EU-2 new countries. On the contrary, *Grandfathering* and the *Ability to pay* approach results in more extreme results with very high gains for the EU-2 new countries (almost up to 8% of their GDP), Lithuania and Cyprus, but also for Portugal and Greece, Ireland and Spain.

5.4 The EU 30% in a multilateral regime scenario

International context – The negotiations succeed in forming a coalition that adopts emission reduction targets, including not just the Annex I countries, but also all advanced developing countries (ADCs) such as China, Mexico, South Korea and Brazil. The EU adopts a 30% reduction target, while the rest of the world adopts targets as presented in Table 5.1. Emission trading is only allowed within the coalition. Furthermore there is the availability of JI and CDM beyond 2012 as an emission reduction option in countries with no restrictions on emissions, such as India.

Model implementation – We assume that the EU adopts its 30% reduction target, while other countries adopt reduction targets as stipulated in Table 5.1. Emission allowances are traded freely with all countries within the coalition. Furthermore there is the option of CDM, which allows trading with countries that have no emission restrictions.

Table 5.6 shows the resulting emission allowances for the individual EU Member States according to the six EU burden-sharing regimes compared to the 1990 and baseline levels. The countries that achieve the highest and the lowest reductions are indicated by red and green cells, respectively (Table 5.6a). Table 5.6b shows the countries with reductions that are twice the EU average (red cells) and those with excess emission allowances (green cells). Table 5.7 shows the emissions traded on the international market and abatement costs as a percentage of GDP for the individual EU Member States. Table 5.7a shows the countries that are net buyers and net sellers (red and green cells, respectively). Table 5.7b shows the countries with net gains (green cells) and countries with net costs that are twice the EU average (red cells). Figure 5.7 shows the reduction targets for the eight largest EU emitters, which together represent about 75% of the total EU emissions, for all regimes (except *Grandfathering*, which was omitted for reporting reasons). Figure 5.8 shows the abatements costs and emissions trading for the same eight largest EU emitters and regimes.

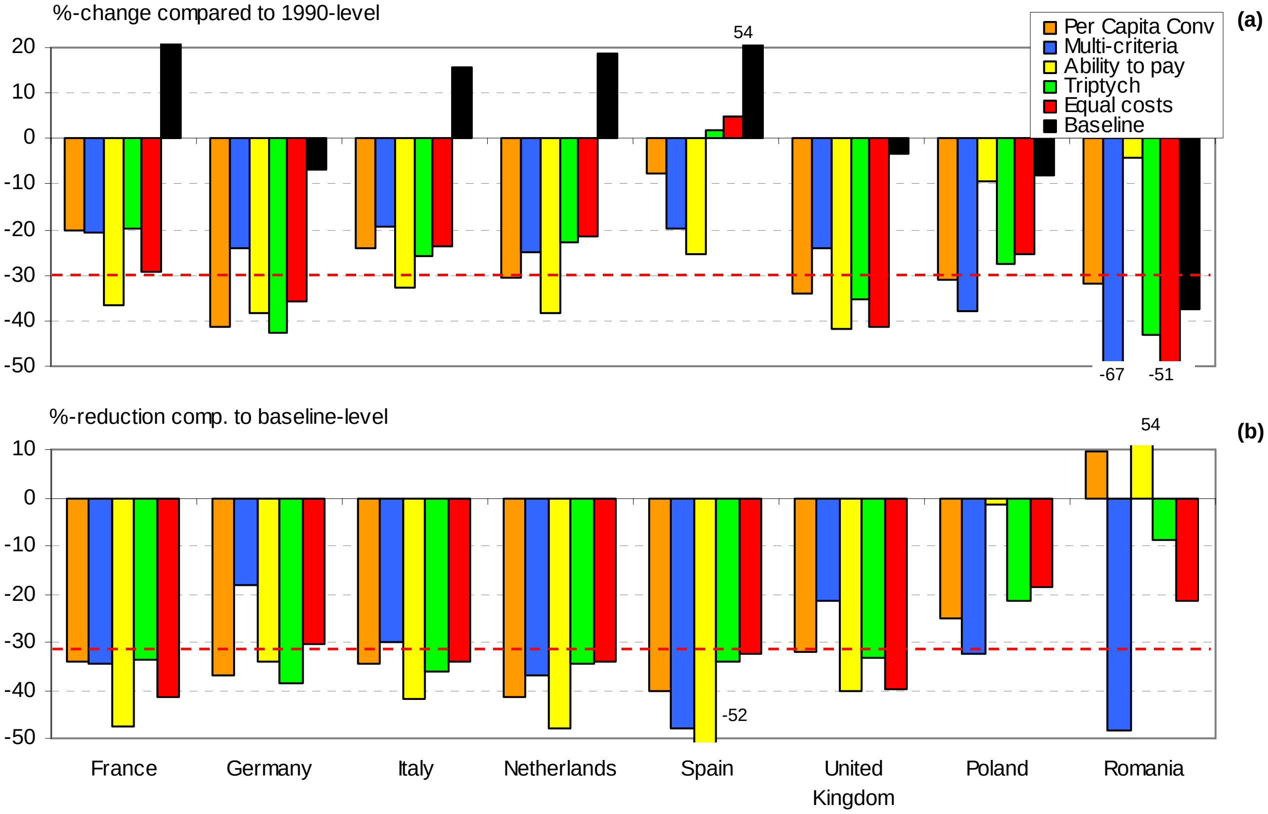

Figure 5.7: Emission allowances compared to 1990 levels (a) and emission allowances compared to baseline levels (b) for 2020 for the eight largest EU emitters for the 'EU 30% in a multilateral regime' scenario. The dotted line represents the EU average.

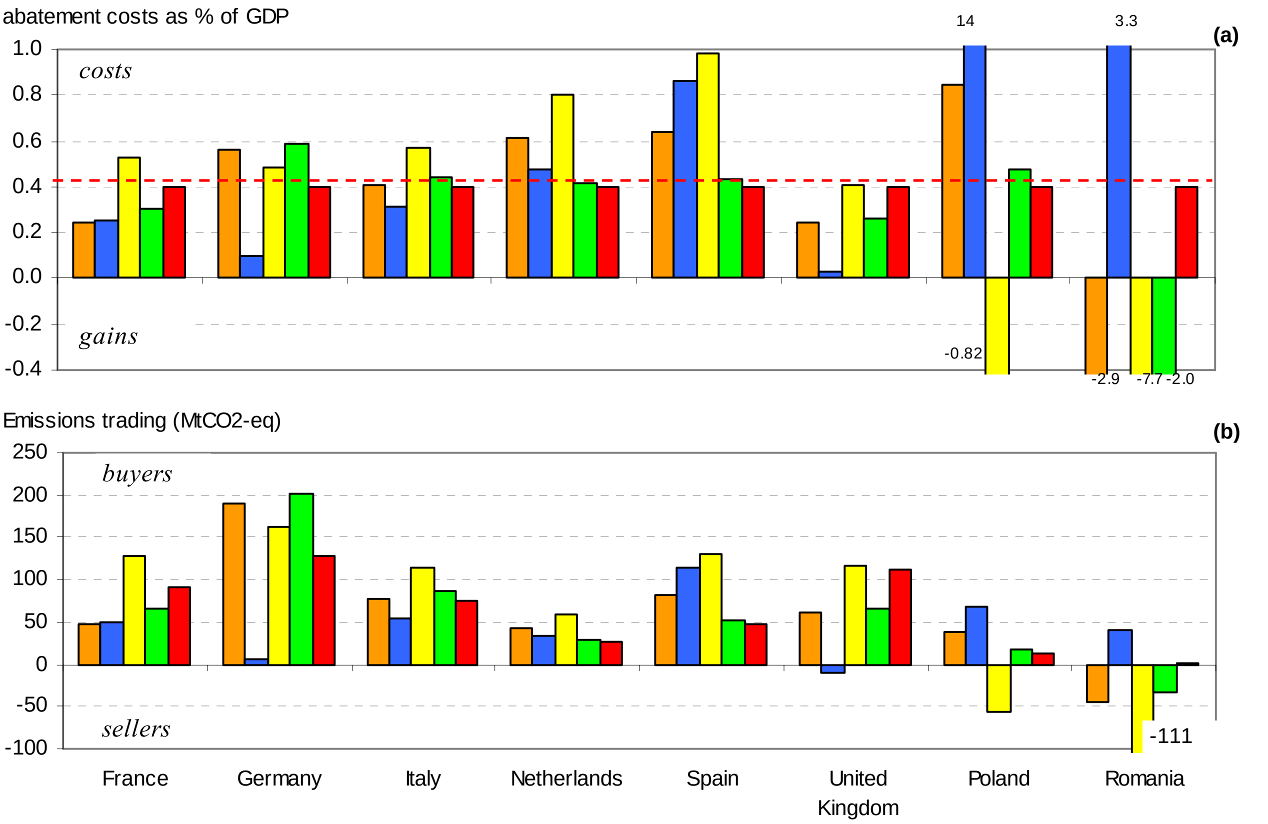

Figure 5.8: Abatement costs as %-GDP (a) and emissions trading (b) for 2020 for the eight largest EU emitters for the 'EU 30% in a multilateral regime' scenario. The dotted line represents the EU average.

Table 5.6: Reduction targets (%) compared to 1990 levels (a) and baseline levels (b) in 2020 for the 'EU 30% in a multilateral regime' scenario. The red cells in upper part Table 5.6a (1990-levels) indicate the regime with the highest reduction and the green cells indicate those with the lowest reductions. The red cells in lower part Table 5.6b (baseline) indicate reductions of twice the EU average and the green cells indicate excess emission allowances.

(a) 1990-levels	Kyoto target	Grand-fathering	Per capita convergence	Multi-criteria	Ability to Pay	Triptych	Equal costs
Austria	-13	-30	-29	-20	**-40**	-29	**-22**
Belgium	-7.5	-30	-33	-26	**-38**	-28	**-21**
Denmark	-21	-30	-40	**-25**	**-50**	-30	-48
Finland	0	-30	-29	-28	**-41**	**-17**	-29
France	0	-30	-20	-21	**-37**	**-20**	-29
Germany	-21	-30	**-41**	**-24**	-39	-43	-36
Greece	+25	**-30**	-7	-26	-21	-9	**5**
Ireland	+13	-30	-22	-33	**-50**	**-5**	-18
Italy	-6.5	-30	-24	**-19**	**-33**	-26	-24
Luxembourg	-28	-30	**-51**	-20	**0**	-48	-13
Netherlands	-6	-30	-31	-25	**-38**	-23	**-22**
Portugal	+27	**-30**	7	-18	-19	15	**32**
Spain	+15	**-30**	-8	-20	-26	2	**5**
Sweden	+4	-30	**-16**	-21	**-44**	-25	-40
United Kingdom	-12.5	-30	-34	**-24**	**-42**	-35	-42
EU-15	-8	-30	-29	**-23**	**-37**	-28	-28
Cyprus	*	**-30**	-15	-18	-22	1	**49**
Czech Republic	-8	-30	-38	**-51**	**-11**	-42	-47
Estonia	-8	-30	-37	**-50**	**-9**	-31	-39
Hungary	-6	-30	-30	-31	**-11**	**-33**	-31
Latvia	-8	**-30**	-11	-19	-7	-6	**-5**
Lithuania	-8	**-30**	-18	-23	-8	-18	**6**
Malta	*	**-30**	-20	-17	**0**	-25	-12
Poland	-6	-30	-31	-38	**-9**	-28	-25
Slovakia	-8	-30	-31	-40	**-8**	**-45**	-32
Slovenia	-8	**-30**	-28	-21	-19	-26	**-11**
EU-10	-8	-30	-32	**-39**	**-10**	-32	-29
Bulgaria	-8	-30	-38	**-110**	**-4**	-51	-54
Romania	-8	-30	-32	**-68**	**-4**	-43	-51
EU-2 new	-8	-30	-34	**-83**	**-4**	-46	-52
EU	-8	-30	-30	-30	-30	-30	-22
(b) Baseline							
Austria	-24	-44	-43	-36	-52	-43	-37
Belgium	-13	-38	-40	-34	-45	-37	-30
Denmark	-15	-23	-34	-17	-45	-23	-43
Finland	6	-30	-29	-28	-41	-16	-28
France	-11	-42	-34	-35	-48	-34	-42
Germany	-11	-25	-37	-18	-34	-39	-31
Greece	-9	-51	-35	-48	-45	-36	-27
Ireland	-6	-43	-37	-45	-59	-22	-33
Italy	-17	-39	-34	-30	-42	-36	-34
Luxembourg	-31	-38	-57	-29	-12	-54	-23
Netherlands	-16	-41	-41	-37	-48	-35	-34
Portugal	-20	-61	-41	-55	-56	-37	-27
Spain	-19	-55	-40	-48	-52	-34	-32
Sweden	-2	-45	-34	-38	-56	-41	-53
United Kingdom	-4	-28	-32	-22	-40	-33	-40
EU-15	-12	-37	-36	-30	-43	-35	-35
Cyprus	-43	-64	-57	-58	-61	-48	-24
Czech Republic	42	8	-4	-24	**38**	-10	-19
Estonia	0	-19	-27	-42	**5**	-20	-29
Hungary	6	-23	-23	-24	-3	-26	-24
Latvia	-15	-47	-33	-39	-30	-29	-28
Lithuania	-24	-52	-44	-47	-36	-44	-27
Malta	-18	-45	-37	-35	-22	-42	-31
Poland	11	-24	-25	-32	-2	-21	-19
Slovakia	20	-20	-21	-31	**6**	-37	-22
Slovenia	-22	-42	-40	-35	-33	-39	-27
EU-10	12	-21	-23	-32	1	-23	-21
Bulgaria	63	18	**4**	**-117**	**63**	-17	-23
Romania	58	12	**9**	-49	**54**	-9	-22
EU-2 new	59	14	**8**	-72	**57**	-11	-22
EU	-10	-34	-34	-34	-34	-34	-34

*: Non-Annex II; **: No limit specified. Country had not ratified the Convention when Kyoto Protocol was adopted

Table 5.7: Emissions trading ($MtCO_2$-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the 'EU 30% in a multilateral regime scenario. The green cells (a) indicate the sellers on the emissions trading market; red cells indicate the buyers. The green cells indicate gains; red cells indicate costs that are more than twice those of the EU. For comparison, the domestic abatement and emissions after emissions trading are also given here.

(a) Emissions trading	*Emissions after trading**	Domestic abatement**	Grand-fathering	Per capita convergence	Multi-criteria	Ability to pay	Triptych	Equal costs
Austria	66	21	17	17	10	24	17	12
Belgium	114	32	23	27	18	34	21	13
Denmark	47	15	-1	6	-4	13	0	12
Finland	58	12	9	8	8	17	0	8
France	451	163	96	46	49	129	65	92
Germany	824	177	71	191	6	163	202	128
Greece	108	26	43	21	38	34	20	10
Ireland	57	16	15	11	17	27	5	8
Italy	418	101	103	77	55	115	86	75
Luxembourg	12	1	4	6	3	0	5	2
Netherlands	180	53	42	44	33	59	28	26
Portugal	81	18	43	22	36	37	20	9
Spain	334	90	142	81	113	130	52	48
Sweden	57	28	10	1	4	20	6	17
United Kingdom	521	155	32	61	-10	115	66	112
EU-15	3328	909	650	621	376	916	594	573
Cyprus	9	2	5	4	4	5	3	1
Czech Republic	98	20	-29	-15	9	-64	-9	2
Estonia	12	5	-2	0	2	-5	-2	0
Hungary	70	18	3	2	4	-16	3	3
Latvia	10	4	3	1	2	1	1	0
Lithuania	22	7	8	6	7	4	6	1
Malta	3	1	1	1	0	0	1	0
Poland	339	63	33	38	68	-57	17	13
Slovakia	40	10	0	0	5	-13	10	1
Slovenia	16	5	4	4	3	2	4	1
EU-10	619	133	26	40	104	-144	33	22
Bulgaria	56	19	-33	-22	69	-66	-11	-2
Romania	116	31	-49	-45	40	-111	-32	1
EU-2 new	173	50	-82	-68	110	-177	-44	-1
Outside EU			-593	-593	-593	-596	-593	-593
(b) Abatement costs								
Austria			0.54	0.53	0.37	0.71	0.53	0.40
Belgium			0.62	0.69	0.50	0.84	0.58	0.38
Denmark			0.03	0.24	-0.07	0.44	0.06	0.39
Finland			0.42	0.41	0.38	0.72	0.07	0.39
France			0.41	0.24	0.25	0.53	0.31	0.40
Germany			0.26	0.56	0.09	0.49	0.58	0.41
Greece			1.40	0.75	1.27	1.14	0.69	0.39
Ireland			0.65	0.48	0.72	1.11	0.27	0.38
Italy			0.52	0.41	0.31	0.57	0.45	0.39
Luxembourg			0.76	1.24	0.52	0.09	0.95	0.38
Netherlands			0.60	0.61	0.48	0.80	0.42	0.39
Portugal			1.56	0.85	1.33	1.35	0.78	0.39
Spain			1.07	0.64	0.87	0.98	0.43	0.39
Sweden			0.26	0.08	0.15	0.46	0.18	0.40
United Kingdom			0.16	0.24	0.03	0.41	0.26	0.40
EU-15			0.44	0.43	0.29	0.59	0.41	0.40
Cyprus			2.12	1.79	1.85	1.95	1.44	0.39
Czech Republic			-1.65	-0.72	0.86	-3.88	-0.32	0.40
Estonia			-0.67	0.21	1.77	-3.22	-0.74	0.39
Hungary			0.36	0.33	0.42	-0.95	0.40	0.39
Latvia			1.51	0.66	1.01	0.48	0.53	0.38
Lithuania			2.35	1.72	1.99	1.14	1.77	0.43
Malta			0.91	0.61	0.53	0.04	0.73	0.38
Poland			0.77	0.85	1.39	-0.82	0.47	0.39
Slovakia			0.24	0.32	1.16	-1.83	1.90	0.39
Slovenia			1.07	0.99	0.75	0.66	0.95	0.38
EU-10			0.44	0.57	1.17	-1.13	0.51	0.39
Bulgaria			-7.32	-4.70	18.35	-15.59	-1.95	0.39
Romania			-3.21	-2.92	3.33	-7.65	-1.97	0.42
EU-2 new			-4.14	-3.32	6.72	-9.44	-1.97	0.41
EU			0.40	0.40	0.40	0.40	0.39	0.40

* The emission allowances (before emissions trading) can be calculated as the emission levels after emissions trading minus the emissions bought on the EU emissions trading market, or the emission levels after emissions trading plus the emissions sold on the EU emissions trading market. ** Excluding surplus emission allowances.

Emission allowances – There are not many countries and regimes with excess emission allowances as compared to the 20% scenarios, only Romania, Bulgaria, Slovenia and the Czech Republic for the *Ability to pay* case. Furthermore, these excess emission allowances are much lower. There are also only two countries i.e. Bulgaria and Romania with twice the averaged reduction compared to the baseline emissions for the EU. In general, the pattern of high and low reductions targets for the different regimes is roughly the same as for the 20% EU reduction target, but evidently we see higher reduction targets for all countries.

Emissions trading – In general, the pattern of buyers and sellers is roughly the same as for the -20% EU scenarios (see Figure 5.9). The only exception are the EU-10 countries (except for Czech Republic and Estonia) that now become net buyers on the market for most regimes, although they still do roughly 80-90% of their total reductions domestically (see Figure 5.9). However, while for the *Ability to pay* approach trading within the EU is approximately 20% of total emission reductions, for all other regimes internal EU trading is almost zero. On the contrary, compared to the -20% scenario (including CDM) emission trading with countries outside the EU is almost doubled. The EU-2 new countries remain net sellers on the market (except for the *Multi-Criteria* approach) while the EU-15 and EU-10 countries are almost exclusively net buyers. Again, the largest buyer is Spain, while the largest sellers within the EU are Bulgaria and Romania.

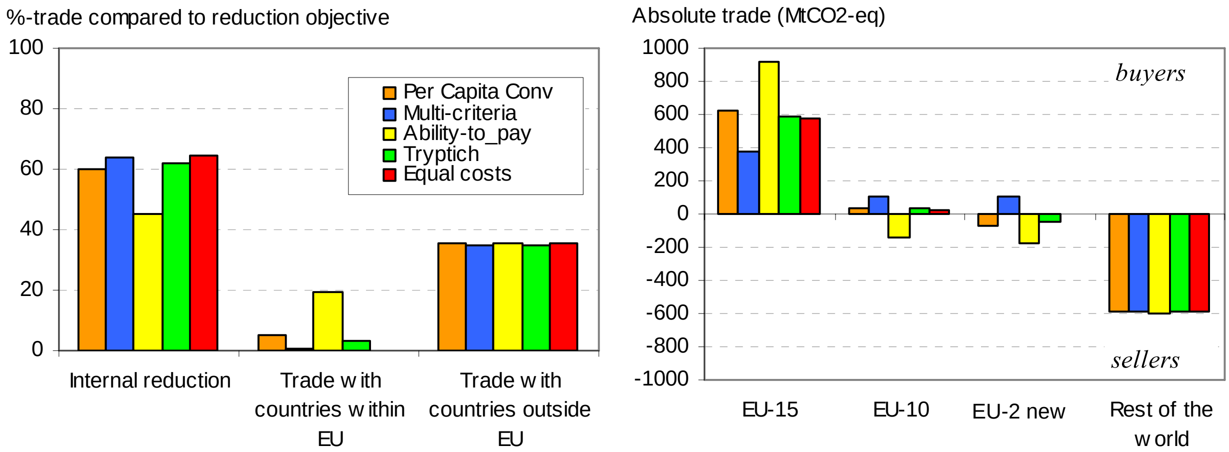

Figure 5.9: Percentage of emission reductions taken domestically, traded within the EU and traded with countries outside the EU (left) and total amount of emissions traded (MtCO_2-eq.) with the different groupings and the rest of the world (right) in 2020 for the 'EU 30% in a multilateral regime' scenario.

Abatement costs – Overall abatement costs are approximately twice as high as for the 20% scenarios. However, there are fewer countries with costs that are more than twice the EU average. Within the EU-15, Portugal and Greece are again the countries with the highest relative costs, while Cyprus and Lithuania have again the highest relative costs within the EU-10. Bulgaria and Romania have high net gains in all regimes, except for *Multi-criteria*. The *Triptych* approach again shows costs for the EU-15 within twice the EU average for most countries, and gains for the EU-10 and EU-2 new countries. On the contrary, the *Multi-*

criteria approach generally shows lower costs for the EU-15, with high costs for the EU-10 and EU-2 new countries.

5.5 Abatement measures for the European countries

This section deals with the domestic abatement measures that are taken on a country basis for the different regime approaches. As emission trading is included the measures are taken there where they are most cost-effective. Therefore, the domestic abatement measures taken per country are the same for the six approaches analysed, although they differ for the three scenarios due to different emission targets (-20% and -30% compared to 1990 levels) and different international participation rules, which determines the amount of credits available on the international market (CDM and IET). The domestic abatements for the 27 EU countries and the three scenarios are summarised in the first columns of Tables 5.4, 5.5 and 5.7. In this section, we subsequently present the domestic abatements or reductions per country, per gas, per sector and per category (renewables, energy efficiency, CHP, etc). This section focuses on the outcomes of the 'EU 20% unilateral without CDM' and the 'EU 30% in a multi-lateral regime' scenario, although both scenarios show small differences in the absolute domestic abatements for each country. In terms of the relative contributions of sectors, reduction categories and greenhouse gases to the domestic abatements, the differences become even negligible, and therefore this section only shows the results of the 'EU 20% unilateral without CDM' scenario. Appendices C and D present an overview of the domestic abatement relating to the various sectors and categories for the three scenarios and 27 EU countries. Furthermore, Appendix D presents the abatement measures per country in more detail for the 'EU 20% unilateral without CDM' scenario only.

It should be noted that the reduction over the various categories (renewables, energy efficiency, CHP, etc) is done on the basis of a cost-effective strategy. Therefore we do not fully account for the Energy Package as recently agreed by the EU, i.e.:

1. Energy efficiency: 20% improvement by 2020
2. Renewable energy: 20% mandatory objective by 2020
   - differentiation of targets between countries
   - flexibility in target setting within a country between sectors
3. Biofuels target of 10% by 2020
4. Sustainable power generation from fossil fuels: 12 large scale CCS demonstration plants by 2015 and aiming at near-zero emissions by 2020
5. Strategic energy technology plan
6. Internal market options unbundling & regulatory powers:
   - important for functioning EU ETS
   - overcoming hurdles for renewables
7. Nuclear: Member States' choice

The first condition for energy efficiency has been fulfilled in our calculations, as this is a relatively cheap option in the GENESIS database.

This study did not analyse the feasibility of the EU 20% renewables target, as in our version of the GENESIS database (a newer version is under development); there are almost no biofuels measures included and only a limited number of biomass reduction measures. The implementation of these biomass reduction measures and the renewables measures in the GENESIS database are relatively conservative and do not include the latest insights. Therefore the implementation of the marginal abatement costs and measures of renewables needs to be improved, after which it will be possible to better account for EU conditions with respect to targets for renewable energy and biofuels. The relatively more expensive renewable options are not chosen for these reasons, and since we have adopted a cost-effective approach, we find a small percentage from renewables in the total reduction.

Finally it should be noted that nuclear power as a reduction measure is not considered in GENESIS.

Distribution among countries ─ Figure 5.10a shows the percentage reductions for the different groups of countries within the EU, as contribution to the total EU reduction for the 'EU 20% unilateral without CDM'. The 'EU 30% in a multi-lateral regime' scenario gives very similar results. Obviously the EU-15 has the largest percentage of the reduction, followed by the EU-10 and EU-2 new countries.

Distribution based on greenhouse gases ─ Figure 5.10b shows the percentages of the different greenhouse gases, and clearly shows that by far the most measures are CO_2 related (85%), followed by measures to reduce methane emissions (5%) and the F-gases (6%). The dominant contribution of CO_2 abatement can also be seen (on a country level) in Appendix C, varying from around 75% to 90% of total country reductions.

Distribution among sectors ─ A large percentage of the measures are taken in the energy supply, household and services sectors (Figure 5.10c). This also applies to the different country groups (Figure 5.11a, first three columns). The contribution by the energy supply sector is even greater in EU-10 and EU-2 new countries due to a significant potential for fuel shift (from coal to natural gas). Households contribute around 27% to the reductions in the EU and, in contrast to the energy supply sector, this percentage is smaller in the EU-10 and EU-2 new countries. It is also noticeable that, in general, the percentage from the transport sector is small compared to this sector's emissions. This is because the reduction measures are relatively expensive in this sector. Figure 5.11a and Table 5.8 illustrate the contribution per sector for selected countries (see Appendix B for all countries) for the 'EU 20% unilateral without CDM'. The 'EU 30% in a multi-lateral regime' scenario gives very similar results (see Table 5.9). The contribution of the transport sector to the overall reduction becomes rather low for certain countries, like Germany and the United Kingdom, and rather high for Italy. This result might be incorrect and follows from the inconsistency between the GENESIS frozen technology baseline and the LREM baseline (see also section 2).[33]

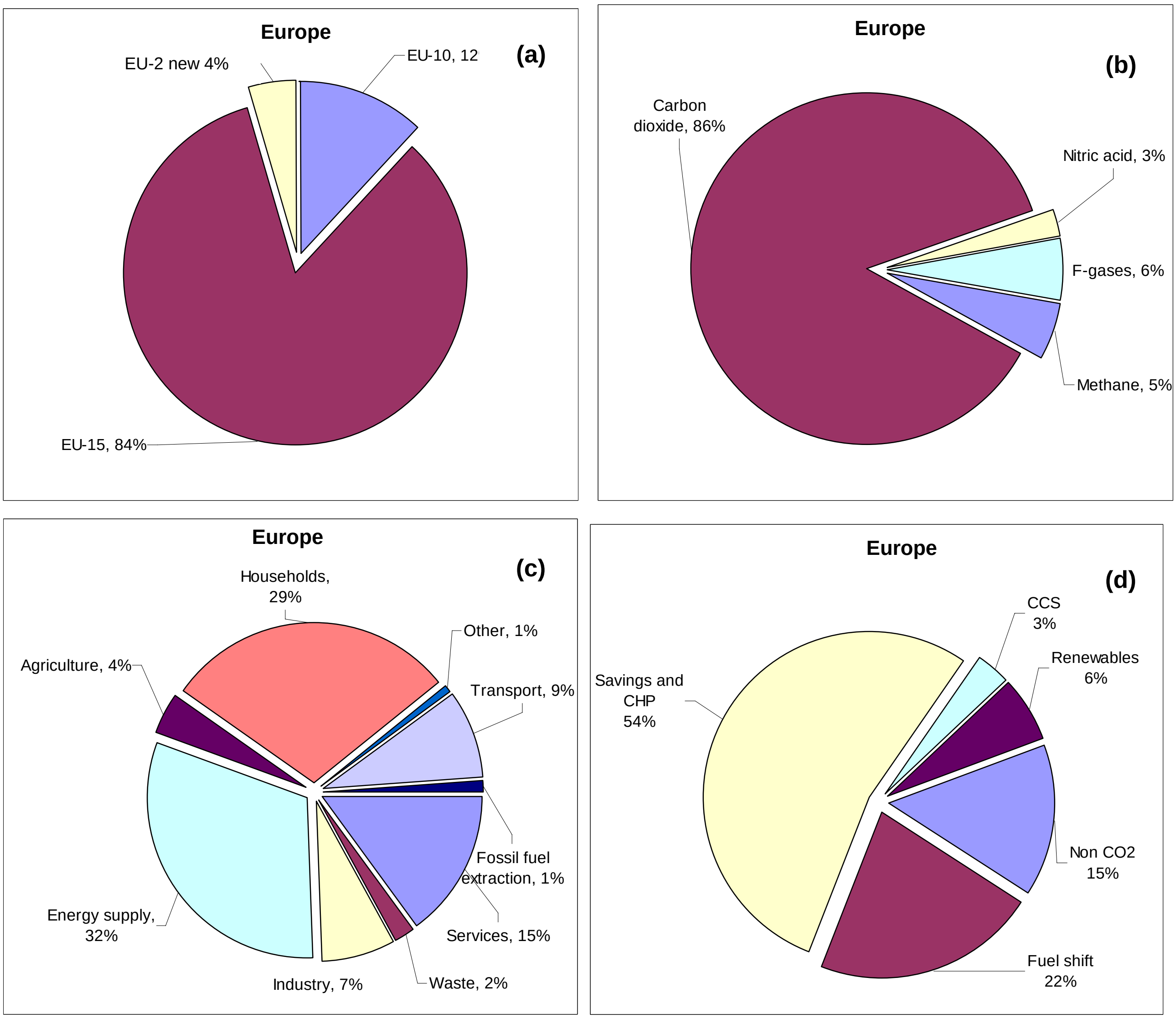

Figure 5.10: Reduction percentage of the total reduction (defined as baseline minus target) per country group (a), per pollutant (b), per sector (c) and per aggregated reduction measure (d) for the year 2020 for the 'EU 20% unilateral without CDM' scenario. The 'EU 30% in a multilateral regime CDM' scenario gives very similar results (see also next two figures).

[33] In the transport sector there are generally reduction measures related to transport of goods that have basically negative costs and reduction measures related to transport of persons with basically positive high costs. If for certain countries like Italy the difference between the GENESIS frozen technology baseline and the LREM baseline is very small, and therefore the negative costs measures are still included after the cutting method (Step 5: section 2.3). These relatively cheap measures will be taken to meet the reduction target. An opposite pattern can be seen for Germany and the United Kingdom, with a large difference between the GENESIS frozen technology baseline and the LREM baseline. Therefore all negative costs measures are excluded after the cutting method (Step 5: section 2.3), which implies that only the more expensive reduction measures are left, which are not taken for meeting the reduction target.

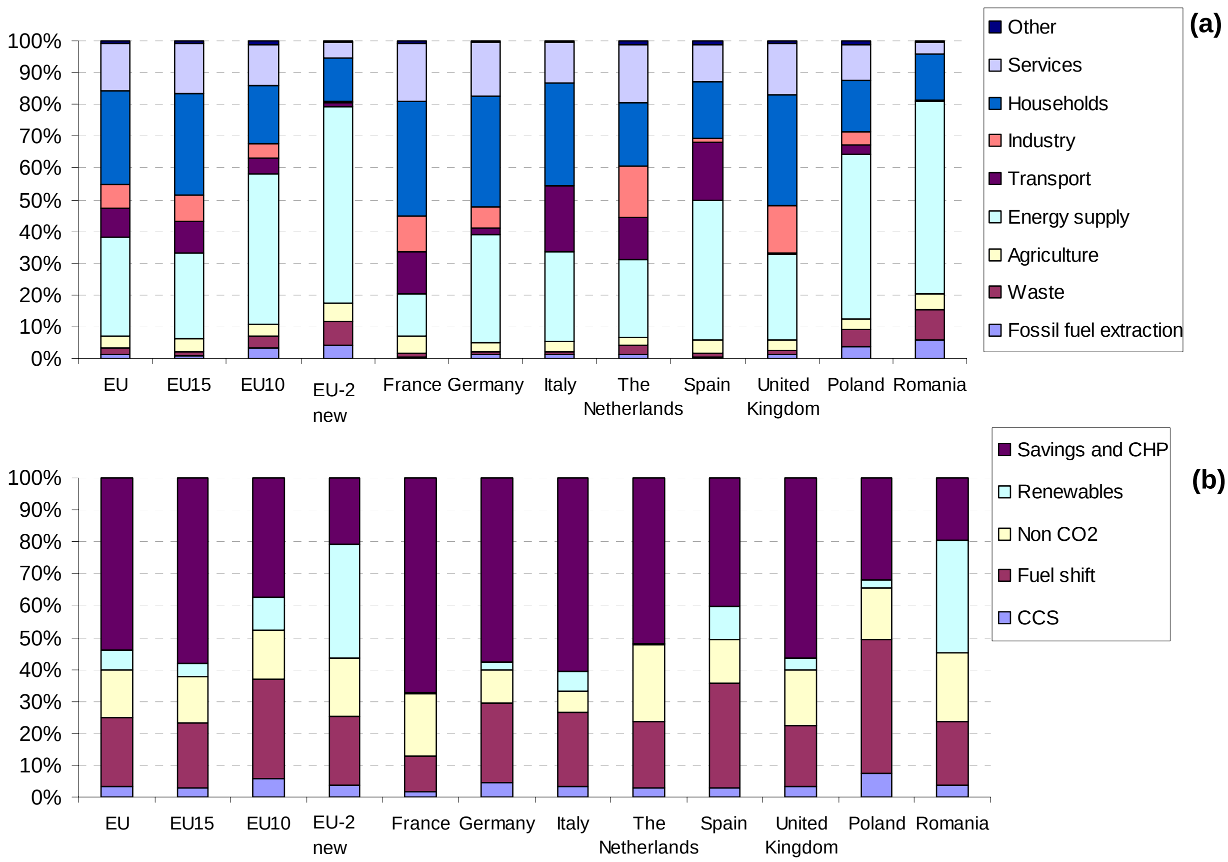

Figure 5.11: Sector shares (a) and per reduction measure (b) for the EU-15 and EU-10 and selected countries for 2020 for the 'EU 20% unilateral without CDM' scenario.

Contribution of reduction measures **—** Figure 5.10d shows the contribution of technological options to the greenhouse gas emission reductions for 2020 for the EU. Within the total portfolio of measures increased energy efficiency improvements and CHP plays a particularly important role. Other options include fuel switch (using natural gas instead of coal) and reductions of non-CO_2 gases. A less important option in 2020 is renewables and carbon capture and storage (CCS), though the latter can be substituted at limited additional costs against other electric power options (nuclear power and renewables).

It should be noted that beyond 2020, the contribution of renewables and CCS can become more important, as also illustrated in Van Vuuren et al. (2007a), whereas the contribution of the energy efficiency can become smaller. The main reason for the later is that the increasing share of zero carbon energy supply options, like renewables, reduces the effectiveness of energy efficiency measures. To have a closer look at the measures for the EU, Table 5.10 gives an overview of the measures with the largest reductions for Europe. Except for the 'New Capacity' measure and 'solid biomass' these measures represents energy savings measures (see also Box 4).

Table 5.8: Reductions of sector (a) and per aggregated reduction measure (b) for the EU-15 and EU-10 and selected countries in 2020 for the 'EU 20% unilateral without CDM' scenario.

(a) Sector shares	*EU*	*EU15*	*EU10*	*EU-2 new*	*France*	*Germany*	*Italy*	*The Netherlands*	*Spain*	*United Kingdom*	*Poland*	*Romania*
CCS	40	30	8	2	3	9	4	2	3	5	5	1
Fuel shift	254	200	43	11	20	52	26	12	32	31	27	7
Non CO_2	173	142	21	10	33	21	7	13	13	27	11	7
Renewables	75	42	15	19	1	6	7	0	10	6	1	11
Savings & CHP	632	570	52	11	116	121	67	29	39	89	21	6
TOTAL	1175	984	139	52	173	210	111	56	97	159	64	32
(b) Reduction measures												
Fossil fuel extraction	14	8	4	2	1	2	1	1	0	2	2	2
Waste	23	14	5	4	2	2	1	2	1	2	3	3
Agriculture	47	38	5	3	10	6	3	2	4	5	2	2
Energy supply	365	267	66	32	23	72	32	14	43	42	34	20
Transport	104	96	7	1	22	4	23	7	18	1	2	0
Industry	87	81	6	0	19	14	0	9	1	23	3	0
Households	345	313	25	7	62	73	36	11	17	55	11	5
Services	177	157	18	3	31	35	15	10	11	25	7	1
Other	9	7	2	0	1	1	0	1	1	1	1	0
TOTAL	1172	980	140	52	170	209	112	56	97	157	65	32

Table 5.9: Reductions of sector (a) and per aggregated reduction measure (b) for the EU-15 and EU-10 and selected countries in 2020 for the 'EU 30% in a multilateral regime' scenario.

(a) Sector shares	*EU*	*EU-15*	*EU-10*	*EU-2 new*	*France*	*Germany*	*Italy*	*The Netherlands*	*Spain*	*United Kingdom*	*Poland*	*Romania*
CCS	37	27	8	2	3	9	4	2	0	5	5	1
Fuel shift	218	168	40	11	18	28	26	10	32	30	25	6
Non CO_2	166	136	21	9	32	21	7	13	11	27	10	6
Renewables	74	41	15	18	1	6	7	0	10	6	1	11
Savings & CHP	601	541	49	10	113	113	57	28	36	88	20	6
TOTAL	1096	913	132	50	166	177	101	53	89	157	63	31
(b) Reduction measures												
Fossil fuel extraction	14	7	4	2	1	2	1	1	0	2	2	2
Waste	20	12	5	3	2	2	1	1	1	2	3	2
Agriculture	46	38	5	3	10	6	3	2	4	5	2	2
Energy supply	332	236	65	32	22	47	32	14	40	42	34	19
Transport	88	84	4	0	19	0	23	6	17	0	0	0
Industry	85	79	6	0	18	14	0	9	1	23	3	0
Households	327	296	24	7	60	73	26	11	15	55	11	5
Services	171	151	17	2	31	33	15	10	10	25	7	1
Other	9	7	2	0	1	1	0	1	1	1	1	0
TOTAL	1093	909	133	50	163	177	102	53	89	155	63	31

Table 5.10: List of ten measures with the largest reductions for the EU for the 'EU 20% unilateral without CDM' scenario.

Sector	**Measure**	**Reduction ($MtCO_2$)**
Energy supply	New capacity by natural gas-fired combined cycles	225
Households	Miscellaneous options (moderate costs tranche)	82
Households	Miscellaneous options (cheap tranche)	61
Services	Office equipment: Best Practice	56
Households	Avoid standby consumption	55
Households	Very energy-efficient refrigerators and freezers	41
Services	Lighting: Best Practice level 2	38
Services	Lighting: Best Practice level 1	34
Energy supply	Solid biomass	32
Services	Building Energy Management Systems: space heating and cooling	31

Figure 5.11b shows the percentages of the different categories for seven European countries and the three aggregates. In the EU-10 and EU-2 new countries the measures related to a fuel shift account for a large proportion, as their energy production is relatively carbon-intensive and more inefficient compared to the EU-15. Also noticeable is the small share in total abatement from renewables. This is because these measures are generally more expensive than measures such as fuel shift, savings and CHP. The category 'fuel shift' represents a relatively large proportion in Poland. This is due to the fact that a fairly large number of power plants run on coal and therefore the shift from coal to gas has a large potential. Furthermore, the non-CO_2 category in the Netherlands accounts for a relatively large percentage. This is because the industrial sector is relatively large and this sector takes many measures that are non-CO_2 based. Finally, measures in the category 'Savings and CHP' count for a large percentage in France. These measures apply mainly to households and the service sectors, which are relatively large sources of emissions here. Appendices D and E present an extensive overview of the abatement measures relating to the various categories.

Box 5: The main reduction measures described in more detail

*Energy supply ─'New capacity by natural gas-fired combined cycles'. A*n effective means of reducing CO_2 emissions is to switch from a fuel with a high carbon content to one with a lower carbon content, e.g. from coal to natural gas. At the same time, a higher efficiency capacity can be installed. Implementation of such a measure depends on many factors, such as costs, political willingness, but also on the availability of natural gas. This option refers to the construction of new capacity. In this case, emission reduction is obtained, because at the 'frozen technology' reference level it is assumed that new capacity power plants are constructed with the average 2000 fossil fuel mix.

Households ─ Miscellaneous options (moderate costs tranche) and miscellaneous options (cheap tranche). The measures for households concern specific appliances. Certain appliances are only partially covered, e.g. appliances for hot water production and cooking, and a range of small electric appliances. These appliances are covered in this measure.

Services ─ Office equipment: Best Practice. Appliances account for 35% of the total electricity consumption in the services sector. Most of these appliances are typical office appliances such as computers, monitors, printers and photocopiers. Office appliances account for one of the fastest growing end-users in the services building sector. Computers are responsible for the largest part of the energy consumption. Energy reduction can be achieved by installing power-down management and LCD screens.

Households ─ Avoid standby consumption.

Households ─ Very energy-efficient refrigerators and freezers. Cooling appliances (refrigerators, freezers etc.) use 20–58% of the energy consumption of all electric appliances. A European labelling system is introduced to make customers more aware of energy efficiency.

Services ─ Lighting: Best Practice level 2 and Lighting: Best Practice level 1. Energy for lighting accounts for about 38% of the total electricity consumption of the services sector. Lighting in the services sector is mainly provided by three systems: incandescent lamps, fluorescent lighting and high-intensity discharge lighting. The following measures can conserve a considerable amount of energy: incandescent lamps can be replaced by efficient fluorescent lamps, which can yield the same amount of light using only 60–80% of the energy used by ordinary incandescent lamps; the luminary efficiency of all lamp types can be improved using better reflectors; a lighting control system detecting occupancy of a room, or operating daylight or time-dependent lighting can all reduce the amount of lighting hours.

Energy supply ─ Biomass: Various biomass resources are (or could be) converted to energy: woody biomass (forest residues, industrial wastes, energy crops such as willow, poplar), other energy crops (sugar beet, wheat, rapeseed, miscanthus, etc.), agricultural and industrial wastes, other wastes with a significant biomass fraction (e.g. municipal solid waste (MSW)), biogas from wastewater treatment or landfill sites, etc. Various technologies are available for these biomass to energy conversions, e.g. incineration, co-firing, gasification, pyrolysis, anaerobic digestion, fermentation, extraction, etc.

Services ─ Building Energy Management Systems (BEMS): space heating and cooling. BEMs automatically regulate the operation of all energy demands (heating, cooling, transport, lighting and equipment). The BEMS saves energy and water demands by producing accurate and proper comfort levels, depending on climate conditions. They particularly realise energy conservation by switching off energy services when rooms are not occupied. For the services sector, where many offices are empty for over 75% of the time, this is an essential source of energy saving.

6 Model analysis of EU burden sharing with ETS allocation at EU level

This chapter uses *EU burden-sharing with ETS allocation at EU level* (Option 2) as its main starting point. The calculations are performed in four steps, as described in Figure 6.1:

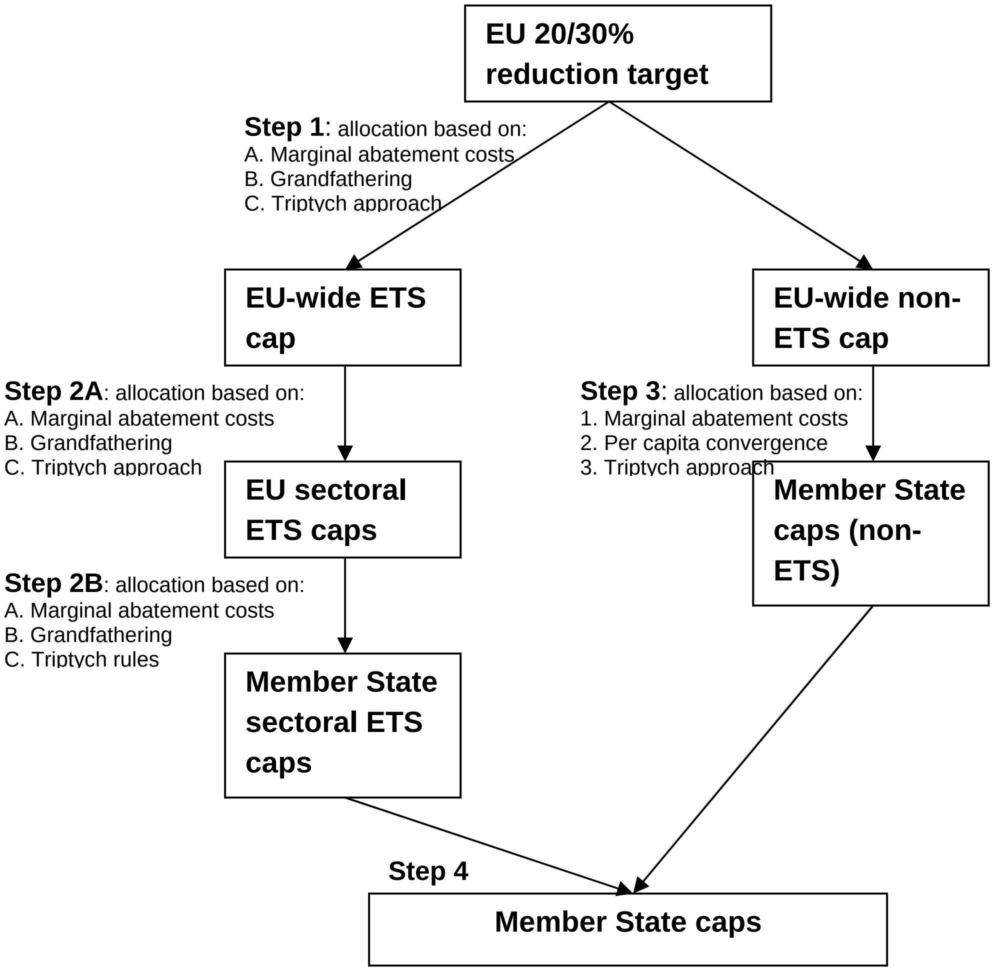

Figure 6.1: The four steps for the calculation of Option 2: *EU burden-sharing with ETS allocation at EU level.*

Steps 1 and 2 use the same bottom-up allocation rules as described in Table 6.1, but at the EU level and at the Member State level (only step 2B), while Step 3 shares the EU target for the non-ETS sectors among the Member States. Step 4 only summarises the sectoral ETS caps in each Member State and Member State caps for non-ETS emissions, and calculates the final Member State caps. The following sections describe Steps 1-3 in more detail.

Note, for the calculations, we simply assume that the ETS sector includes all GHG emissions from the industrial and electricity sectors, and that the non-ETS sector includes the remaining GHG emissions.

Table 6.1: The various allocation methods used in the three calculation steps for Option 2: EU burden-sharing with ETS allocation at EU level.

Step 1: EU-wide cap for ETS and non-ETS	*Step 2: Allocation of reduction targets across the ETS sub-sectors for the EU (step 2A) and EU Member States (step 2B) based on the EU-wide ETS cap*	*Step 3: Allocation of reduction targets for the non-ETS emissions across the EU Member States based on the EU-wide non-ETS cap*
A. Marginal abatement costs	A. Marginal abatement costs	A1. Marginal abatement costs A2. Per capita convergence A3. Triptych*
B. Grandfathering:	B. Grandfathering	B1. Marginal abatement costs B2. Per capita convergence B3. Triptych* B4. Grandfathering
C. Triptych	C. Triptych approach	C1. Marginal abatement costs C2. Per capita convergence** C3. Triptych

* Not analysed here, as the outcomes are very similar to the *Per capita convergence*, as the non-ETS sector emissions are dominated by the transport and residential emissions, for which *Triptych* assumes a *Per capita convergence* rule.
** This is not analysed here, for similar reasons.

6.1 Step 1: EU-wide cap for ETS and non-ETS

For Option 2, setting an EU-wide target for the ETS as a whole versus the other sectors can be based on three allocation approaches:

1. *Marginal abatement costs* of ETS versus non-ETS sectors, i.e. the EU-wide reduction commitments are divided between the ETS and non-ETS sectors, based on the same marginal abatement costs of these sectors, in order to equalise these costs between the ETS and other sectors of the EU and, hence, to minimise the social costs of the mitigation commitments.
2. *Grandfathering,* i.e. allocation based on historic emissions of ETS versus non-ETS sectors over a certain reference period, adjusted for new entrants and other changes in sector coverage, and corrected by a uniform ('flat') reduction rate in order to meet the overall EU mitigation target.
3. *Triptych* approach*,* i.e. the allocation of emissions from ETS versus non-ETS sectors over a certain reference period using the *Triptych approach* rules, i.e. carbon intensity improvements in the industrial and electricity sectors (ETS) and convergence in the per capita domestic emissions (non-ETS). The parameter settings are the same as those assumed in chapter 3 (see Table 3.2).

So far, the *Grandfathering* is used presently as the allocation rule, and for this reason it is analysed here. The *Marginal abatement costs* approach is selected here, as this best satisfies the criteria of cost-efficiency. Next the *Triptych* approach is selected here, as the approach has been used in the past for the internal EU burden-sharing during the Kyoto negotiations and as an alternative approach, which best satisfies the various types of criteria (environmental, political, economic, technical, institutional) in the multi-criteria evaluation (see section 7.1).

Figure 6.2 illustrates the EU-wide cap for ETS and non-ETS for the three allocation approaches as well as the ‘EU 20% unilateral without CDM’ and ‘EU 30% in a multilateral regime’ scenarios. It should be noted that the reductions presented for the three allocation methods are *before* emissions trading and CDM, and are independent of the final CDM amounts, and therefore ‘EU 20% unilateral with CDM’ gives similar results to ‘EU 20% unilateral without CDM’.

For both the *Triptych* approach and the *Marginal abatement costs* approach, the reduction for the ETS sector, compared to the *1990 levels,* exceeds the reduction in the non-ETS sector, although the differences for a cost-effective approach are small. However, as in the baseline scenario, the total emissions in the non-ETS sector (especially from transport) increase more than the emissions in the ETS sector (see column 4 in Figure 6.2). Compared to the *baseline levels* the reductions in the non-ETS sectors exceed the reductions in the ETS sectors, as reducing emissions in the non-ETS sector is more cost-effective or more effective in terms of reduction potentials compared to the ETS sector. This was also illustrated in Figure 5.10c.

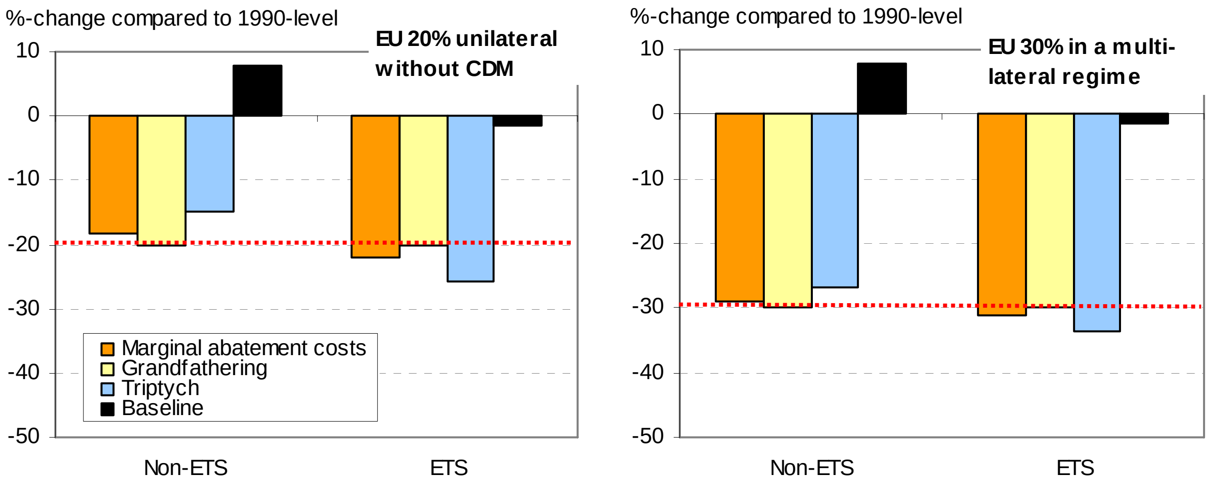

Figure 6.2: The EU-wide cap for ETS and non-ETS pertaining to the three allocation options considered for the ‘EU 20% unilateral without CDM’ scenario (left) and ‘EU 30% in a multilateral regime’ scenario (right). The ‘EU 20% unilateral with CDM’ scenario gives similar results to ‘EU 20% unilateral without CDM’ (left). For comparison, the change with respect to the baseline emissions is also given here.

6.2 Step 2: EU and Member State Sectoral ETS Caps

The first step calculates the EU-wide cap for the ETS. This is allocated here among the different sub-sectors, according to the same allocation rules (selected here for the same reasons) as described in Step 1. Given the limited availability of the baseline emission data at the industrial sub-sector level, we focus here on just two ETS sub-sectors, the power and industrial sectors.

Figure 6.3 presents the emission reductions of the power and industrial sectors at EU level compared to the 1990 levels for the two scenarios 'EU 20% unilateral without CDM' (gives similar results to 'EU 20% unilateral with CDM') and 'EU 30% in a multilateral regime'. In general, the industrial sector reductions (compared to the 1990 levels) are well above the overall EU reductions (-20% or -30%), whereas the power sector reductions come to only just above the overall EU reductions. It should be noted that this only holds for the (relative) reductions compared to the 1990 levels and not for the absolute reductions compared to the baseline levels. The absolute emission reductions for the power sector are indeed higher than for the industrial sector: just as in the baseline scenario the power emissions show an increasing trend compared to 1990 levels (column 4 in Figure 6.3), whereas the industrial emissions show a decreasing trend.

For the -20% EU reduction target the reductions compared to the 1990 levels in the industrial sector are higher than in the power sector, but for the -30% EU reduction target the differences become less. The power sector reductions even exceed the industrial reduction in the *Marginal abatement costs* approach. The latter can be explained by the fact that for the 30% EU reduction target the cost-effective approach leads to reductions in the sectors that are as high as the maximum cost reduction potentials. Using the GENESIS database, those potentials (at EU level) are higher for the power sector than for the industrial sector, and therefore the power sector needs to achieve greater reductions than the industrial sector for the 'EU 30% in a multilateral regime' scenario.

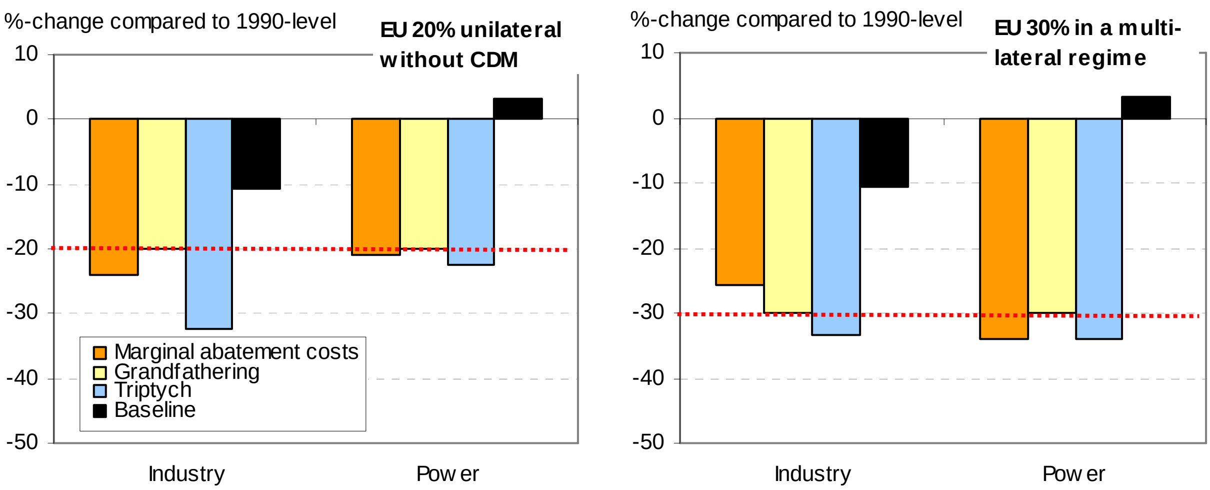

Figure 6.3: The EU-wide reduction targets (before emissions trading and CDM) for the industrial and power sectors, based on an EU-wide ETS cap for the 'EU 20% unilateral without CDM' scenario (left) and 'EU 30% in a multilateral regime' scenario (right). The 'EU 20% unilateral with CDM' scenario gives similar results to 'EU 20% unilateral without CDM' (left). For comparison, the change compared to the baseline emissions is also given here.

Although the allocation of the emission reductions for the various ETS installations (here only the power and industrial sectors) will be arranged at the European level, we can also make projections for the reduction targets in individual countries (industrial and power sectors) for the three allocation approaches, as shown in Figure 6.4 and Figure 6.5, for the eight largest EU emitters. The reduction levels for all countries are not shown here.

In general the figure shows a similar pattern to the previous illustration, i.e. higher reductions in the industrial sector than the power sector for the -20% EU reduction target, and smaller differences in the reductions of both sectors for the -30% target. However, at the individual country level we see some considerable differences in reductions, varying from a growth target as high as 33% for Spain, to a reduction target as high as -75% for Romania, under the *Marginal abatement costs* approach for the industrial sector (-20% EU reduction). A similar range exists for the power sector.

The *Triptych* approach leads to the highest reductions for most countries, compared to the other two approaches (*Grandfathering* and *Marginal abatement costs*), for both the power sector and the industrial sector. This result is consistent with the pattern we have already seen at EU level. However, it should be noted that this finding largely depends on the assumptions that were made for the *Triptych* parameter settings. Different assumptions, such as choosing a lower final per capita emission convergence level for the domestic sector, would lead to less stringent reductions for the industrial sector.

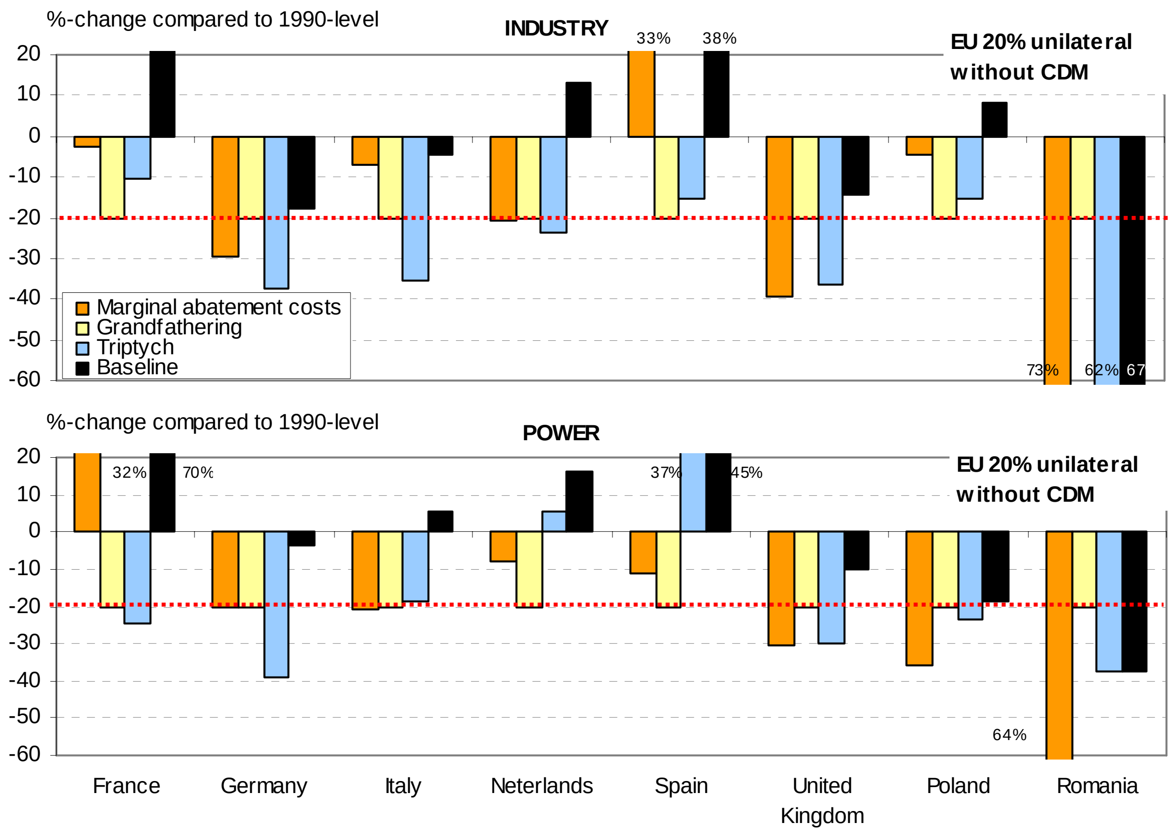

Figure 6.4: The reduction targets (before emissions trading and CDM) for the industrial (upper) and power (lower) sectors for the eight largest EU emitters, for the three allocation approaches for the 'EU 20% unilateral without CDM' scenario. For comparison, the change compared to the baseline emissions is also given here.

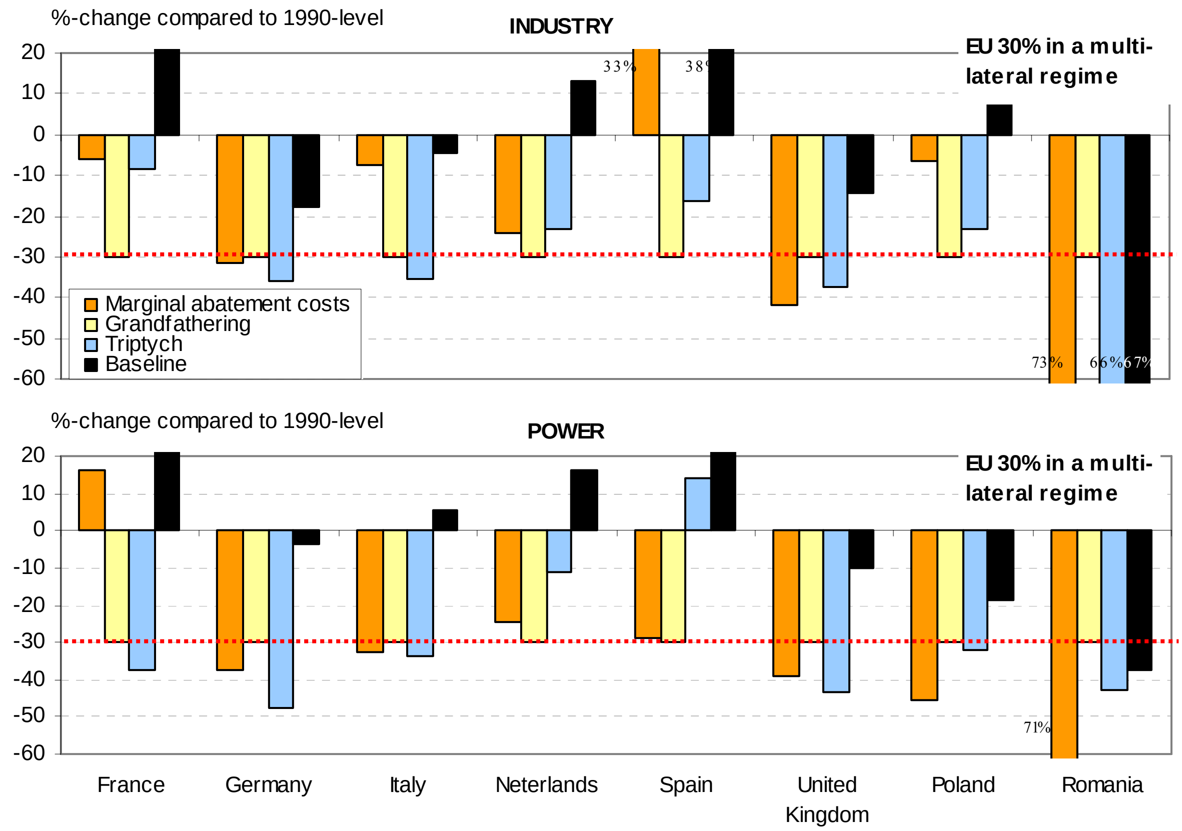

Figure 6.5: Similar to Figure 6.4, but for 'EU 30% in a multilateral regime', Source: the FAIR 2.1 EU model.

6.3 *Step 3:* Member State non-ETS Caps

In the final step, the methodology calculates the EU non-ETS cap using the different burden-sharing approaches, as described in Table 6.1, to allocate the non-ETS sector among the individual European countries.

Here we have selected the same three approaches as for the first two steps, except for *Grandfathering* for national targets for the non-ETS sector in combination with the complex approaches *Triptych* and *Marginal abatement costs* for the ETS sector, as this is less logical. We have further included the *Per capita convergence* approach as this is a straightforward and simple approach, and also more commonly used as allocation scheme for population-related emissions, as the non-ETS emissions.

Here, for the convergence cases we assume a convergence year of 2050 for the two scenarios 'EU 20% unilateral without CDM' and 'EU 30% in a multi-lateral regime'. For the Triptych approach we assume the same parameter settings as assumed in chapter 3 (see Table 3.2).

Each Member State is then free to further subdivide its national target for the non-ETS sectors and to set its domestic/sector policies to achieve this target (including Member State purchases of JI/CDM credits). Figure 6.6 and Figure 6.7 present the reductions for the eight largest EU emitters for the two scenarios 'EU 20% unilateral without CDM' and 'EU 30% in a multilateral regime'. Tables 6.2 and 6.3 give similar results for all countries. Note that 'EU 20% unilateral with CDM' gives similar results, for all cases, to the 'EU 20% unilateral without CDM' scenario.

The reductions for the non-ETS sector show a wide range for all countries, with higher reductions for Germany and the United Kingdom and lower reductions for Italy, and even growth targets for Spain. There are also wide-ranging reductions across the various allocation methods, although the total range of these reductions, i.e. the difference between the highest and lowest, for the main eight emitters, seems to be in the order of 10–15%. For some individual countries, such as Spain, Sweden and Bulgaria, the range is much higher (see also Table 6.3).

The *Per capita convergence* approach (A2, B2) leads to lower reductions for countries with low per capita emissions, such as France. The *Marginal abatement costs* approach shows high reductions for the Eastern European countries and some of the EU-15 countries, similar to what we have seen before in chapter 5 (such as Figure 5.2). The *Triptych* approach leads to similar results as the *Per capita convergence* cases (compare C3 with A2 and B2), as the *Triptych* approach also assumes *Per capita convergence* for the residential and transport emissions, which dominate the domestic ETS emissions.

The figure also shows that *Triptych* ETS cases (C1 and C3) generally lead to the lowest reductions, except for Germany.

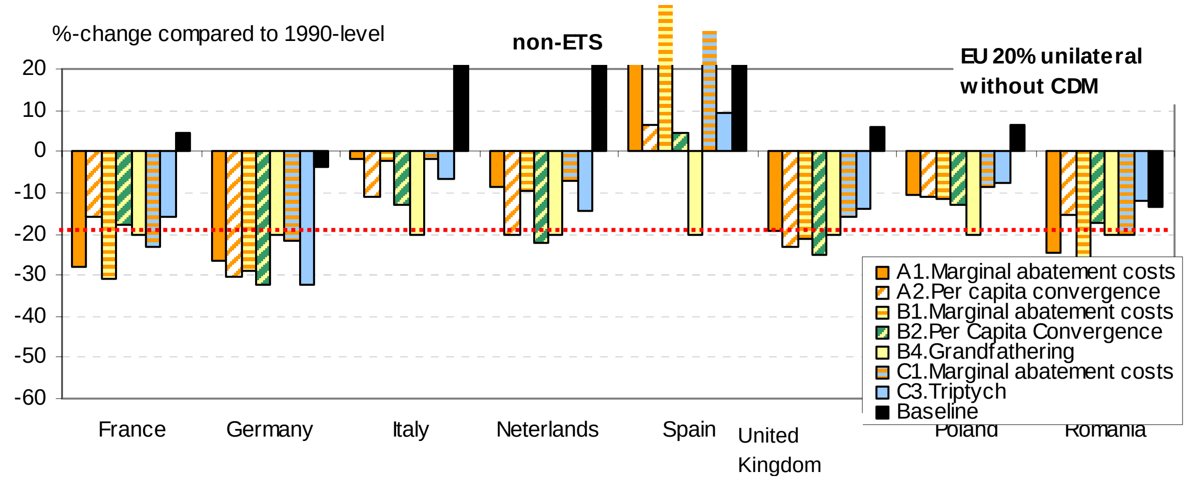

Figure 6.6: EU countries' reduction targets for the non-ETS sector (the eight largest EU emitters) for the six considered allocation approaches for 'EU 20% unilateral with/without CDM'. Source: the FAIR 2.1 EU model.

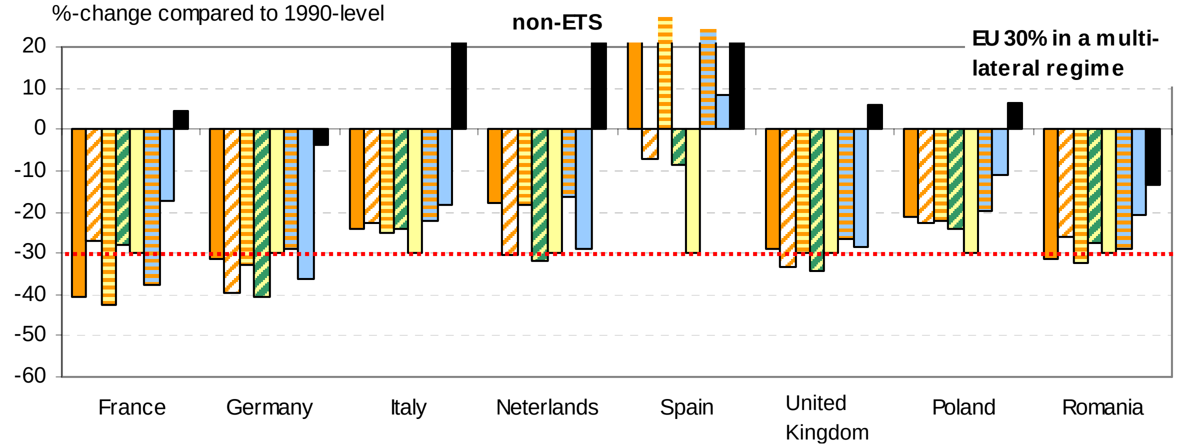

Figure 6.7: Similar to Figure 6.6, but for 'EU 30% in a multilateral regime'. Source: the FAIR 2.1 EU model.

Table 6.2: Reduction targets for the non-ETS sector (%) compared to 1990 levels (a) and baseline levels (b) in 2020 for the 'EU 20% unilateral without CDM' scenario for selected cases. B4 (*Grandfathering*) leads to -20% for all countries, and is not presented here. The 'EU 20% unilateral with CDM' scenario gives similar results to 'EU 20% unilateral without CDM'.

Step 1: Allocation, ETS and non-ETS Step 2: Allocation within ETS		A. Marginal abatement costs		B. Grandfathering		C. Triptych	
(a) 1990 levels	Kyoto target	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	C1. Marginal abatement costs	C3. Triptych
Austria	-13	-19	-23	-20	-24	-15	-21
Belgium	-7.5	-19	-22	-21	-24	-16	-15
Denmark	-21	-31	-31	-34	-33	-25	-22
Finland	0	-41	-16	-45	-18	-33	-18
France	0	-28	-16	-31	-18	-23	-14
Germany	-21	-26	-31	-29	-32	-22	-29
Greece	+25	14	12	15	10	11	8
Ireland	+13	-26	-16	-29	-18	-21	-13
Italy	-6.5	-2	-11	-2	-13	-2	-6
Luxembourg	-28	82	-40	91	-42	67	3
Netherlands	-6	-9	-20	-9	-22	-7	-14
Portugal	+27	42	20	47	17	35	23
Spain	+15	36	7	39	4	29	16
Sweden	+4	-62	-9	-68	-11	-50	-13
United Kingdom	-12.5	-19	-23	-21	-25	-16	-14
EU-15	-8	-16	-18	-18	-20	-13	-14
Cyprus	*	42	-2	46	-4	34	0
Czech Republic	-8	-53	-24	-58	-25	-43	-32
Estonia	-8	-3	-17	-3	-19	-2	-1
Hungary	-6	-17	-20	-18	-22	-14	-17
Latvia	-8	19	3	21	0	15	17
Lithuania	-8	23	0	25	-3	19	1
Malta	*	11	0	12	-3	9	-5
Poland	-6	-10	-11	-12	-13	-9	-9
Slovakia	-8	-45	-19	-50	-21	-37	-32
Slovenia	-8	-4	-17	-4	-19	-3	-12
EU-10	-8	-21	-16	-23	-17	-17	-16
Bulgaria	-8	-53	-29	-59	-30	-44	-40
Romania	-8	-25	-15	-27	-17	-20	-10
EU-2 new	-8	-37	-21	-40	-23	-30	-23
EU	-8	-18	-18	-20	-20	-15	-15
(b) Baseline				0		0	
Austria	-24	-40	-32	-44	-34	-33	-42
Belgium	-13	-31	-32	-34	-33	-26	-27
Denmark	-15	-8	-27	-9	-29	-7	4
Finland	6	-53	-4	-59	-6	-44	-35
France	-11	-58	-20	-63	-21	-47	-49
Germany	-11	-24	-28	-26	-29	-19	-26
Greece	-9	-26	-23	-29	-24	-22	-31
Ireland	-6	-49	-13	-53	-15	-40	-39
Italy	-17	-7	-31	-8	-32	-6	-12
Luxembourg	-31	39	-72	43	-72	32	-22
Netherlands	-16	-21	-34	-24	-36	-18	-26
Portugal	-20	-26	-30	-29	-32	-22	-36
Spain	-19	-7	-36	-7	-38	-5	-20
Sweden	-2	-89	-7	-98	-10	-73	-75
United Kingdom	-4	-11	-27	-12	-29	-9	-5
EU-15	-12	-25	-27	-28	-29	-21	-23
Cyprus	-43	-33	-45	-36	-47	-27	-52
Czech Republic	42	-50	22	-55	20	-41	-28
Estonia	0	34	-35	37	-36	28	37
Hungary	6	-11	-21	-12	-23	-9	-11
Latvia	-15	19	-33	21	-34	16	17
Lithuania	-24	-30	-34	-34	-35	-25	-43
Malta	-18	-8	-30	-8	-32	-6	-21
Poland	11	10	-17	11	-18	8	12
Slovakia	20	-75	12	-82	9	-61	-69
Slovenia	-22	-25	-31	-28	-32	-21	-32
EU-10	12	-13	-13	-14	-15	-11	-8
Bulgaria	63	-20	26	-21	23	-16	3
Romania	58	21	-2	23	-5	17	43
EU-2 new	59	5	7	5	4	4	27
EU	-10	-21	-24	-23	-26	-17	-17

*: Non-Annex II; **: No limit specified. Country had not ratified the Convention when the Kyoto Protocol was adopted

Table 6.3: Reduction targets for the non-ETS sector (%) compared to 1990 levels (a) and baseline levels (b) in 2020 for the 'EU 30% in a multilateral regime' scenario for selected cases. B4 (*Grandfathering*) leads to -30% for all countries and is not presented here.

Step 1: Allocation, ETS and non-ETS Step 2: Allocation within ETS		A. Marginal abatement costs		B. Grandfathering		C. Triptych	
(a) 1990 levels	Kyoto target	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	C1. Marginal abatement costs	C3. Triptych
Austria	-13	-34	-33	-35	-34	-31	-31
Belgium	-7.5	-34	-32	-35	-33	-31	-29
Denmark	-21	-36	-40	-38	-41	-33	-30
Finland	0	-56	-27	-58	-29	-52	-31
France	0	-41	-27	-42	-28	-38	-25
Germany	-21	-31	-40	-33	-41	-29	-40
Greece	+25	-2	-2	-2	-4	-2	-6
Ireland	+13	-31	-27	-32	-28	-29	-25
Italy	-6.5	-24	-23	-25	-24	-22	-18
Luxembourg	-28	57	-48	60	-49	53	-22
Netherlands	-6	-18	-31	-18	-32	-16	-29
Portugal	+27	24	4	25	3	22	13
Spain	+15	26	-7	27	-9	24	2
Sweden	+4	-86	-21	-89	-22	-79	-24
United Kingdom	-12.5	-29	-33	-30	-34	-27	-28
EU-15	-8	-27	-29	-29	-30	-25	-26
Cyprus	*	23	-15	24	-16	21	-9
Czech Republic	-8	-60	-34	-63	-35	-56	-43
Estonia	-8	-18	-28	-19	-29	-17	-16
Hungary	-6	-25	-31	-26	-32	-23	-28
Latvia	-8	4	-11	5	-12	4	12
Lithuania	-8	6	-13	6	-15	6	-1
Malta	*	1	-13	1	-15	1	-16
Poland	-6	-21	-23	-22	-24	-20	-20
Slovakia	-8	-51	-30	-53	-31	-47	-40
Slovenia	-8	-14	-28	-14	-29	-13	-22
EU-10	-8	-30	-27	-32	-28	-28	-26
Bulgaria	-8	-61	-38	-63	-39	-56	-45
Romania	-8	-31	-26	-33	-28	-29	-23
EU-2 new	-8	-44	-31	-45	-32	-40	-32
EU	-8	-29	-29	-30	-30	-27	-27
(b) Baseline							
Austria	-24	-42	-41	-44	-42	-39	-40
Belgium	-13	-42	-40	-44	-41	-39	-37
Denmark	-15	-32	-37	-34	-38	-30	-26
Finland	6	-50	-17	-52	-18	-46	-21
France	-11	-43	-30	-45	-31	-40	-28
Germany	-11	-29	-37	-30	-38	-27	-37
Greece	-9	-33	-33	-34	-34	-30	-35
Ireland	-6	-29	-24	-30	-26	-27	-23
Italy	-17	-41	-40	-43	-41	-38	-36
Luxembourg	-31	-25	-75	-26	-76	-23	-63
Netherlands	-16	-32	-43	-33	-44	-30	-41
Portugal	-20	-28	-39	-29	-40	-26	-35
Spain	-19	-25	-45	-26	-46	-23	-39
Sweden	-2	-85	-19	-89	-21	-79	-22
United Kingdom	-4	-33	-37	-34	-38	-30	-32
EU-15	-12	-35	-37	-37	-38	-33	-34
Cyprus	-43	-31	-52	-33	-53	-29	-49
Czech Republic	42	-36	6	-38	5	-34	-9
Estonia	0	-36	-43	-37	-44	-33	-34
Hungary	6	-26	-31	-27	-33	-24	-28
Latvia	-15	-31	-41	-33	-42	-29	-26
Lithuania	-24	-29	-42	-31	-43	-27	-34
Malta	-18	-29	-39	-30	-40	-27	-41
Poland	11	-26	-27	-27	-29	-24	-25
Slovakia	20	-32	-3	-34	-4	-30	-16
Slovenia	-22	-28	-40	-29	-41	-26	-35
EU-10	12	-28	-24	-30	-26	-26	-24
Bulgaria	63	-30	10	-32	8	-28	-3
Romania	58	-21	-15	-22	-16	-19	-11
EU-2 new	59	-24	-7	-25	-9	-22	-8
EU	-10	-34	-34	-35	-35	-32	-32

*: Non-Annex II; **: No limit specified. Country had not ratified the Convention when the Kyoto Protocol was adopted.

6.4 Reduction targets and abatement costs for all GHG emissions for the individual EU countries for the EU 20% unilateral without CDM scenario

Table 6.4 shows the resulting emission allowances for the individual EU Member States for the various cases, compared to the 1990 and baseline levels. The countries that achieve the highest and lowest reductions are indicated by red and green cells respectively. Table 6.4b shows the countries with reductions amounting to twice the EU average as red cells, and those with excess emission allowances ('hot air') as green cells. Table 6.5shows the emissions traded on the international EU internal trading market and abatement costs as a percentage of GDP for the individual EU countries. Table 6.5a shows the countries with net gains in green and countries with net costs (twice the EU average) in red. Table 6.5b shows the countries that are net buyers and net sellers (red and green, respectively). Figure 6.8 shows the reduction targets for the eight largest EU emitters, which together represent around 75% of the total 2000 EU emissions, for all cases. Figure 6.9 shows the abatement costs and emissions trading for the eight largest EU emitters.

Emission allowances – The reductions for all GHG emissions (ETS and non-ETS sector, in all countries) show a wide range for the various allocation methods, with the higher reductions for Germany and the United Kingdom and lower reductions for Italy, and even growth targets for Spain (see Figure 6.8). Romania and Bulgaria still have excess emission allowances for most cases, except for *Marginal abatement costs* (A1 and A2).

The range of reductions, defined as the difference between the highest and lowest reduction, for the main eight emitters seems to be in the order of 10–15%. For some countries, such as Spain, Sweden and Bulgaria, the range is much higher (see also Table 6.4). Comparing these ranges of reductions with those presented in the previous chapter (i.e. Figure 5.2) confirms that these ranges are quite similar, although for some major countries (for example, the United Kingdom, Germany and Poland) the ranges here are smaller, although they are higher for other countries (e.g. France and Spain).

The *Grandfathering* cases (B1, B2 and B4), particularly B4 (allocation entirely based on *Grandfathering*), lead to the highest reductions for many countries (red cells in Table 6.4), in particular for EU Member States that had growth targets under the Kyoto Protocol compared to 1990 levels (Greece, Portugal, Spain and Ireland, but also Cyprus). These cases also lead to substantial excess emission allowances for the Czech Republic, Bulgaria and Romania (see green cells in Table 6.4).

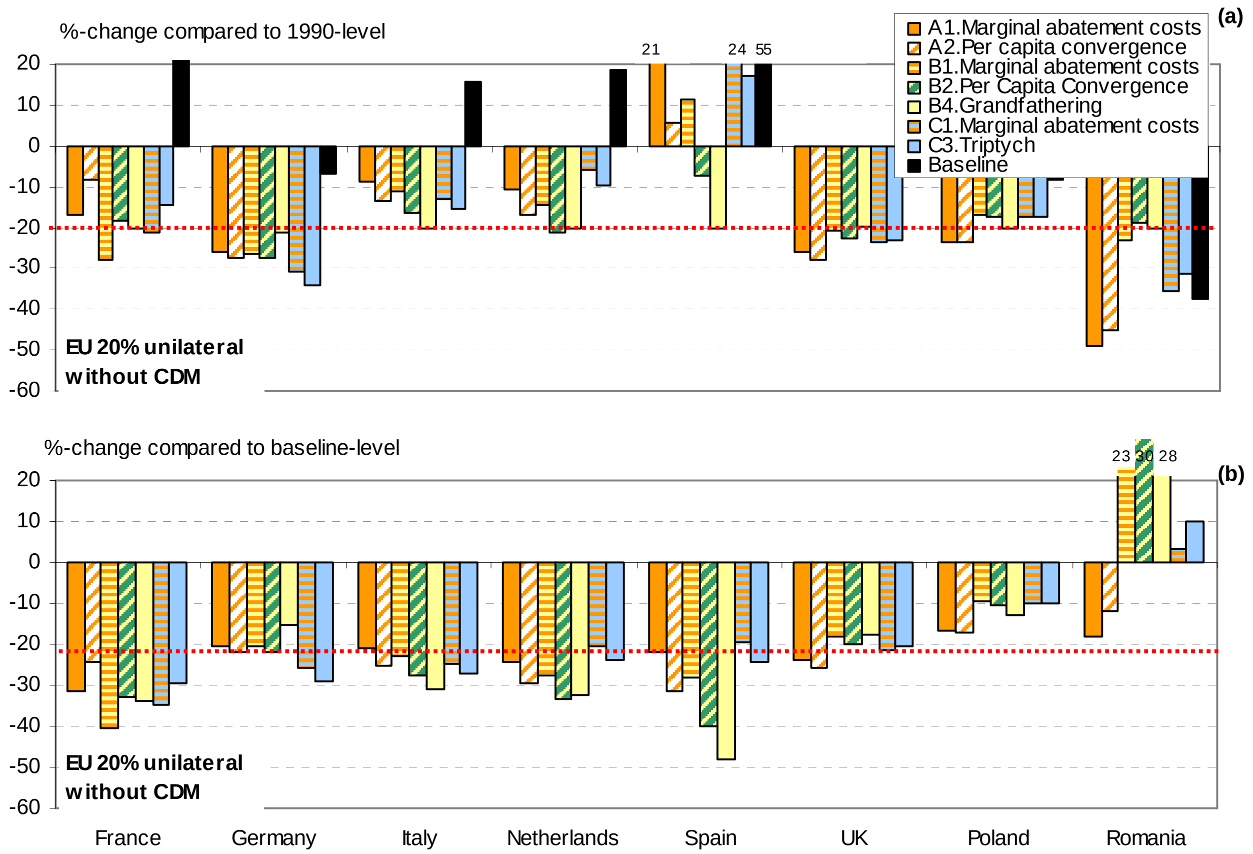

Figure 6.8: Emission allowances compared to 1990 levels (a) and to baseline levels (b) for 2020 (eight largest EU emitters) for the six considered allocation approaches under the 'EU 20% unilateral without CDM' and the 'EU 20% unilateral with CDM' scenarios. The dotted line represents the EU average.

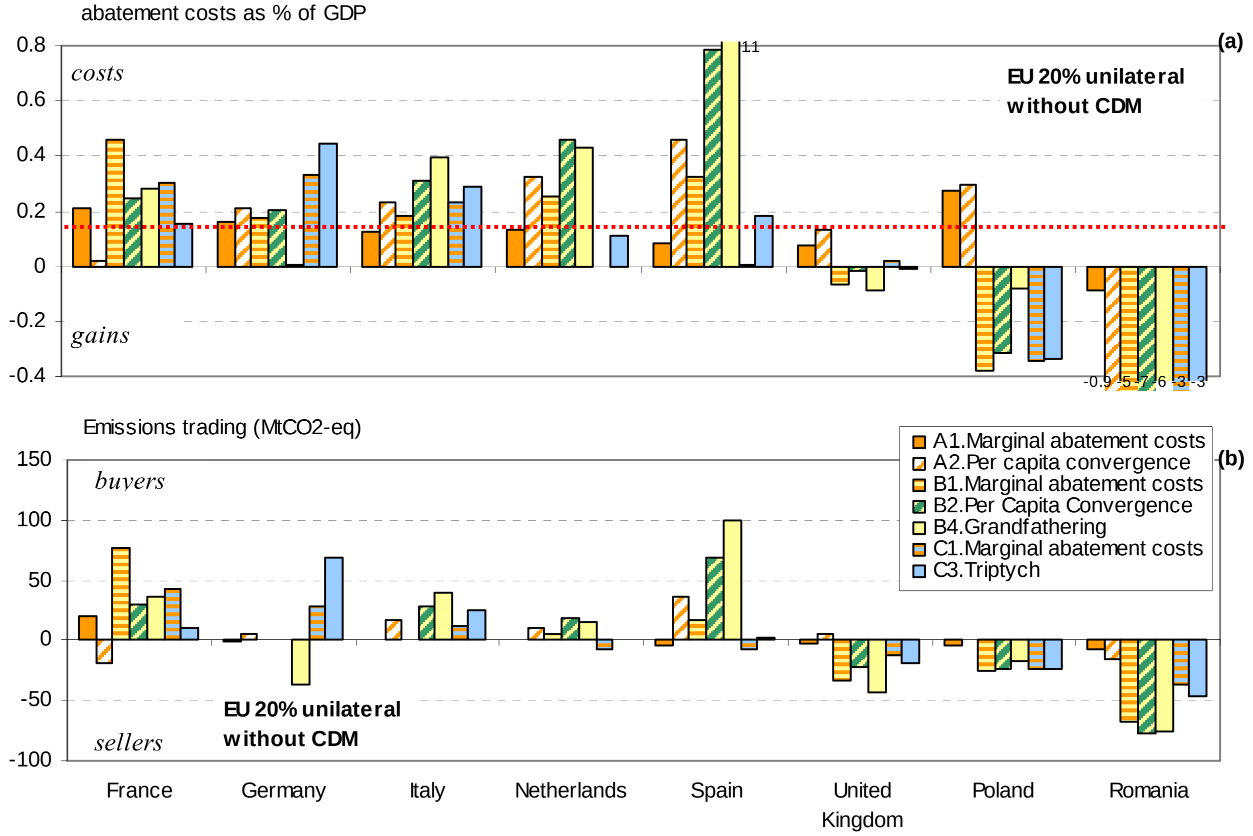

Figure 6.9: Abatement costs as %-GDP (a) and emissions trading (b) for 2020 (eight largest EU emitters) for the six allocation approaches under the 'EU 20% unilateral without CDM' scenario. The dotted line represents the EU average.

Table 6.4: Reduction targets (%) compared to 1990 levels (a) and baseline levels (b) in 2020 for the 'EU 20% unilateral without CDM' scenario for selected cases. The red cells in Table 6.4a indicate the regime with the highest reduction and the green cells represent the lowest reductions. The red cells in Table 6.4b indicate reductions of twice the EU average and the green cells indicate excess emissions. B4 (*Grandfathering*) leads to -20% for all countries and is now included. The 'EU 20% unilateral with CDM' scenario gives similar results to 'EU 20% unilateral without CDM'.

Step 1. Allocation ETS non-ETS *Step 2 : Allocation within ETS*		*A. Equal marginal costs*		*B. Grandfathering*			*C. Triptych*	
(a) 1990-levels	Kyoto target	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	B4. Grand-fathering	C1. Marginal abatement costs	C3. Triptych
Austria	-13	-8	-10	-20	-23	-20	-18	-21
Belgium	-7.5	-13	-15	-21	-22	-20	-18	-18
Denmark	-21	-34	-34	-27	-27	-20	-26	-24
Finland	0	-18	-7	-32	-19	-20	-16	-9
France	0	-17	-8	-28	-18	-20	-21	-15
Germany	-21	-26	-27	-26	-27	-20	-31	-34
Greece	+25	17	17	-4	-7	-20	12	10
Ireland	+13	-19	-11	-26	-18	-20	-7	0
Italy	-6.5	-9	-13	-11	-17	-20	-13	-16
Luxembourg	-28	19	-36	29	-30	-20	0	-29
Netherlands	-6	-10	-17	-14	-21	-20	-6	-10
Portugal	+27	41	28	17	1	-20	30	23
Spain	+15	21	6	11	-7	-20	24	17
Sweden	+4	-14	21	-52	-14	-20	-41	-16
United Kingdom	-12.5	-26	-28	-21	-22	-20	-24	-23
EU-15	-8	-15	-16	-19	-21	-20	-18	-18
Cyprus	*	60	37	15	-12	-20	38	20
Czech Republic	-8	-48	-37	-34	-22	-20	-38	-34
Estonia	-8	-39	-43	-15	-20	-20	-21	-20
Hungary	-6	-27	-29	-19	-21	-20	-19	-20
Latvia	-8	-6	-14	1	-10	-20	-5	-4
Lithuania	-8	7	-4	0	-12	-20	-7	-15
Malta	*	-2	-7	-6	-13	-20	1	-6
Poland	-6	-24	-24	-17	-18	-20	-17	-17
Slovakia	-8	-37	-24	-34	-21	-20	-45	-43
Slovenia	-8	-9	-16	-12	-19	-20	-12	-17
EU-10	-8	-29	-27	-21	-19	-20	-23	-23
Bulgaria	-8	-59	-47	-39	-25	-20	-49	-47
Romania	-8	-49	-45	-23	-19	-20	-35	-31
EU-2 new	-8	-53	-46	-29	-21	-20	-40	-37
EU		-20	-20	-20	-20	-20	-20	-20
(b) Baseline								
Austria	-24	-26	-28	-36	-38	-36	-34	-37
Belgium	-13	-23	-24	-30	-31	-29	-28	-27
Denmark	-15	-27	-28	-20	-20	-12	-19	-17
Finland	6	-18	-6	-31	-19	-20	-16	-9
France	-11	-31	-24	-40	-33	-34	-35	-29
Germany	-11	-20	-22	-21	-22	-15	-26	-29
Greece	-9	-18	-18	-33	-35	-44	-22	-23
Ireland	-6	-34	-27	-40	-33	-35	-24	-18
Italy	-17	-21	-25	-23	-28	-31	-25	-27
Luxembourg	-31	5	-43	14	-38	-29	-12	-37
Netherlands	-16	-24	-30	-28	-33	-32	-21	-24
Portugal	-20	-22	-29	-35	-44	-56	-29	-32
Spain	-19	-22	-32	-28	-40	-48	-20	-24
Sweden	-2	-32	-5	-62	-32	-37	-53	-33
United Kingdom	-4	-24	-26	-18	-20	-17	-21	-20
EU-15	-12	-24	-25	-27	-28	-28	-26	-26
Cyprus	-43	-19	-30	-41	-55	-59	-30	-39
Czech Republic	42	-20	-3	2	21	24	-4	2
Estonia	0	-30	-35	-2	-7	-8	-8	-8
Hungary	6	-20	-23	-11	-14	-12	-11	-13
Latvia	-15	-29	-35	-24	-32	-40	-28	-28
Lithuania	-24	-27	-34	-31	-40	-45	-36	-42
Malta	-18	-24	-28	-27	-32	-38	-22	-27
Poland	11	-17	-17	-10	-10	-13	-10	-10
Slovakia	20	-27	-13	-25	-9	-8	-37	-34
Slovenia	-22	-25	-30	-27	-33	-34	-27	-31
EU-10	12	-20	-17	-11	-9	-10	-13	-13
Bulgaria	63	-31	-10	2	27	35	-14	-11
Romania	58	-18	-12	23	30	28	3	10
EU-2 new	59	-23	-11	16	29	31	-2	3
EU	-10	-26	-28	-36	-38	-36	-34	-37

Table 6.5: Emissions trading ($MtCO_2$-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the 'EU 20% unilateral without CDM' scenario. The green cells (a) indicate the sellers on the emissions trading market; and red cells indicate the buyers. The green cells indicate gains; red cells indicate costs of more than twice the EU average.

Step 1. Allocation ETS non-ETS *Step 2 : Allocation within ETS*		*A. Equal marginal costs*		*B. Grandfathering*			*C. Triptych*	
(a) emissions trading	Emissions after trading	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	B4. Grand-fathering	C1. Marginal abatement costs	C3. Triptych
Austria	65	0	2	9	11	9	7	10
Belgium	112	0	1	8	10	7	5	5
Denmark	45	0	1	-3	-3	-8	-3	-4
Finland	57	0	-7	9	1	1	-1	-6
France	442	0	-18	76	29	36	42	10
Germany	798	0	5	0	0	-37	28	69
Greece	106	0	-1	13	16	28	0	1
Ireland	53	0	0	9	4	5	-1	-5
Italy	410	0	17	1	28	39	12	25
Luxembourg	12	0	4	-3	4	2	0	3
Netherlands	176	0	11	5	19	15	-7	0
Portugal	78	0	9	15	24	35	8	12
Spain	328	0	36	16	69	100	-7	3
Sweden	57	0	-24	25	-1	3	17	1
United Kingdom	512	0	6	-34	-22	-43	-12	-19
EU-15	3251	0	42	147	191	194	89	103
Cyprus	9	0	1	2	4	4	1	2
Czech Republic	94	0	-17	-22	-44	-49	-15	-22
Estonia	11	0	0	-4	-4	-4	-3	-3
Hungary	69	0	0	-9	-6	-8	-9	-7
Latvia	10	0	1	0	0	1	0	0
Lithuania	22	0	2	1	4	5	2	4
Malta	3	0	0	0	0	0	0	0
Poland	330	0	0	-26	-23	-17	-24	-24
Slovakia	37	0	-4	0	-6	-7	6	5
Slovenia	15	0	1	0	2	1	0	1
EU-10	599	0	-15	-58	-74	-72	-42	-44
Bulgaria	52	0	-12	-22	-40	-47	-9	-12
Romania	113	0	-15	-67	-77	-75	-37	-47
EU-2 new	166	0	-27	-89	-117	-122	-47	-59
Outside EU		0	0	0	0	0	0	0
(b) Costs								
Austria		0.16	0.22	0.44	0.50	0.44	0.38	0.47
Belgium		0.17	0.22	0.43	0.48	0.41	0.35	0.33
Denmark		0.12	0.13	-0.04	-0.05	-0.23	-0.07	-0.11
Finland		0.11	-0.28	0.58	0.14	0.17	0.04	-0.21
France		0.21	0.02	0.46	0.25	0.28	0.31	0.16
Germany		0.16	0.21	0.17	0.21	0.00	0.33	0.44
Greece		0.02	0.04	0.82	0.90	1.41	0.20	0.27
Ireland		0.49	0.26	0.71	0.47	0.52	0.13	-0.06
Italy		0.13	0.23	0.18	0.31	0.40	0.23	0.29
Luxembourg		-0.45	1.12	-0.73	0.95	0.68	0.10	0.92
Netherlands		0.13	0.32	0.25	0.46	0.43	0.00	0.11
Portugal		0.25	0.56	0.83	1.23	1.75	0.52	0.68
Spain		0.08	0.46	0.32	0.79	1.12	0.00	0.18
Sweden		0.05	-0.55	0.70	0.04	0.15	0.51	0.08
United Kingdom		0.08	0.13	-0.07	-0.02	-0.09	0.02	-0.01
EU-15		0.14	0.17	0.25	0.28	0.28	0.21	0.22
Cyprus		0.16	0.82	1.43	2.18	2.44	0.78	1.28
Czech Republic		0.55	-1.10	-1.59	-3.44	-3.78	-0.96	-1.57
Estonia		0.47	1.16	-3.37	-2.60	-2.60	-2.47	-2.53
Hungary		0.14	0.34	-0.58	-0.37	-0.49	-0.60	-0.44
Latvia		0.46	0.94	0.09	0.68	1.29	0.40	0.36
Lithuania		0.43	1.15	0.86	1.73	2.28	1.37	1.92
Malta		0.10	0.29	0.25	0.49	0.77	0.01	0.24
Poland		0.27	0.30	-0.38	-0.32	-0.08	-0.34	-0.33
Slovakia		1.01	-0.48	0.73	-0.91	-0.99	2.07	1.76
Slovenia		0.33	0.65	0.44	0.81	0.85	0.48	0.70
EU-10		0.35	0.15	-0.41	-0.62	-0.52	-0.21	-0.25
Bulgaria		2.22	-2.84	-5.91	-11.72	-13.97	-1.99	-2.68
Romania		-0.09	-0.94	-5.84	-6.73	-6.53	-3.06	-3.96
EU-2 new		0.43	-1.37	-5.85	-7.86	-8.21	-2.82	-3.67
EU		0.15	0.15	0.15	0.15	0.15	0.15	0.15

The *Marginal abatement costs* cases (cases A1 and A2) lead to reduction targets that are rather different to the other cases. For some EU-15 countries (e.g. Sweden and Portugal) this approach leads to lower reduction targets than the other approaches, while for other countries (e.g. Denmark and Germany) this approach leads to the highest reductions. For many EU-10 nations (Poland, Hungary), this approach leads to the highest reductions (compared to the reductions for the other cases). This also applies to Romania and Bulgaria, as these countries do not have excess emission allowances in 2020, which they do have in the other cases. Therefore this approach may meet considerable resistance from these countries. It should again be noted that the results greatly depend on the assumptions used for marginal abatement costs.

The *Triptych* cases (C1 and C3) lead to less extreme reduction targets, as indicated in Table 6.4, except for Germany (somewhat higher than the other cases) and Poland (lower than the other cases). However, for many countries the reductions under the *Triptych* approach are generally somewhere in the middle compared to the reductions resulting from the other approaches.

Emissions trading – Figure 6.9a-b shows the emissions trading and abatement costs as a percentage of GDP. In general, similar to what we have seen in the previous chapter, the EU-15 countries act as buyers on the internal EU trading market (except for the United Kingdom and Denmark, in some cases), and the EU-2 new and EU-10 countries act as sellers. The sellers are the EU-2 new countries (Bulgaria and Romania in particular) as well as the Czech Republic, due to their excess emission allowances, but also Poland.

The *Grandfathering* cases (B1, B2 and B4) lead to the largest transfer of permits from the EU-10 and EU-2 new countries to the EU-15 countries, in particular France, Spain and Portugal (Table 6.5). The transfer flows are much lower under the *Triptych* cases (C1 and C3) and evidently the lowest for *Marginal abatement costs* cases (A1 and A2).

Abatement costs – The total abatement costs for all EU countries for this 'EU 20% unilateral without CDM' scenario (Figure 6.9b and Table 6.5) show considerable similarities to the cost projections of the previous chapter (Figure 5.3 and Table 5.4). Again we see that the EU-15 shows net costs for almost all countries and regimes. Denmark and the United Kingdom also show the lowest costs (sometimes less than twice the EU average) and sometimes even some gains (e.g. for the *Grandfathering* cases), while Portugal and Spain show costs that are over twice the EU average for every regime.

Most of the EU-10 countries show net gains, except for the *Marginal abatement costs* cases. An exception is Cyprus, with costs that are always more than 1% of its GDP. Lithuania and

Slovenia also show high costs for several cases. The EU-2 new countries almost always show very large gains, even up to 14% of Bulgaria's GDP (under the *Grandfathering* cases).

In general the *Triptych* cases lead to the most balanced cost projections, in terms of medium costs for the EU-15 countries (except for Austria, Germany, Portugal and Luxembourg) and gains for the EU-10 (except for Cyprus, Latvia and Lithuania) and the EU-2 new countries. In contrast, the *Grandfathering* cases produce the most extreme results, with very high gains for the EU-2 new countries and high costs for many EU-10 countries, such as Greece, Portugal and Spain.

6.5 Reduction targets and abatement costs for all GHG emissions for the individual EU countries for the EU 20% unilateral with CDM scenario

The resulting emission allowances for the individual EU Member States, according to the cases, are the same as the 'EU 20% unilateral without CDM' scenario, except those for *Marginal abatement costs*. However, the accompanying emissions trading and abatement costs (as percentages of GDP) are different, as this scenario also allows emissions trading with countries outside the EU. Table 6.6 shows the emissions traded on the international market and abatement costs as percentages of GDP for the individual EU Member States: countries with net gains are shown in green and countries with net costs that are twice the EU average are shown in red. Table 6.6b shows the countries that are net buyers and net sellers, in red and green, respectively. Figure 6.10 shows the abatements costs and emissions trading for the same eight largest EU emitters and regimes.

Emissions trading – Compared to the 'EU 20% unilateral without CDM' scenario, total internal reduction is substantially lower, as a large amount of cheap emission reductions from outside the EU enter the emissions trading market. The lower permit price on the emissions trading market also results in increased emissions being traded within the EU. However, the emissions trading per country also shows the same trends as in the 'EU 20% unilateral without CDM' scenario. The *Grandfathering* cases again show the most trading within the EU, while the *Marginal abatement costs* approach again shows internal trading as almost zero, and trading takes place almost exclusively with countries outside the EU.

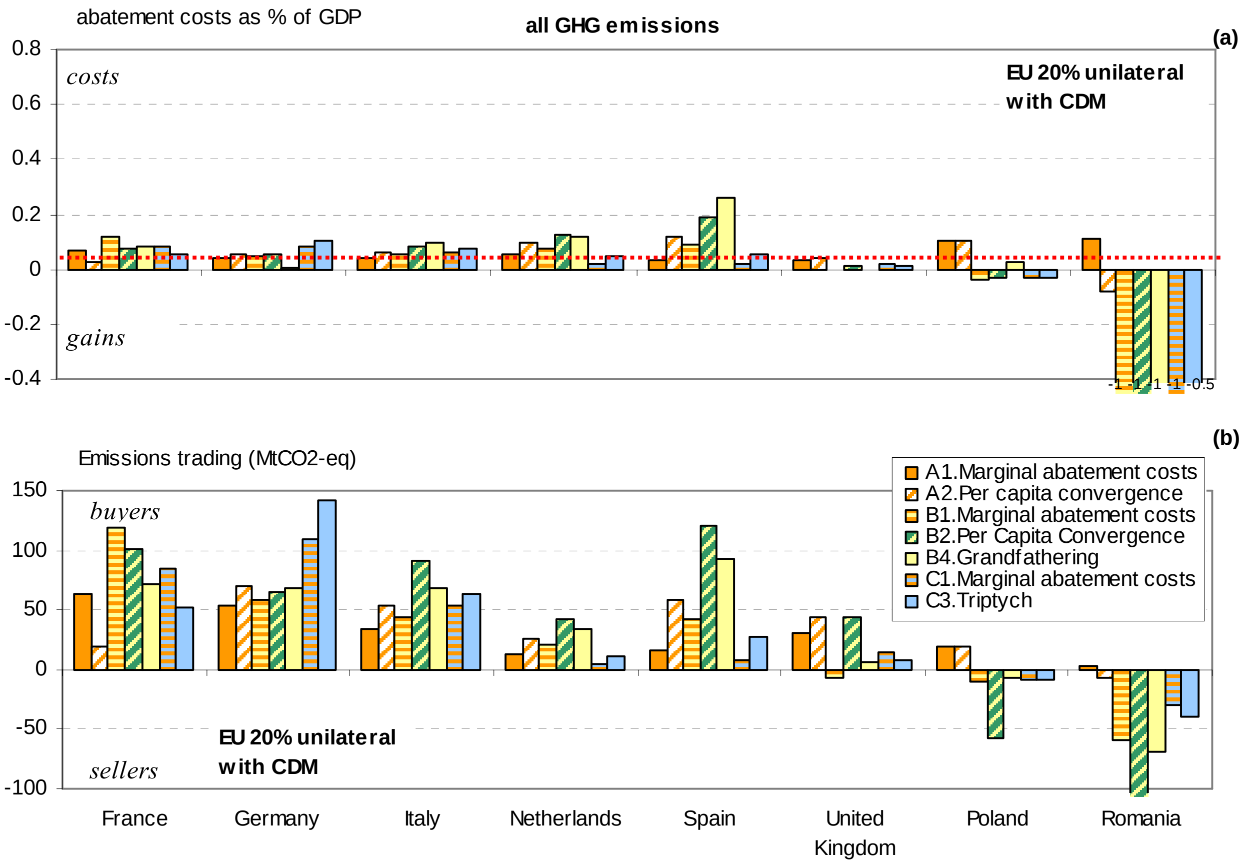

Figure 6.10: Abatement costs as %-GDP (a) and emissions trading (b) for 2020, for the eight largest EU emitters for the six allocation approaches under the 'EU 20% unilateral with CDM' scenario. The dotted line represents the EU average.

Abatement costs – The abatement costs also show similar trends to the 'EU 20% unilateral without CDM' scenario, although these are generally much lower (Table 6.6). The projections show a similar trend to those shown in the previous chapter (Figure 5.5). Gains for EU-10 and EU-2 new countries (now up to 3% of GDP for Bulgaria) – especially Cyprus, but to a lesser extent also Lithuania and Slovenia – are confronted with considerable costs of over double the EU average. Portugal again shows costs that are more than twice the EU average for every regime. Again, the *Triptych* approach results in the most balanced sharing of costs, with medium costs for the EU-15 countries (except Portugal and Luxembourg) and gains for the EU-10 (except Cyprus) and EU-2 new nations. In contrast, *Grandfathering* produces more extreme results, with high costs for the EU-15 and some EU-10 countries, such as Lithuania and Cyprus. The *Marginal abatement costs* cases lead to medium costs for the EU-15 countries, but to relatively high costs for the EU-2 new countries and many EU-10 countries.

Table 6.6: Emissions trading (MtCO_2-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the ‘EU 20% unilateral with CDM’ scenario. B4 (Grandfathering) leads to -20% for all countries and is not included. The green cells (a) indicate the sellers on the emissions trading market; and red cells indicate the buyers. The green cells indicate gains; red cells indicate costs of more than twice that of the EU average.

Step 1. Allocation ETS non-ETS *Step 2 : Allocation within ETS*		*A. Equal marginal costs*		*B. Grandfathering*			*C. Triptych*	
(a) emissions trading	Emissions after trading	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	B4. Grand-fathering	C1. Marginal abatement costs	C3. Triptych
Austria	72	8	9	16	21	18	14	17
Belgium	122	10	12	20	26	21	17	16
Denmark	50	5	5	0	5	0	0	-2
Finland	61	3	-5	13	10	4	2	-3
France	485	64	20	119	101	71	85	51
Germany	866	54	71	58	66	69	109	142
Greece	112	2	3	22	32	25	7	9
Ireland	60	12	7	16	20	11	4	0
Italy	443	33	54	44	91	68	53	64
Luxembourg	13	-2	5	-3	1	4	1	4
Netherlands	189	13	25	21	43	34	4	12
Portugal	84	7	14	20	36	29	13	17
Spain	347	16	58	43	120	93	7	27
Sweden	61	3	-20	29	14	3	21	5
United Kingdom	546	31	45	-7	44	6	15	8
EU-15	3511	260	302	410	627	456	352	367
Cyprus	9	0	2	3	5	4	2	3
Czech Republic	103	8	-11	-17	-65	-39	-9	-17
Estonia	12	1	2	-4	-5	-3	-3	-3
Hungary	74	3	5	-5	-16	-2	-5	-3
Latvia	11	1	2	0	1	2	1	1
Lithuania	23	2	4	3	4	6	5	6
Malta	3	0	0	0	0	0	0	0
Poland	353	18	20	-10	-57	-8	-9	-8
Slovakia	43	6	-1	5	-12	-3	11	10
Slovenia	17	2	3	2	3	4	3	3
EU-10	648	43	26	-21	-143	-39	-5	-8
Bulgaria	60	8	-7	-17	-64	-35	-5	-7
Romania	123	2	-7	-59	-107	-69	-29	-39
EU-2 new	183	11	-14	-76	-171	-104	-34	-46
Outside EU		313	313	313	313	313	313	313
(b) Costs								
Austria		0.06	0.08	0.13	0.14	0.12	0.11	0.13
Belgium		0.07	0.08	0.12	0.13	0.12	0.10	0.10
Denmark		0.05	0.05	0.01	0.01	-0.03	0.00	-0.01
Finland		0.04	-0.04	0.14	0.05	0.06	0.03	-0.03
France		0.07	0.02	0.12	0.07	0.08	0.09	0.05
Germany		0.04	0.05	0.04	0.05	0.01	0.08	0.10
Greece		0.02	0.03	0.19	0.21	0.32	0.06	0.08
Ireland		0.13	0.08	0.18	0.13	0.14	0.05	0.01
Italy		0.04	0.06	0.05	0.08	0.10	0.06	0.08
Luxembourg		-0.09	0.25	-0.15	0.22	0.16	0.03	0.21
Netherlands		0.05	0.09	0.08	0.12	0.12	0.02	0.05
Portugal		0.07	0.14	0.19	0.28	0.39	0.13	0.16
Spain		0.03	0.12	0.09	0.19	0.26	0.02	0.06
Sweden		0.02	-0.11	0.16	0.02	0.04	0.12	0.03
United Kingdom		0.03	0.04	0.00	0.01	0.00	0.02	0.01
EU-15		0.05	0.05	0.07	0.08	0.08	0.06	0.06
Cyprus		0.06	0.20	0.33	0.50	0.55	0.19	0.30
Czech Republic		0.21	-0.15	-0.25	-0.66	-0.72	-0.12	-0.25
Estonia		0.24	0.39	-0.60	-0.43	-0.43	-0.40	-0.42
Hungary		0.07	0.12	-0.08	-0.04	-0.07	-0.09	-0.06
Latvia		0.18	0.29	0.10	0.23	0.36	0.17	0.16
Lithuania		0.15	0.31	0.25	0.44	0.55	0.36	0.48
Malta		0.05	0.09	0.09	0.14	0.20	0.03	0.08
Poland		0.10	0.11	-0.04	-0.03	0.02	-0.03	-0.03
Slovakia		0.30	-0.03	0.24	-0.12	-0.14	0.53	0.46
Slovenia		0.13	0.20	0.15	0.23	0.24	0.16	0.21
EU-10		0.13	0.09	-0.04	-0.08	-0.06	0.01	0.00
Bulgaria		0.84	-0.27	-0.93	-2.19	-2.65	-0.08	-0.23
Romania		0.11	-0.08	-1.13	-1.33	-1.28	-0.54	-0.73
EU-2 new		0.28	-0.12	-1.09	-1.53	-1.59	-0.43	-0.62
EU		0.05	0.05	0.05	0.05	0.05	0.05	0.05

6.6 Reduction targets and abatement costs for all GHG emissions for the individual EU countries for the EU30% in a multilateral regime scenario

Table 6.7 shows the resulting emission allowances for the individual EU Member States compared to the 1990 and baseline levels for the 'EU 30% in a multilateral regime' scenario. Table 6.8 shows the emissions traded on the international market and abatement costs as a percentage of GDP for the individual EU Member States. Figure 6.11 shows the reduction targets for the eight largest EU emitters, which together represent about 75% of the total EU emissions, for all regimes. Figure 6.12 shows the abatements costs and emissions trading for the same eight largest EU emitters and regimes.

Emission allowances – There are not many countries and regimes with excess emission allowances as compared to the -20% scenarios, only Romania, Bulgaria and the Czech Republic for the *Grandfathering* cases. Furthermore, these excess emission allowances are much lower. Only Sweden has twice the reduction objective as the average reduction compared to the baseline for the EU. In general, the pattern of high and low reduction targets for the different cases is roughly the same as for the -20% EU reduction target, but evidently we see higher reduction targets for all countries. The *Triptych* approach leads to reductions that are somewhere in the middle compared to the other cases.

Emissions trading – The pattern of buyers and sellers is roughly the same as for the -20% EU scenarios, except for the EU-10 countries (excluding Czech Republic and Estonia) that now become buyers on the market for most regimes, although small buyers, as they still do their roughly 80-90% of their total reductions domestically. This was also found for the first options for EU burden-sharing and ETS allocation *Present system*, as described in the chapter 5.

Abatement costs – Overall abatement costs are approximately twice as high as for the -20% scenarios. The costs seem more equally distributed. Within the EU-15, Portugal and Greece are again the countries with the highest relative costs, while Cyprus and Lithuania again have the highest relative costs within the EU-10. Bulgaria and Romania have high net gains in all regimes. The *Triptych* approach again shows costs for the EU-15 that are less than twice the EU average for most countries, and gains for the EU-10 and EU-2 new countries. On the contrary, the *Marginal abatement costs* cases generally show lower costs for the EU-15, with higher costs for the EU-10 and EU-2 new countries.

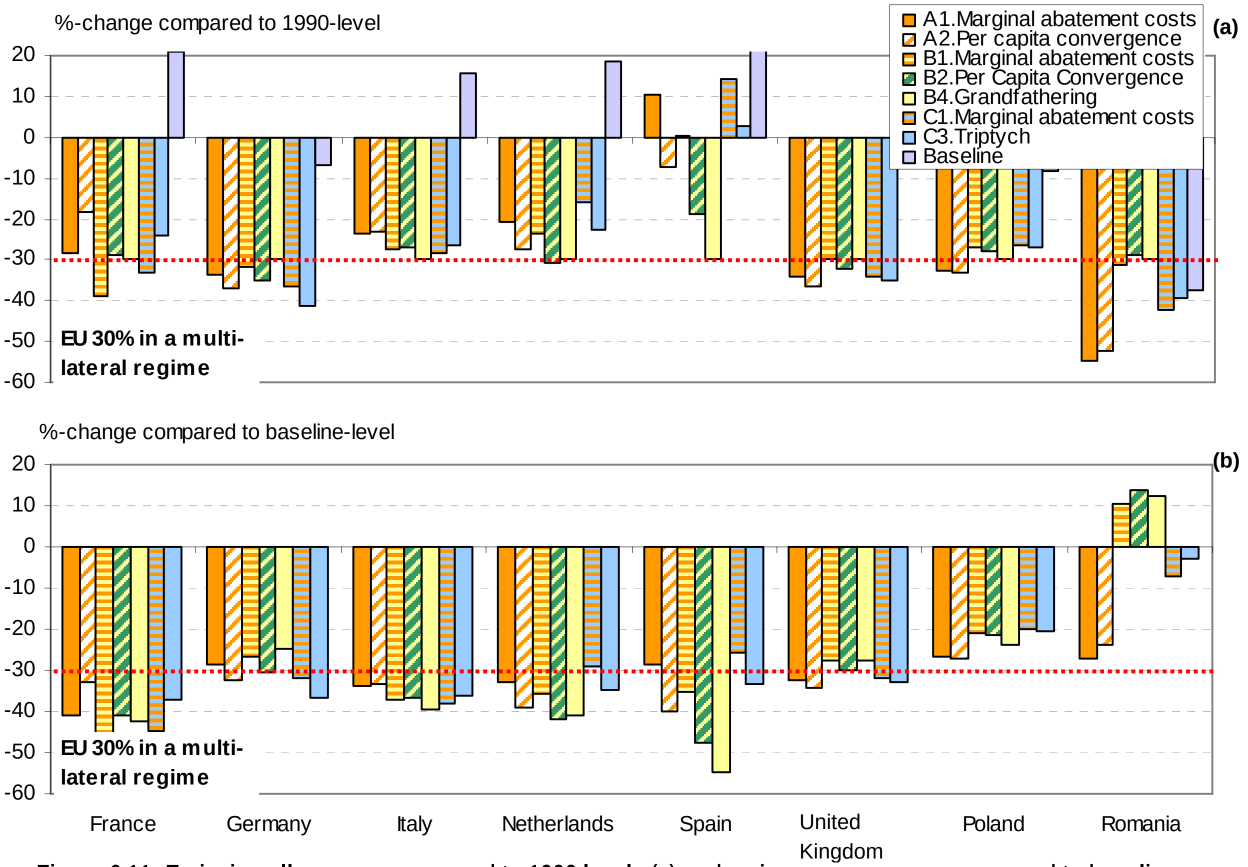

Figure 6.11: Emission allowances compared to 1990 levels (a) and emission allowances compared to baseline levels (b) for 2020, for the eight largest EU emitters for the six considered allocation approaches under the 'EU30% in a multilateral regime' scenario. The dotted line represents the EU average.

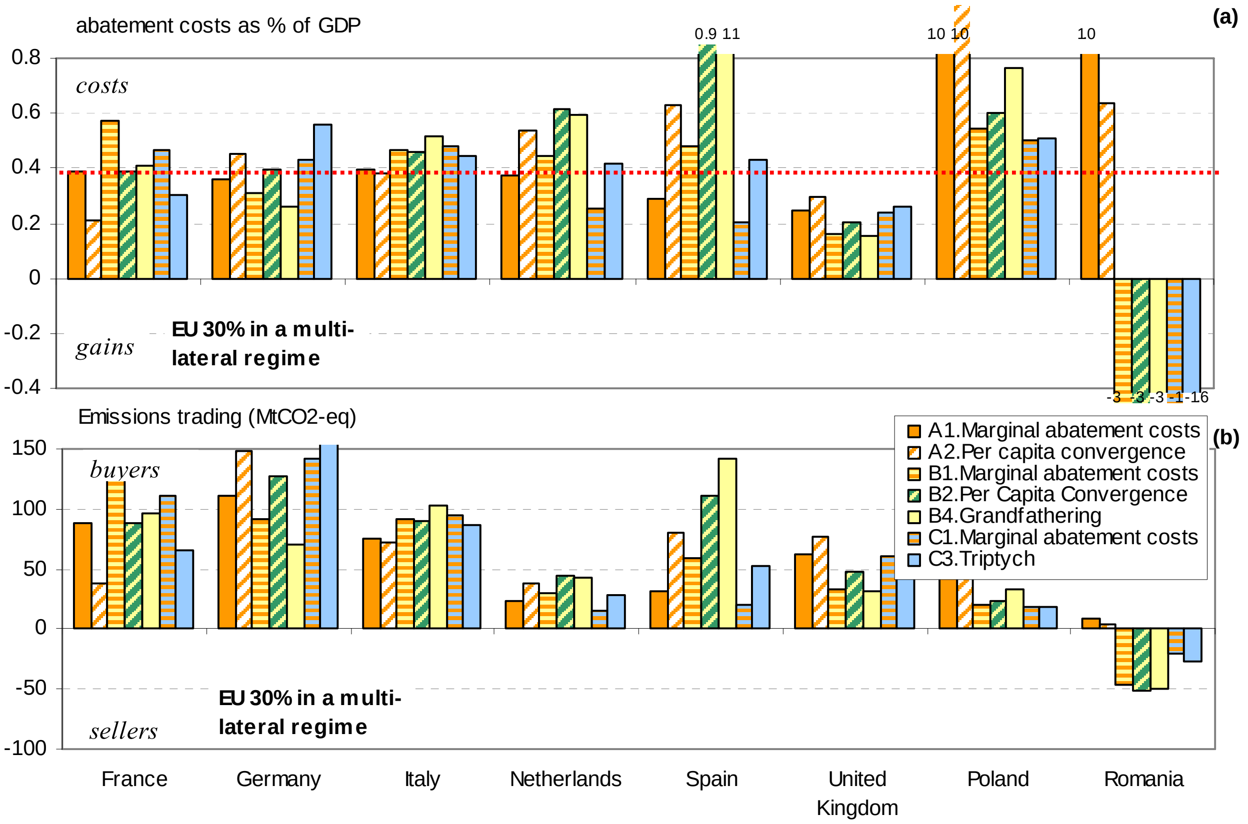

Figure 6.12: Abatement costs as %-GDP (a) and emissions trading (b) for 2020, for the eight largest EU emitters for the six allocation approaches under 'EU30% in a multilateral regime'. The dotted line represents the EU average.

Table 6.7: Reduction targets (%) compared to 1990 levels (a) and baseline levels (b) in 2020 for the 'EU30% in multilateral regime' scenario for selected cases. The red cells in Table 6.7a indicate the regime with the highest reduction and green cells represent the lowest reductions. The red cells in Table 6.7b indicate reductions of twice the EU average and green cells indicate excess emissions. The case B4 Grandfathering leads to -20% for all countries is now included. The EU 20% unilateral with CDM scenario gives similar results as EU 20% unilateral without CDM.

Step 1. Allocation ETS non-ETS *Step 2 : Allocation within ETS*		*A. Equal marginal costs*		*B. Grandfathering*			*C. Triptych*	
(a) 1990-levels	Kyoto target	A1. Marginal abateme nt costs	A2. Per capita converg ence	B1. Marginal abatement costs	B2. Per capita con-vergence	B4. Grand-fathering	C1. Marginal abatement costs	C3. Triptych
Austria	-13	-19	-19	-33	-32	-30	-30	-30
Belgium	-7.5	-24	-23	-33	-32	-30	-30	-28
Denmark	-21	-47	-50	-34	-36	-30	-33	-31
Finland	0	-30	-17	-43	-29	-30	-27	-17
France	0	-29	-19	-39	-29	-30	-33	-24
Germany	-21	-34	-37	-32	-35	-30	-37	-41
Greece	+25	3	3	-18	-18	-30	-4	-6
Ireland	+13	-27	-23	-32	-29	-30	-17	-14
Italy	-6.5	-24	-23	-27	-27	-30	-28	-26
Luxembourg	-28	6	-41	10	-38	-30	-6	-39
Netherlands	-6	-21	-28	-24	-31	-30	-16	-23
Portugal	+27	26	15	0	-12	-30	16	11
Spain	+15	10	-7	0	-19	-30	14	3
Sweden	+4	-31	12	-69	-25	-30	-61	-24
United Kingdom	-12.5	-34	-37	-30	-32	-30	-34	-35
EU-15	-8	-26	-27	-29	-30	-30	-28	-28
Cyprus	*	38	18	-1	-23	-30	18	1
Czech Republic	-8	-54	-44	-42	-32	-30	-47	-42
Estonia	-8	-53	-56	-27	-30	-30	-30	-29
Hungary	-6	-35	-39	-28	-31	-30	-29	-31
Latvia	-8	-21	-29	-12	-21	-30	-13	-8
Lithuania	-8	-8	-17	-14	-23	-30	-16	-19
Malta	*	-19	-25	-16	-23	-30	-16	-24
Poland	-6	-33	-33	-27	-28	-30	-27	-27
Slovakia	-8	-44	-33	-41	-30	-30	-52	-49
Slovenia	-8	-19	-27	-22	-29	-30	-22	-27
EU-10	-8	-37	-36	-31	-29	-30	-32	-32
Bulgaria	-8	-66	-54	-47	-34	-30	-59	-53
Romania	-8	-55	-52	-31	-29	-30	-42	-39
EU-2 new	-8	-59	-53	-37	-31	-30	-48	-44
EU		-30	-30	-30	-30	-30	-30	-30
(b) baseline								
Austria	-24	-36	-35	-47	-46	-44	-44	-44
Belgium	-13	-33	-32	-40	-40	-38	-38	-37
Denmark	-15	-42	-45	-27	-30	-23	-27	-24
Finland	6	-30	-16	-43	-29	-30	-27	-17
France	-11	-41	-33	-50	-41	-42	-45	-37
Germany	-11	-29	-32	-27	-30	-25	-32	-37
Greece	-9	-28	-28	-42	-43	-51	-33	-34
Ireland	-6	-40	-37	-44	-42	-43	-32	-30
Italy	-17	-34	-33	-37	-37	-39	-38	-36
Luxembourg	-31	-7	-48	-3	-46	-38	-17	-46
Netherlands	-16	-33	-39	-36	-42	-41	-29	-35
Portugal	-20	-31	-37	-45	-51	-61	-36	-39
Spain	-19	-29	-40	-35	-47	-55	-26	-33
Sweden	-2	-45	-11	-76	-40	-45	-69	-40
United Kingdom	-4	-32	-34	-28	-30	-28	-32	-33
EU-15	-12	-33	-34	-36	-37	-37	-35	-35
Cyprus	-43	-30	-40	-50	-61	-64	-40	-48
Czech Republic	42	-29	-14	-10	6	8	-18	-11
Estonia	0	-46	-49	-15	-19	-19	-19	-19
Hungary	6	-29	-33	-21	-25	-23	-22	-25
Latvia	-15	-40	-46	-34	-40	-47	-34	-31
Lithuania	-24	-37	-43	-41	-47	-52	-42	-45
Malta	-18	-37	-42	-35	-40	-45	-35	-40
Poland	11	-27	-27	-21	-22	-24	-20	-20
Slovakia	20	-35	-24	-33	-20	-20	-45	-41
Slovenia	-22	-33	-39	-35	-42	-42	-35	-39
EU-10	12	-29	-28	-22	-20	-21	-24	-23
Bulgaria	63	-42	-23	-10	11	18	-30	-21
Romania	58	-27	-24	10	14	12	-7	-3
EU-2 new	59	-32	-24	4	13	14	-15	-9
EU	-10	-32	-32	-32	-32	-32	-32	-32

Table 6.8: Emissions trading ($MtCO_2$-eq.) (a) and abatement costs (% of GDP) (b) in 2020 for the 'EU30% in multilateral regime' scenario. B4 Grandfathering leads to -20% for all countries is now included. The green cells (a) indicate the sellers on the emissions trading market and red cells indicate the buyers. The green cells indicate gains; red cells indicate costs of more than twice that of the EU average.

Step 1. Allocation ETS non-ETS *Step 2 : Allocation within ETS*		*A. Equal marginal costs*		*B. Grandfathering*			*C. Triptych*	
(a) emissions trading	Emissions after trading	A1. Marginal abatement costs	A2. Per capita convergence	B1. Marginal abatement costs	B2. Per capita con-vergence	B4. Grand-fathering	C1. Marginal abatement costs	C3. Triptych
Austria	66	10	9	20	19	17	17	17
Belgium	114	16	15	27	26	23	23	21
Denmark	47	11	13	2	4	-1	2	0
Finland	58	9	0	18	8	9	7	0
France	451	89	38	142	89	96	111	65
Germany	824	110	148	91	127	71	141	192
Greece	108	12	12	31	32	43	18	20
Ireland	57	13	11	16	14	15	7	6
Italy	418	75	72	92	90	103	95	86
Luxembourg	12	-1	5	-1	5	4	1	5
Netherlands	180	24	38	30	44	42	14	28
Portugal	81	12	18	26	33	43	18	20
Spain	334	32	80	59	111	142	20	52
Sweden	57	11	-18	37	7	10	31	6
United Kingdom	521	62	78	32	47	32	60	66
EU-15	3328	485	517	621	654	650	566	585
Cyprus	9	1	2	4	5	5	2	3
Czech Republic	98	14	-4	-7	-26	-29	2	-7
Estonia	12	3	3	-2	-2	-2	-2	-2
Hungary	70	8	11	0	4	3	1	4
Latvia	10	2	3	1	2	3	1	1
Lithuania	22	4	6	5	7	8	5	6
Malta	3	1	1	0	1	1	0	1
Poland	339	44	46	21	24	33	18	19
Slovakia	40	8	2	6	0	0	12	10
Slovenia	16	2	4	3	4	4	3	4
EU-10	619	87	74	30	18	26	44	39
Bulgaria	56	13	-2	-12	-27	-33	4	-3
Romania	116	9	4	-47	-52	-49	-21	-27
EU-2 new	173	22	2	-58	-79	-82	-17	-30
Outside EU	4119	593	594	593	593	593	593	593
(b) costs								
Austria		0.53	0.34	0.60	0.58	0.54	0.53	0.53
Belgium		0.69	0.44	0.69	0.67	0.62	0.62	0.69
Denmark		0.24	0.43	0.11	0.15	0.03	0.10	0.24
Finland		0.41	0.07	0.78	0.40	0.42	0.34	0.41
France		0.24	0.21	0.57	0.39	0.41	0.47	0.24
Germany		0.56	0.45	0.31	0.40	0.26	0.43	0.56
Greece		0.75	0.45	1.04	1.06	1.40	0.65	0.75
Ireland		0.48	0.50	0.70	0.62	0.65	0.36	0.48
Italy		0.41	0.38	0.47	0.46	0.52	0.48	0.41
Luxembourg		1.24	1.00	-0.13	0.95	0.76	0.21	1.24
Netherlands		0.61	0.54	0.45	0.62	0.60	0.26	0.61
Portugal		0.85	0.70	0.98	1.21	1.56	0.69	0.85
Spain		0.64	0.63	0.48	0.85	1.07	0.21	0.64
Sweden		0.08	-0.30	0.79	0.19	0.26	0.68	0.08
United Kingdom		0.24	0.29	0.16	0.20	0.16	0.24	0.24
EU-15		0.43	0.37	0.43	0.45	0.44	0.40	0.43
Cyprus		1.79	1.07	1.49	1.96	2.12	1.08	1.79
Czech Republic		-0.72	0.03	-0.22	-1.45	-1.65	0.36	-0.72
Estonia		0.21	2.57	-1.07	-0.69	-0.67	-0.71	0.21
Hungary		0.33	0.96	0.20	0.44	0.36	0.25	0.33
Latvia		0.66	1.46	0.71	1.10	1.51	0.71	0.66
Lithuania		1.72	1.66	1.48	1.98	2.35	1.61	1.72
Malta		0.61	0.78	0.52	0.72	0.91	0.51	0.61
Poland		0.85	1.01	0.54	0.60	0.77	0.50	0.85
Slovakia		0.32	0.57	1.29	0.29	0.24	2.35	0.32
Slovenia		0.99	0.95	0.77	1.05	1.07	0.77	0.99
EU-10		0.57	0.89	0.48	0.37	0.44	0.61	0.57
Bulgaria		-4.70	0.41	-2.05	-5.90	-7.32	1.76	-4.70
Romania		-2.92	0.64	-3.02	-3.39	-3.21	-1.13	-2.92
EU-2 new		-3.32	0.59	-2.80	-3.95	-4.14	-0.48	-3.32
EU		0.40	0.40	0.40	0.40	0.40	0.40	0.40

7 Discussions

7.1 Evaluating the burden-sharing approaches

Quantitative assessment – The key difficulty in designing a post-2012 EU burden-sharing agreement is related to the acceptability of the corresponding emission reduction targets to the different Parties. The regimes should preferably not lead to extreme results (for example, when abatement costs as a percentage of GDP far exceeds the EU average costs), or be particularly (un)attractive in terms of reductions for certain Parties only.

Comparing the resulting reduction targets shows that the *Grandfathering* approach yields no differentiation, and therefore leads to high reductions and thus also high costs for countries that presently have growth targets. In general, applying a uniform reduction target for all countries seems politically unacceptable for all EU Member States. *Per capita convergence* leads to high reductions (and again costs) for Eastern European countries with relatively high per capita emissions. This is even worse under the Multi-criteria (EQ) approach, given our assumptions of equal weighting of all thee criteria. However, another weighting here may lead to different outcomes. This is illustrated by the *Ability to pay* approach, which is a special case of the *Multi-criteria* rule, and only accounts for the criteria income (see chapter 3). This *Ability to pay* approach leads to huge amounts of excess emission allowance for the EU-2 new countries (and therefore very high gains), and thus relatively high reductions for the EU-15 countries.

The *Equal costs* approach, which set targets so that the costs are equally distributed over all participating countries (e.g. a percentage of the GDP), seems to be a fair option, at least from a theoretical point of view. However for our model assumptions, the *Equal costs* approach is very unattractive for the Eastern European countries and some EU-15 countries, such as France and the United Kingdom. The outcomes depend quite a lot on the model and costs definition assumptions used, forming a major barrier to the implementation of this method. The political feasibility of this approach may therefore be low.

Given assumptions made for the parameters, the results of the *Triptych* approach take a fairly central position in terms of reduction targets for countries compared to the other regimes. It has proven to be helpful in arriving of past EU burden-sharing agreements. The revised approach presented here can be applied to the group of all (27) EU countries, which are more diverse than the original EU-15 countries. The *Triptych* approach seems again to provide a good prospect supporting a negotiation outcome based on compromises by all Parties, accounting for sectoral differences and national circumstances.

However, it should be acknowledged that all quantitative results are largely dependent on the policy parameter settings, baseline emission scenarios and the marginal abatement cost curves. Therefore, we should be careful about drawing conclusions with respect to regimes on the basis of the quantitative outcomes presented, only.

Qualitative assessment – In practice, regime proposals will be evaluated on the basis of a much wider set of considerations, not just on quantitative assessments as described in chapter 4. This can be supported by a qualitative multi-criteria analysis to identify relative strengths and weakness of the regime approaches examined on the basis of set of criteria. Here, we use the environmental criteria, political criteria, economic criteria and technical criteria, as defined by Höhne et al. (2003) and Den Elzen and Berk (2003). The assessment given here is based on the work of Sijm et al. (2007) and briefly described here.

Table 7.1 shows that the regime proposals analysed here score differently with regard to the selected policy evaluation criteria, but that no option scores highest or lowest in all respects. For instance, *Grandfathering* scores 'very good' (i.e. '++') for the criterion 'simplicity/ease of implementation' but 'poor' (i.e. '–') for 'equity', while the *Triptych* approach scores 'poor' in terms of simplicity, but 'very good' regarding equity concerns as it covers various equity principles (see section 3.1: for the explanation of the equity).Nevertheless, depending on the weighing and adding of the criteria, some regime proposals seem to have a better overall score than others. For instance, balancing the number of pluses and minuses according to equal weights, the overall score for the *Grandfathering* approach seems to be lower than the other options, while the overall performance of the *Multi-criteria* (EQ) regime and the *Triptych* regime seem to be relatively higher.

Table 7.1: Indicative evaluation matrix for the qualitative comparison of six post-2012 EU burden-sharing approaches.

Criteria	*Grand-fathering*	*Per capita convergence*	*Multi-criteria (EQ)*	*Ability to pay*	*Triptych*	*Equal mitigation costs*
Environmental effectiveness	0	0	0	0	0	0
Economic efficiency (before trading)	–	–	–	–	+	+
Political acceptability	–	–	–	–	+	0
Equity	–	+	++	0	++	+
Simplicity/ease of implementation	++	++	+	+	–	–

Note: ++ (very good score), + (good), 0 (intermediate), – (poor), – – (very poor).

However, some qualifications should be added to Table 7.1. Firstly, although partly based on Torvanger and Godal (1999), Höhne et al. (2003) and Den Elzen and Berk (2004), the scores for the EU burden-sharing approaches with regard to the policy evaluation criteria are qualitative, and to some extent subjective, while the overall assessment of the approaches depends highly on the weighing and adding of these individual scores. Secondly, some criteria are rather general and need further specification, differentiation or clarification before they can be used unequivocally, for instance:

Economic efficiency. This criterion cannot only be regarded from a static perspective (i.e. what is the cost-effectiveness of an approach in the short term?), but also from a dynamic perspective (i.e. what is the effect of a regime to generate cost/carbon-saving technologies in the long term?). Moreover, the evaluation of the approaches mentioned in Table 7.1 assumes no emissions trading. However, once full emissions trading is allowed (among the EU Member States themselves and/or with their emitting installations), all approaches may achieve a very good score regarding (static) economic efficiency. In Table 7.1 only the Triptych approach and Equal costs have a good score. The Triptych approach would ensure that emission targets will largely be compatible with the existing technical emission reduction potentials in the various countries. Hence, emission reductions would be shared cost-efficiently. Evidently the equal costs approach accounts for the costs-efficiency. The other approaches all score poor in terms of costs-efficiency.

Environmental effectiveness. Similarly, this criterion can also be regarded from a short-term perspective (i.e. does an EU burden-sharing approach meets the mitigation target in the short term?) and a long-term perspective (i.e. does an approach contribute to generate cost/carbon-saving technologies, thereby enabling a more stringent target in the future?). Moreover, environmental effectiveness may be considered not only with regard to the countries covered by the approach, but also covering leakage effects to outside these countries. Finally, the environmental effectiveness of an approach depends not so much on how the emission reductions are set for different countries, but rather on how these reductions are achieved, as well as the adequacy of the monitoring and compliance system. While the setting or differentiation of mitigation targets is generally well covered by the burden-sharing approaches mentioned in Table 7.1 they barely deal with these other (more important) aspects of environmental effectiveness. This is why all approaches have scored 'intermediate' (i.e. '0') regarding this criterion.

Political acceptability. Political criteria generally relate to factors directly affecting the political acceptability of a climate change regime, in particular, regimes with significant emissions such as the eight major EU emitters like Germany, France and United Kingdom. This means that the approach is perceived as not posing a disproportional reduction burden to some countries, while favouring others. In the chapters 5 and 6 we concluded that the *Triptych* approach, in particular, takes a kind of central position in terms of differences in reduction targets between countries compared to the other regimes, and therefore scores good here. Other reasons for its positive score here are the strengths of the Triptych approach that are more positive in terms of political acceptability due to the Triptych strengths:

- Triptych explicitly accommodates national circumstances and allows specifically for economic growth at improving efficiency in all countries;
- Triptych aims to put internationally competitive industries on the same level;
- Triptych has been successfully been applied (on EU level) as a basis for negotiating targets and is compatible with the Kyoto Protocol (reporting and mechanisms) (see also Höhne et al., 2005).

The other approaches all show high reductions for the EU-10 countries or for the EU-15 countries, and therefore all score low. The exception is the equal costs approach that scores 'intermediate' as this leads to a central position in terms of costs. Other reasons for a positive score for the equal costs approach are its mains strengths: national circumstances explicitly accommodated; cost-efficient considerations taken into account, despite its main weaknesses (difficult to agree on a model or calculation method for calculating the costs of countries in advance) and uncertainties in costs projections.

Finally, some burden-sharing approaches are not unambiguously defined but may have to be further specified or interpreted. For instance, how are the different elements of the *Multi-criteria* (EQ) regime weighted and added? And what version of the *Triptych* approach – including which values for the parameters – will be used? Therefore, the overall evaluation of the EU burden-sharing approaches depends not only on the selection of the assessment criteria and the scores of the approaches regarding these criteria, but also on the weighing and adding of the evaluation criteria, as well as the interpretation and specification of both the criteria and approaches concerned.

7.2 Comparing countries' reduction targets of the EU 20% and 30% reduction

Figure 7.1 summarises the reduction range for some major EU emitters pertaining to the two major options for EU burden-sharing and ETS allocation, i.e. option 1 *Present system* (see also Table 5.3 and Table 5.6) and option 2 *EU burden-sharing with ETS allocation at EU level* (see also Table 6.4 and Table 6.7). Looking broadly at the necessary reductions common to the approaches, we observe significant reductions below 1990 levels for all approaches and see that agreed EU emission reduction levels (either 20% or 30%) are necessary for EU countries. We also observe that for the EU-15 region the difference in reductions between the agreed EU emission reduction levels is larger than that between the various approaches aiming at the same reduction level. But this does not apply to individual EU-15 countries and the EU-10: the difference in reductions between the regimes is larger than that between the agreed EU reduction levels (20% or 30%). In general, for most of the major emitting countries (as summarised in Figure 7.1) the 20% and 30% reduction ranges (reductions due to the various applied regimes) overlap for both options for EU burden-sharing and ETS allocation. However, for option 2, the overlap for some of (in particular) the major emitting countries is somewhat less, yet the maximum in the 20% reduction is close to the minimum in the 30% reduction. We do not conclude that option 2 leads to lower reduction ranges than option 1, as this may also be the result of the limited number of approaches analysed for allocating a country's emissions for the non-ETS sector under option 2 (i.e. only Triptych, per capita convergence and marginal abatement costs), whereas for option 1 we analysed a wide range of allocation approaches.

In summary, based on these overlaps and the wide range in reductions, we conclude that an agreement on the *approach* is more relevant than an agreement on the *overall EU reduction level* (20% or 30%).

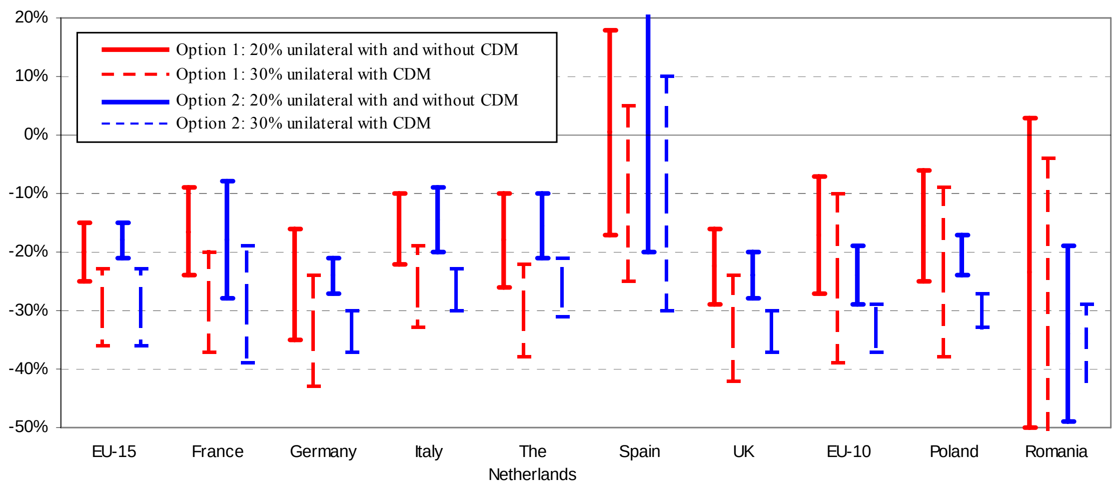

Figure 7.1: Emission allowances: reductions (compared to 1990 levels) in 2020 for the eight major emitting countries referring to the three scenarios for two options for EU burden-sharing and ETS allocation, i.e. option 1: the present system (upper) and option 2: EU burden-sharing with ETS allocation at EU level (lower). Ranges reflect different approaches.

7.3 Comparing countries' reduction targets with earlier studies

The finding of the previous section is in contrast with an earlier study of Höhne et al. (2005; 2005) studies, which found that the differences in emission allowances between the approaches are small compared to the necessary total long-term effort (450 or 550 ppm CO_2 concentration targets), and concluded that an agreement on the approach is less relevant than an agreement on the overall ambition level. Although Höhne et al. focused on concentration targets of 450 ppm and 550 ppm CO_2, their EU-25 reductions of about 10% and 20% below 1990 level respectively show a comparable difference (of about 10%) with this study. For example, Höhne et al. found that the United Kingdom needs to reduce emissions by around 25–30% compared to 1990 levels for all approaches under the 450ppm case, whereas under the EU 20% reduction target we observe a wider range of reductions (15–30%) below 1990 levels. Höhne et al. also concluded that the initial emissions (2010) form the starting point of the calculation, i.e. the Kyoto targets in 2010 make a significant difference, whereas our results show that the starting point is an important factor, but is still less important than the assumed approach. There are two reasons why our results show a wide range of reductions compared to the small ranges found by Höhne et al.:

1. The use of country-specific data for the baseline for population, economic GDP, population and activity levels, i.e. the LREM baseline, whereas Höhne et al. use the regional growth rate of the region Western Europe and Eastern Europe from the IMAGE baseline for population, GDP and emissions on the latest available data points of the individual EU countries within the respective regions, thus basically using the same trend for all European countries;[34]

[34] This regional downscaling method was criticised in the literature (see Den Elzen, 2005; see Pitcher, 2004; Van Vuuren et al., 2007b), as it may lead to unrealistic results.

2. This study considers a wide range of regime proposals, including those based on costs, whereas Höhne et al. focus solely on approaches that show some convergence in the per capita emissions around 2050.

Another earlier study of Wagner and Michaelowa (2005) also calculates emission reduction targets for the individual EU countries, showing a range in the order of -60% to +21% compared to 1990 levels. The reductions for the various European countries are in line with the reductions found in our study, although these are not easy to compare, as Wagner and Michaelowa focus on (i) CO_2 emissions only; (ii) an EU reduction of 25% below 1990 levels in 2020; and (iii) on one EU burden-sharing regime, i.e. a multi-sector convergence regime, although they also present variants based on different parameter settings.

Kemfert et al. (2007) have also recently analysed the emission reduction targets (before emissions trading) for the EU 20% reduction target. In their study they proposed a calculated 'fair' distribution due to the changes in growth of the GHG emissions from 1990-2005. More specifically, they simply weight a distribution of emission reduction that is related to the pure share of country emissions with the past development of emissions. For example, Germany and United Kingdom have already reduced emissions considerably. The 'fair' distribution includes this effect, so that Germany would achieve less reduction but other countries, who did not reduce emissions, would need to achieve more than the Kyoto target. In Spain, for example, emissions have risen substantially above the Kyoto target, so Spain's reduction would be accordingly higher.

Comparing the reductions shows the 'fair' approach to yield reductions in the range of our reductions. If we compare their reductions of the 'fair' approach with our reductions under the Triptych and Equal costs approach, we see that the 'fair' approach leads to higher reductions for Spain, France and the Netherlands, as these countries have achieved less reduction than their Kyoto target.

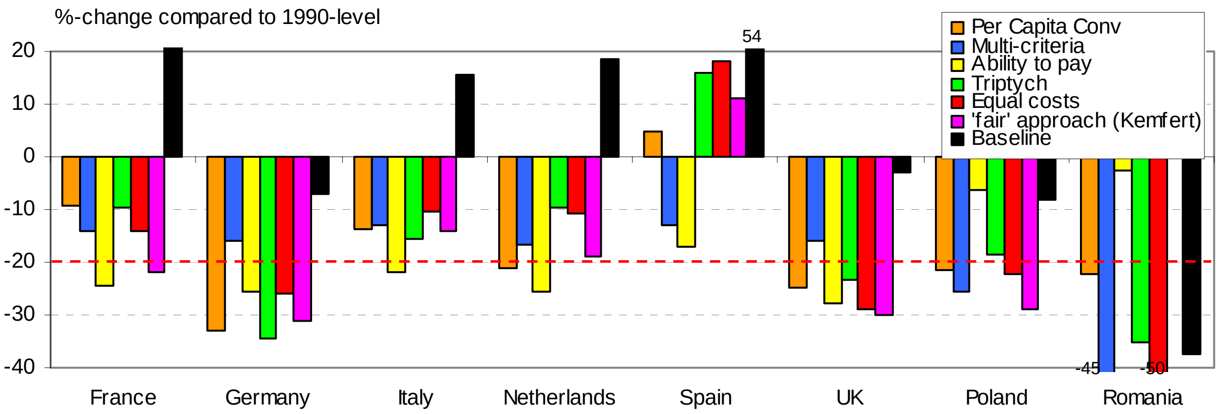

Figure 7.1: Emission allowances compared to 1990 levels for this study (column 1-4: option 1 see Figure 5.2) compared to those of Kemfert et al. (2007) (column 5) for the EU 20% reduction target.

7.4 Comparing results with announced emission reduction targets of individual countries

Several European countries have announced medium- and long-term targets to reduce emissions. The United Kingdom government has announced targets for a 60% reduction in CO_2 emissions by 2050, and a 26–32% reduction by 2020, which is legally binding (for further details, see: www.pm.gov.uk). A new system of five-year ‘carbon budgets’, set at least 15 years ahead, to provide clarity concerning the United Kingdom’s pathway towards its key targets, i.e. a 60% reduction by 2050. This United Kingdom target was based on reductions necessary under convergence of per capita emissions towards 550 ppm CO_2 concentration. This target corresponds with our United Kingdom 23% to 29% reduction range for the EU 20% reduction objective for option 1 Present system. The range is based on the outcomes of all regimes except *Multi-criteria* (EQ). However the United Kingdom’s new target is outside our United Kingdom reduction range associated with the EU 30% reduction objective (i.e. 34% to 42%) (again leaving out *Multi-criteria* (EQ)). This finding is robust for the reductions of the United Kingdom under option 2 *EU burden-sharing with ETS allocation at EU level*, i.e. in the order of 20% to 28% for the EU 20% reduction objective and 30% to 37% for the EU 30% reduction objective.

Germany has announced that it is willing to reduce emissions by 40% by 2020, if the EU as a whole agrees to reduce by -30% (Germany, 2002). If we compare this 40% reduction target with our range of Germany’s reduction targets for the EU 30% objective (36–42%, excluding *Multi-criteria* for option 1; and 30-37% for option 2), we can conclude that this reduction target is in line with this range. Evidently, Germany’s target is even more ambitious than the EU 20% reduction range (25–33%, excluding *Multi-criteria*).

The Netherlands has announced a 2020 reduction target of 30%, which is higher than the range under the overall EU 20% reduction objective for option 1 *Present system*, i.e. 10% to 25%, but is in line with the range under the overall EU 30% reduction objective, i.e. 22% to 31% (excluding *Ability to pay*). For the EU 20% reduction objective reductions for the Netherlands this study shows the *Triptych*, *Multi-criteria* and *Equal costs* approaches as being 10–20% and *Per capita convergence* and *Ability to pay* approach as being about 20–25%. Given the low political feasibility for *Per capita convergence* and burden-sharing based solely on income, the analysis indicates that the Netherlands would only need to adopt a target of 10–20%, thus somewhat lower than the average EU 20% reduction. Again this finding is robust for the reductions under option 2 *EU burden-sharing with ETS allocation at EU level*, i.e. in the order of 10% to 21% for the EU 20% reduction objective and 21% to 31% for the EU 30% reduction objective.

The Dutch government might therefore consider either conditioning its commitment, i.e. ‘only if the EU as a whole agrees to reduce by -30%’, as Germany has done, or separating its domestic target from its (binding) EU target, as the United Kingdom has done.

Sweden has agreed to reduce its emissions by 30% by 2020, which is within our range of Sweden’s reduction targets for the EU 30% objective (16–40% for option 1; and 6%-37% for option 2).

The Czech Republic has announced an emission reduction of 42% by 2020 compared to 1990 levels, which is within our range of the Czech Republic's reduction targets for the EU 30% objective (11–51% for option 1; and 32%-54% for option 2).

France is willing to reduce its emissions by a factor of 4–5 (-75% to -80%) by 2050 (France, 2004), but no 2020 reduction targets were given. A linear interpolation would lead to a reduction target of about 20% for 2020, which is at the higher end of our reduction targets range under the EU 20% reduction objective, but outside the range for the EU 30% reduction objective.

7.5 Robustness of the results

Emission allowances – One major uncertainty for the countries' emission allowance projections comes from the baseline development in population, GDP and emissions. This study uses the LREM baseline from the PRIMES model (Mantzos et al., 2003), i.e. the September 2003 EU baseline scenario of DG-TREN[35] (see Box 2). As only one baseline scenario is considered, it does not cover the full range of uncertainty about future developments. For the uncertainties in the population and GDP projections this could be relevant, as all approaches depend on these socioeconomic indicators. On the other hand the future baseline emissions are not as relevant to the calculations of the future emission targets for all approaches, except for the *Triptych* approach and the *Equal costs* approach, since all European countries must reduce their emissions in all approaches, independent of the baseline development. For the *Triptych* approach, industrial and electricity production baseline growth rates could affect the results. This also holds for the agricultural baseline emissions. For the *Equal costs* approach the baseline affects the reduction effort, i.e. the difference between the baseline and the emission targets, and thus also the abatement costs.

Another source of uncertainty is the starting point in 2010, as this also affects the future commitments (see section 5.2). Here, we have assumed that all countries start in 2010 at their Kyoto targets, including those countries with baseline emissions in 2010 that are much less than their Kyoto targets (i.e. excess emission allowances). If we were to assume that these 2010 emissions are based on the lowest targets under the Kyoto Protocol or the baseline emissions in 2010, this would also affect the reduction targets of 2020 as presented in this report. In general countries with excess emission allowances in 2010 would have far lower excess emission allowances in 2020 and it would relax the reduction targets of the other European countries. More specifically, the reduction targets of all individual EU-15 countries would decrease by around 3%. The reduction target for the EU-10 as a whole would increase

[35] In 2005 an update of the EU baseline was developed, which took into account higher oil price levels. Due to this, both energy price scenarios and activity levels have been changed. This updated data was not available at the time of this study and has therefore not been used.

by 6%, i.e. this increases Poland's reduction targets by 3%, the Czech Republic by 15%, Bulgaria and Romania by 20%. The latter shows that, for the Czech Republic, Bulgaria and Romania in particular, the assumption about the initial 2010 emissions can become a very important issue in the post-2012 EU negotiations, as their reductions are influenced even more by the initial emissions than the regime or agreed EU reduction objective.

A further important source of uncertainty concerns the choice of the approaches that have been included here, because there may also be other approaches available in the coming post-2012 discussions. A wide variety of six approaches have been analysed here, varying from a simple approach such as *Per capita convergence,* to more sophisticated approaches, such as the *Triptych* and the *Equal costs* approach. All these approaches have been proposed in the past during the negotiations of the Kyoto targets for the individual European countries.

Another important source of uncertainty is the choice of parameters for the different approaches that have been modelled here. Almost all approaches leave room to alter the balance of burden between high- and low- per capita emission countries, by varying some of the parameters. For *Per capita convergence*, the only parameter is the convergence year. Moving this convergence year to a later date favours high-emission countries, while moving it to an earlier date favours low-emission countries. For the *Multi-criteria* (EQ) rule, the choice of the weighting factors considerably influences the balance of effort between high-emission and low-per-capita-emission countries. This study assumes equal weights. Another weighting would affect the results, as shown by the results of *Grandfathering* and *Ability to pay*, plus particular cases of the *Multi-criteria* (EQ) rule.

The results of the *Triptych* and *Equal costs* approaches particularly depend on the choice of the many parameters. We have aimed for a balanced set of parameters, but ultimately this remains a subjective choice. For the *Equal costs* approach the results will largely depend on the assumptions for the marginal abatement costs curves used. Besides, the outcomes could be different if not based on abatement costs but on macro-economic impacts.

Abatement costs – The uncertainty concerning the countries' abatement cost projections stems from the regime assumptions, the overall EU reduction objective, the baseline emissions and the marginal abatement costs curves. This study extensively explores the first two. The latter is analysed here.

The baseline of the EU region is based on the LREM scenario, whereas the baselines of the other regions (used for international trading) are based on the IMAGE IPCC B2 baseline scenario. To assess the impact of using this baseline, the IMAGE IPCC B2 baseline scenario for Western and Eastern European regions is used to represent the EU region. However, due to regionalisation, several countries are excluded (e.g. the Baltic states), while the former

Yugoslavian states are included in these regions. This makes a comparison with the LREM scenario inconsistent and is therefore omitted.

The MAC curves for the EU are based on GENESIS, whereas the MAC curves for the other regions (used for international trading) are based on the IMAGE/TIMER model (van Vuuren et al., 2007a). Here, we consider the impact of using the MAC curves of the TIMER/IMAGE model for the EU region. The impact of different MAC curves for individual countries within the EU is not analysed here, as individual European countries are not available in the TIMER model.

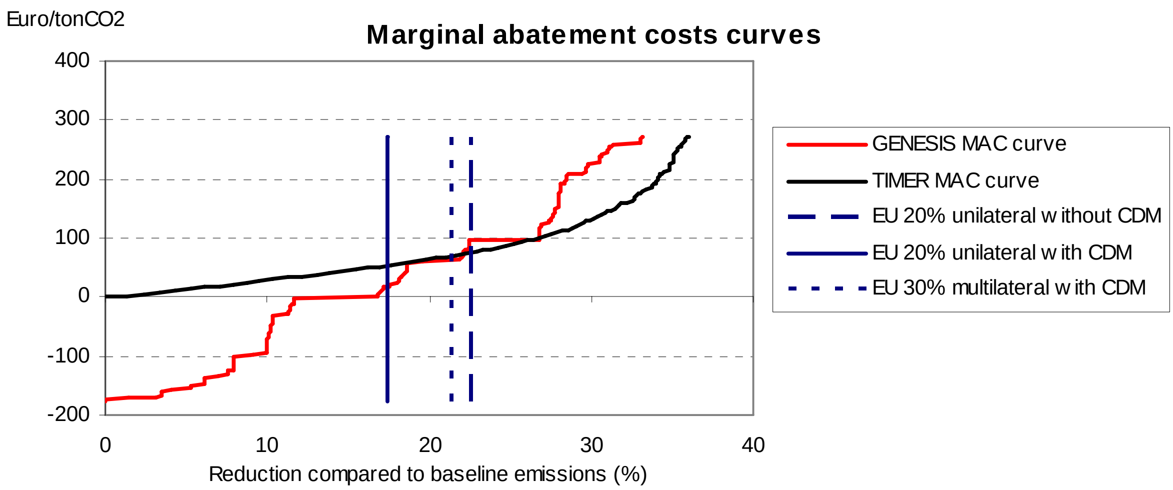

Figure 7.2: MAC curves in 2020 of the TIMER model (Van Vuuren et al., 2007a) for the EU region and the GENESIS database (this study).

Table 7.2 shows the permit price, total internal reduction and the overall abatement costs including emissions trading. Figure 7.2 shows the MAC curves of the EU region for GENESIS and TIMER/IMAGE in 2020. The figure shows that both MAC curves are quite similar for emission reductions in the range of 19% to 27% compared to the baseline. This covers the ‘EU 20% unilateral without CDM’ and ‘EU 30% multilateral with CDM’ scenarios (see the blue vertical lines). Furthermore, Figure 7.1 also shows a large number of zero and negative cost options for the GENESIS database (about 16% of the baseline emissions).

Both MAC curves are approximately the same for the ‘EU 30% unilateral with CDM’ scenario, Therefore, the permit prices and internal reduction percentage are also the same. However, due to the high share of zero and negative cost options in the GENESIS database, the overall costs using the TIMER MAC curves are much higher. The same holds for the ‘EU 20% unilateral without CDM’ scenario. The large share of negative cost options in the GENESIS database also explains the relatively low costs of the ‘EU 20% unilateral with CDM’. Most reductions can be done at very low to zero costs, while the remaining reductions are bought on the international permit trading market for a relatively low price, as the CDM market is exclusively accessible for the EU.

Table 7.2: Sensitivity analysis of the main indicators for the EU for the three scenarios using the GENESIS MAC curves and the PRIMES baseline (default).

	EU 20% unilateral without CDM	EU 20% unilateral with CDM	EU 30% in a multilateral regime
Reduction compared to 1990 (%)	20	20	30
Reduction compared to baseline (%)	25	25	34
Default: *GENESIS* MAC curves and the *PRIMES* baseline			
Red. comp. baseline after trading (%)	23	17	21
Permit price (€/tCO_2-eq.)	96	23	74
Internal reduction (%)	100	77	66
Costs (%-GDP)	0.13	0.05	0.38
***TIMER* MAC curves and the *PRIMES* baseline**			
Red. comp. baseline after trading (%)	23	15	22
Permit price (€/tCeq.)	75	43	73
Internal reduction (%)	100	67	69
Costs (%-GDP)	0.24	0.20	0.49

Using a different set of MAC curves (in this case from TIMER/IMAGE) does not change the overall trends, although the overall costs can be substantially different. The difference here is mainly attributable to the large amount of zero and negative cost measures, although in this analysis we have changed reduction measures with negative costs to zero costs. Including the negative costs would have resulted in overall negative costs, probably for all countries, thus making climate policy a so-called ‘no-regret’ option.

7.6 Important limitations of the current study

This study uses an integrated modelling framework (FAIR EU) to explore the regional emission reduction targets and abatement costs for the EU countries. However, there are a few important limitations to the study that are essential to interpreting the results.

First, as already mentioned, this study uses the LREM baseline from the PRIMES model (Mantzos et al., 2003). This baseline, updated in 2005, took into account higher oil price levels, which causes changes in both energy price scenarios and activity levels.. This updated data, which became available in 2007, was not available at the time of this study and has therefore not been used.

The cost concept used in this study refers to direct abatement costs only on the basis of MAC curves derived from underlying expert models – and does not capture the macroeconomic impacts of climate policy. Macroeconomic cost measures (such as consumption or GDP losses, but also sectoral impacts) might, in some cases, be larger as they also include effects such as loss of competitiveness, impacts on fuel trade, combined effects of climate policy and existing taxes etc. On the other hand, they could also be smaller, since there be will sectors and industries that profit from climate policy and since there might be benefits from recycling the revenues of carbon taxes (see an extensive discussion on costs: Van Vuuren et al., 2007a; Den Elzen et al., 2007b).

Furthermore, the reduction measures used in this analysis are subject to uncertainties, particularly regarding costs assumptions. These assumptions are based on the GENESIS database, which might be rather optimistic with respect to the ‘no-regret’ measures: approximately 850 $MtCO_2$-eq. (about 15% of the baseline emissions) can be reduced in 2020 with costs that are equal to or less than zero. The shapes of the curves for the different countries are very similar, which is due to the generic character of the GENESIS algorithms. Every country has in principle the same set of measures (e.g. affected by geography – for example for offshore wind – and industrial structure) and each measure is similarly characterised for each Member State. The impact of a measure differs slightly for each country, mainly driven by the percentage of emissions in each country to which the measure applies.

In addition to these uncertainties, the GENESIS database does not account for technological changes (including learning effects) and inertia of the energy system, relating to explicit capital turnover rates. The first may not be very relevant in the short term, but for the second, inertia, this does not hold, not accounting this, makes relatively inexpensive fuel-switching an interesting reduction option. Furthermore, the GENESIS database identifies the most cost-effective reduction options, while ‘uneconomical behaviour’ is not incorporated into the analysis. For instance, many options with net negative specific costs will probably not be implemented due to numerous non-technological barriers. On the other hand, options with high specific costs may be implemented for various other psychological or cultural reasons. Therefore the GENESIS approach can help support the formulation of sector or option-specific policies and measures that should remove the implementation barriers, in order to achieve the most cost-effective way to reduce GHG emissions (Blok et al., 2001). The GENESIS database does not take account of all structural changes, modal split changes in transportation, shifts from primary to secondary materials and nuclear energy.

Our analysis does not fully account for the Energy Package as recently agreed by the EU, in particular with respect to the renewable energy and biofuels targets for the EU, mainly as we apply a costs-effective approach, i.e. allocating the relatively cheap abatement measures (like energy efficiency) first, followed by the more expensive abatement measures (like renewable energy and Biofuels). Meeting in particular the biofuels targets would also require an update of the potentials and costs of renewable energy and biofuels measures in our modelling framework. This can be done by updating GENESIS or using another source for this information. The version of GENESIS used for this study is not fully up to date, as it includes no biofuels measures and only a limited number of biomass measures.

Finally, as our modelling framework uses marginal abatement costs and baseline data from various sources, this may lead to inconsistencies in the calculations. This particularly applies to the calculations of the permit price on the international emissions trading market, and relating to this, international emissions trading, plus domestic and external abatement. The baseline and MAC curves for the EU are based on the LREM baseline scenario and GENESIS, respectively, whereas the baseline and MAC curves for the other regions are based on the IMAGE IPCC B2 baseline. The underlying socioeconomic assumptions are very similar, both based on the reference scenario of the World Energy Outlook 2004 (IEA, 2004), thus leading to comparable emission levels between both sets. For the MAC curves, we have already concluded similarities within the range of 17–27% reduction compared to the baseline emissions. However, outside this range, reduction potentials and costs are completely different. Although using both MAC curve sets for the EU results in similar trends with respect to permit price, internal abatement and abatement costs over the three scenarios, overall costs levels differ significantly (see section 7.4).

8 Conclusions

This report explores the implications of options for allocating the EU reduction objectives (20% unilateral or 30% multilateral) adopted by the Council of the European Union among its Member States. More specifically, the analysis focuses on three scenarios based on different assumptions for the level of international participation and the EU reduction objective. These scenarios are: *EU 20% unilateral without CDM*, *EU 20% unilateral with CDM* and *EU 30% in a multilateral regime*. The report analyses the countries' reduction targets and abatement costs on the basis of two major types of options for EU burden-sharing and ETS allocation beyond 2012:

1. ***Present system,*** i.e. initially sharing the overall EU emission target among its Member States and with each Member State subsequently dividing its national target between the ETS and other sectors.
2. ***EU burden-sharing with ETS allocation at EU level,*** i.e. both the top-down ETS cap and the bottom-up allocation rules are set at EU level, while the EU target for the non-ETS sectors is shared among the Member States.

Option 1 is characterised by a high level of decision-making at the Member State level, whereas option 2 is characterised by a high level of decision-making at the EU level. Six different allocation schemes or regimes for internal EU burden-sharing are used for option 1: i.e. *Grandfathering*, *Per capita convergence*, *Ability to pay*, *Multi-criteria*, *Triptych* approach and *Equal costs*. For option 2, the allocation between the ETS and non-ETS sector at EU level is based on the allocation schemes *Marginal abatement costs*, *Grandfathering* and *Triptych* approach, and the allocation of the non-ETS sector is based on *Marginal abatement costs*, *Per capita convergence*, *Grandfathering* and *Triptych* approach. All allocation schemes act as effective schemes to systematically derive emission targets according to certain principles for the distribution of emission reduction obligations. Besides the countries' reduction targets, the report further analyses whether it is technically feasible to meet these EU reduction objectives and what portfolios of reduction measures (including the Kyoto mechanisms) are needed.

We draw the following conclusions from the analysis:

- **It is technically feasible for the EU to meet a 20% reduction target unilaterally, with abatement costs in the order of 0.13–0.24% of GDP when CDM is excluded. Including CDM would lower the costs towards 0.05- 0.20% of GDP.**

Restricting the greenhouse gas emissions to meet the EU 20% reduction objective in 2020 under a post-2012 unilateral climate mitigation regime without CDM ('EU 20% unilateral without CDM') was found to be technically feasible, although it will require major changes in the energy system. In our calculations, abatement costs in the order of 0.13–0.24% of GDP were found.[36] Inclusion of CDM ('EU 20% unilateral with CDM') significantly increases the amount of cheap emission reductions on the EU permit trading market, which affects mainly the permit price, lowers both the domestic abatement and the overall costs for the EU as a group up to two-thirds[0.05%;0.20%].

It should be noted that these costs only represent the direct costs based on two sets of MAC curves (derived from the GENESIS database and from the TIMER energy model), but not the various linkages and rebound effects via the economy or impacts of carbon leakage. In other words, there is no direct link with macroeconomic indicators, such as GDP losses or other measures of income of utility loss. Furthermore, these absolute cost projections are subject to some major uncertainties. The lower range estimates include large amounts of 'no-regret' reduction options, which significantly lower the overall costs. Furthermore, they do not account for technological improvements in time and inertia in the energy system, making relatively inexpensive fuel-switching an interesting reduction option. The upper range estimates include technological change and learning effects, as well as inertia in the energy system. However, the time-horizon is too small for a significant effect of technological change. Nevertheless, the inertia and the lack of 'no-regret' options produce an upward effect on the overall costs.

- **Meeting a 30% reduction objective as part of a multilateral regime leads to much higher abatement costs for the EU than meeting a 20% reduction target in a unilateral regime.**

Restricting the greenhouse gas emissions to meeting the EU 30% reduction objective in 2020 under a post-2012 multilateral climate mitigation regime (including emissions trading outside the EU) leads to abatement costs in the order of 0.38–0.49% of GDP. These costs are about twice as high compared to those if the EU unilaterally adopts its 20% reduction objective without using CDM [0.13%; 0.24%]. The 20% unilateral and 30% multi-lateral lead to approximately the same level of domestic reductions for the EU (i.e. 20% compared to 1990 level). For the 30% multi-lateral regime the additional reduction to meet the EU 30% target is met through CDM and the international emissions trading market, increasing the overall costs significantly.

- **For both major options for EU burden-sharing and ETS allocation beyond 2012 the outcome in terms of emission reduction targets between European countries due to the applied burden-sharing approach are very diverse.**

The key difficulty in designing a post-2012 EU burden-sharing agreement is related to the acceptability of the corresponding emission reduction targets to the different Parties. The regimes should preferably not lead to extreme results (for example, when abatement costs as

[36] The ranges represent the lower outcome of our default calculations using the GENESIS marginal abatement costs and the higher outcome using the marginal abatement costs estimates of the TIMER calculations.

a percentage of GDP far exceeds the EU average costs), or be particularly (un)attractive in terms of reductions for certain Parties only.

For the first option for EU burden-sharing and ETS (***Present system***) the reduction targets show a wide range of outcomes for the six burden-sharing regimes explored. A uniform reduction target (*Grandfathering*) leads to high reductions for countries which at present have emission growth targets under the Kyoto Protocol. *Per capita convergence* and the *Multi-criteria* approaches lead to high reductions for countries with relatively high per capita emissions, while the *Ability to pay* approach leads to a huge amount of excess emission allowance for Bulgaria and Romania, which have to be compensated by relatively high reductions for the EU-15 countries. From a theoretical point of view, the *Equal costs* approach seems to be fair. However, in practice it may be difficult to agree on a model or calculation method for calculating the costs of countries in advance. Furthermore, the *Equal costs* approach leads to high reductions for the Eastern European countries and some EU-15 countries, such as France and the United Kingdom. Considering our assumptions for the parameters for the different approaches, the *Triptych* approach takes a kind of central position in terms of differences in reduction targets between countries compared to the other regimes. The approach leads to somewhat higher reductions for the EU-10 countries (particularly the less energy-efficient countries), which have to contribute more to the EU reduction effort.

For the second option for EU burden-sharing and ETS (***EU burden-sharing with ETS allocation at EU level***) the countries' overall reduction targets also show a wide range. In general, we see the same pattern of differences in reductions for the various burden-sharing regimes, as discussed above for option 1. More specifically, the allocation schemes for the ETS allocation at EU level based on *Grandfathering* leads to high reductions for countries which at present have emission growth targets under the Kyoto Protocol: Greece, Portugal and Spain, and substantial excess emission allowances for Czech Republic and EU-2 new countries. The *Marginal abatement costs* cases lead to high reductions for many EU-10 countries and EU-2 new countries, and a mixture of high and low reductions for the EU-15 countries. The reductions under the *Triptych* cases are more-or-less in the middle compared to the reduction of all cases.

It should be acknowledged that the quantitative results for the emission allowances are particularly dependent on the policy parameter settings and, to a lesser extent, on the baseline emission scenarios and the starting-point (2010) emissions. In particular for the Czech Republic and EU-2 new countries, the choice of the starting point emissions (either the Kyoto targets (as assumed here), or the lower of the Kyoto reduction targets or baseline emissions) can significantly affect these countries' 2020 targets even more than the regime or the agreed EU reduction objective. Therefore care must be taken in interpreting the conclusions with respect to regimes on the basis of the quantitative outcomes presented.

- **EU burden-sharing with ETS allocation at EU level leads to higher reductions compared to the baseline emissions in the non-ETS sectors vs. emissions in the ETS sectors.**

For the second option for EU burden-sharing and ETS (*EU burden-sharing with ETS allocation at EU level*), the reduction for the non-ETS sectors compared to baseline levels exceeds the reduction in the ETS sector for the *marginal abatement costs* and *Triptych* cases. This is because reducing emissions in the non-ETS sector is more cost-effective or more effective in terms of reduction potentials compared to the ETS sector. However, as, compared to 1990 levels, total emissions in the non-ETS sector (especially from transport) increase more than the emissions in the ETS sector; compared to 1990 levels the reductions in the emissions in the ETS sector are larger (especially from industry). For the industry sector the reductions are well above the overall EU reductions (20% or 30%), whereas in the power sector the reductions are just above the overall EU reductions. The reductions for the non-ETS sector show a wide range for all countries, with relatively high reductions for Germany and the United Kingdom (in the order of 30%) and relatively lower reductions for Italy and even growth targets for Spain up to +30% compared to 1990 levels.

- **There are large differences among the regimes in the countries' abatement costs. Generally, the EU-15 countries are confronted with costs above the EU average, while many EU-10 countries, and Bulgaria and Romania, may benefit from emissions trading.**

The total abatement costs per country, presented here as a percentage of GDP, differ per country and per regime. For the EU 20% reduction objective, the EU-15 shows net costs for almost all countries and regimes. Where Denmark, Finland, France, Sweden and the United Kingdom show the lowest costs and sometimes even gains, Portugal and Greece are confronted with costs that are more than twice the EU average. Most EU-10 countries show net gains for the six regimes. An exception is Cyprus, with costs that are always more than 1% of its GDP. Lithuania and Slovenia also show high costs for several regimes. Bulgaria and Romania almost always show very large gains.

For the EU 30% multilateral scenario, the abatement costs are approximately twice as high as for the EU 20% unilateral without CDM scenario. However, in the 30% scenario, the costs seem more evenly distributed; there are fewer countries with costs more than twice the EU average. Portugal, Greece, Cyprus and Lithuania are countries with very high costs for both EU reduction objectives and for all six regimes, while Bulgaria and Romania always show high net gains.

- **The 'Triptych' approach would seem to result in the most equally spread distribution of reduction efforts and abatement costs among all European countries. The approach also scores high in qualitative multi-criteria analyses.**

Given our assumptions for the different approaches, the *Triptych* approach takes a kind of central position in terms of differences in reduction targets between countries compared to the other regimes. The methodology has proven to be helpful in arriving at the EU-15 burden-sharing agreement for their joint Kyoto target. The revised approach presented here can be applied to the group of 27 European countries that are more diverse than the original EU-15 countries. The combination of convergence of per capita emissions in the domestic sectors with the flexibility for growing production with increasing efficiency (in industry and electricity) −accounting for structural differences− could be attractive to many European Parties. For this reason the *Triptych* approach provides a good prospect for a negotiation outcome based on compromises by all Parties.

In practice, regime proposals will be evaluated on the basis of a much wider set of considerations. This can be achieved through a qualitative multi-criteria analysis to identify relative strengths and weakness of the regime approaches examined on the basis of environmental criteria, political criteria, economic criteria and technical criteria. Earlier studies by Torvanger and Godal (1999), Höhne et al. (2003) and Den Elzen and Berk (2004) have shown that the *Triptych* approach achieves a high score for these criteria compared to the other international regimes, which also favour the approach

- **The agreement on the burden-sharing regime is more significant than the agreement on the overall EU reduction level.**

Our study shows that differences in emission reduction targets between European countries can be large; even the differences between approaches for a single country are quite large. For all European countries the difference in reductions between the various approaches aiming at the same agreed EU reduction objective (20% or 30%) is greater than the difference in the reduction between the EU overall objectives. Hence for these countries an agreement on the approach is more relevant than an agreement on the overall EU reduction level (20% or 30%).

- **For the EU 20% unilateral regimes the EU-15 countries are net buyers on the emissions trading market, while the EU-10 and Bulgaria and Romania are net sellers. Many EU-10 countries become small buyers for the EU 30% multilateral regime.**

For almost all regimes and overall reduction objectives, the EU-15 countries are net buyers on the international and internal EU market, while the EU-10 and EU-2 new countries are net sellers. The largest suppliers are Romania and Bulgaria, while the Czech Republic and Poland are also large suppliers. Spain is a large overall buyer. For the EU 30% reduction objective, emissions trading with countries outside the EU has almost doubled compared to the 20% unilateral with CDM scenario.

- **The United Kingdom's 2020 reduction target of 27–32% (compared to 1990 levels) is consistent with the range of reductions for the United Kingdom that is associated with the EU 20% reduction objective found in this study [23% – 29%], but lower than our United Kingdom range for the EU 30% target.**

- **The Netherlands' 2020 reduction target for greenhouse gases of 30% is outside the range resulting from various allocation approaches for meeting the 20% EU target [10% – 20% emission reduction]. However, it is inside the range for a 30% reduction [about 20% – 30% emission reduction].**

Several EU countries have announced national long-term emission targets that are ambitious, but that differ considerably. The United Kingdom government has adopted a legally binding reduction target of 60% reduction in CO_2 emissions by 2050, and a 26–32% reduction by 2020. The 2020 target corresponds with our United Kingdom reduction range associated with the EU 20% reduction objective for EU burden-sharing and ETS allocation under option 1 - *Present system*, However, it is outside our range associated with 30% reduction. This finding is also robust under option 2 - *EU burden-sharing with ETS allocation at EU level*. This results in slightly lower reductions for the United Kingdom compared to its option 1 reductions.

The Netherlands has announced a 2020 reduction target of 30%, which is higher than the ranges resulting from various allocation approaches under option 1 - *Present system* for meeting the 20% EU target (10–20%, excluding *Ability to pay*), but in line with the range under the overall EU 30% reduction objective (22–31%, excluding *Ability to pay*). Again, these findings are robust for the reductions under option 2 - *EU burden-sharing with ETS allocation at EU level*, i.e. 10-21% and 21-31% for the EU 20% and 30% reduction objective, respectively.

Germany has announced that it is willing to reduce emissions by 40% by 2020 if the EU as a whole agrees to reduce emissions by 30%. The reduction target of 40% is within our range of Germany's reduction targets for the EU 30% (36–42%, excluding *Multi-criteria*). Evidently, Germany's target is even more ambitious than our EU 20% reduction range (25–35%, excluding *Multi-criteria*).

- **Energy efficiency improvements represent by far the largest share in emission reductions, followed by fuel shift switch and non-CO_2.**

As already concluded, meeting the 20% EU reduction target will require major changes in the energy system. The EU-15 has the largest share in the overall 20% emission reduction, with 76% total (domestic) reduction, followed by the EU-10, and Bulgaria and Romania. Furthermore, most measures by far are CO_2-related (85%), while the largest share of the measures must be taken in the sector energy supply, followed by the household and the service sector. Energy efficiency improvements make the largest contribution, with around 50% of total greenhouse gas emission reductions. Fuel shifts (coal to natural gas) account for around 25% of total emission reductions. For most of the EU-10 countries the share of fuel shifts is even larger, due to the fact that countries' energy production sectors are relatively carbon-intensive and more inefficient compared to the EU-15. This study did not analyse the feasibility of the EU 20% renewables target, as the database for costs used in our modelling framework includes almost no biofuel measures and only a limited number of biomass reduction measures. For this reason, and our adoption of a cost-effective approach, we find a small percentage from renewables in the total reduction.

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Appendix A The description of the MAC-EU tool

The MAC-EU tool converts the data from the GENESIS database (Blok et al., 2001) into marginal abatement cost (MAC) data for the FAIR model (Den Elzen and Lucas, 2005). Figure A.1 illustrates the data flow of the MAC-EU tool.

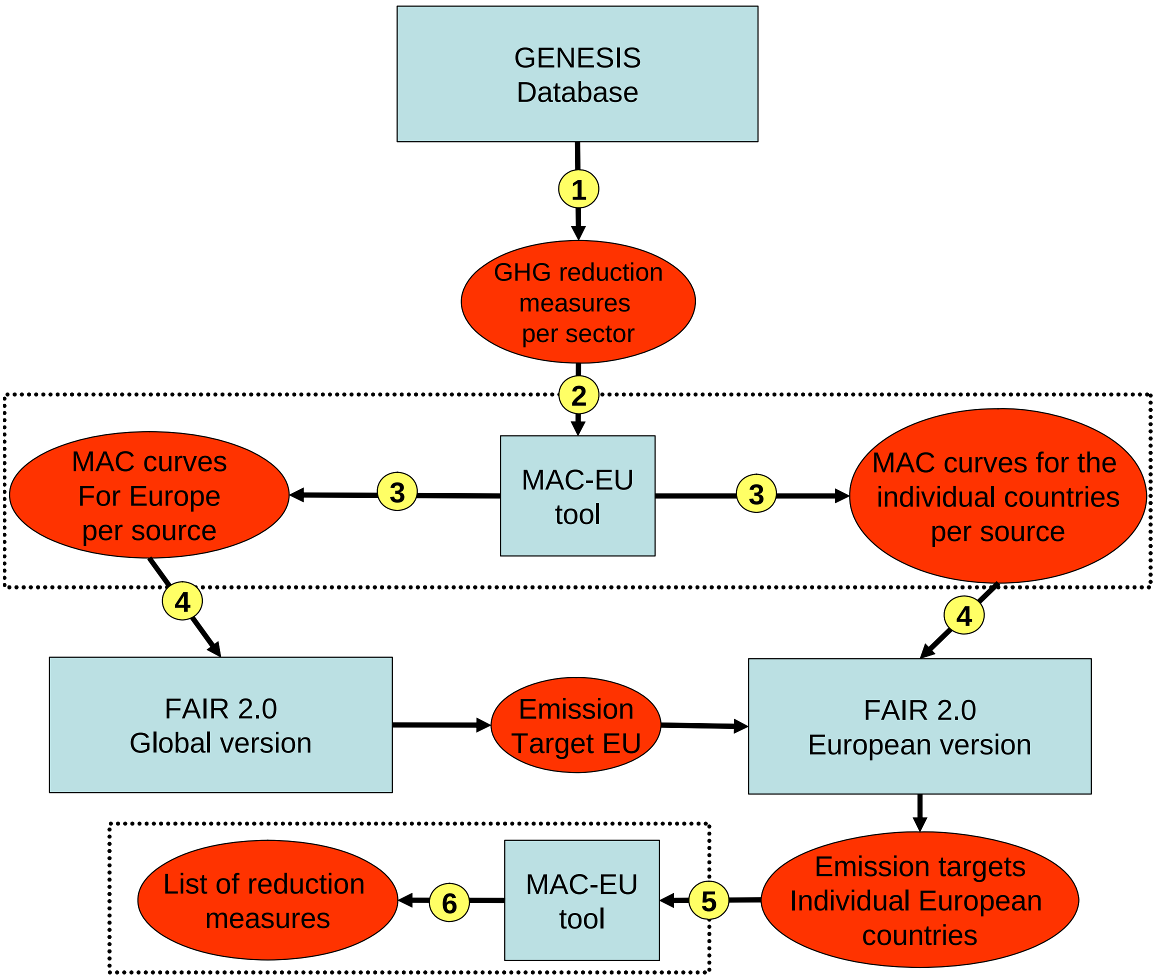

Figure A.1: Data flow from GENESIS to FAIR.

This section outlines the different steps (numbers in text correspond to the numbers in Figure A.1):

1. The GENESIS database generates Excel files with measures to reduce greenhouse gases for each main sector. Each GENESIS file contains data of the measures to reduce GHG emissions for the 30 EU countries.
2. The MAC-EU tool compares this GENESIS data with the LREM (long-range energy modelling) baseline data to determine which measures are already included in the baseline, and therefore need to be excluded from further calculations.
3. The MAC-EU tool creates MAC (marginal abatement cost) curves for the FAIR model, for Europe as a whole (for the FAIR 2.0 region model), and MAC curves for the individual EU countries (for the FAIR 2.0 EU model).

4. The FAIR instrument then calculates the emission targets for the individual European countries.
5. These emission targets are subsequently integrated back into the MAC-EU tool.
6. Finally, the MAC-EU tool determines and reports the reduction measures that European countries must take in order to achieve these reduction targets. These final two steps are not described here.

Step 1: the GENESIS files

The GENESIS model provides output files with greenhouse gas emission reduction measures, covering a total of nine sectors: agriculture, energy supply, fossil fuel extraction, households, industry, services, transport, waste and other, for three pollutants, i.e. CO_2, CH_4, N_2O and the F-gases for 30 European countries. For each country 228 measures are defined for both 2020 and 2030, which makes a total of 13,680 measures (Table A.1).

Table A.1: Number of measures per sector and per pollutant.

	Pollutant						
Sector	CO_2	CH_4	N_2O	HFC	PFC	SF_6	Total
Agriculture		432	54				486
Energy supply	2.700		108				2.808
Fossil fuel extraction		1.242					1.242
Households	864			216			1.080
Industry	2.862		108	756	378	108	4.212
Other				54			54
Services	702			216			918
Transport	756			216			972
Waste		540					540
Total	7.884	2.214	270	1.458	378	108	12.312

Table A.1 shows the associated emission level for each measure. This level is based on a frozen efficiency emission level and is known as the GENESIS emission level.

Step 2: from frozen efficiency to baseline

The 13,680 measures and the related GENESIS emission level are imported into the MAC-EU tool. As mentioned earlier, MAC-EU adds up all the GENESIS emission levels to sector levels and subsequently compares these levels with the PRIMES emission levels (Table A.2).

Table A.2: Emission levels and reduction potentials in GENESIS.

Sector	Emission levels 2020			Emission levels 2030		
	GENESIS	PRIMES	Reduction potential	GENESIS	PRIMES	Reduction potential
	$MtCO_2eq$	$MtCO_2eq$	$MtCO_2eq$	$MtCO_2eq$	$MtCO_2eq$	$MtCO_2eq$
Agriculture	468	504	53	441	476	50
Energy supply	1702	1671	650	1927	1886	742
Fossil fuel extraction	86	94	17	83	91	17
Households	538	511	919	531	502	880
Industry	671	748	184	667	756	187
Other	9	24	9	10	25	10
Services	273	246	252	289	261	254
Transport	1093	1291	266	1057	1344	256
Waste	87	121	61	65	98	46
TOTAL	**4927**	**5211**	**2411**	**5071**	**5440**	**2441**

It's interesting to see that the total reduction potential of households is far greater than the actual emissions from that sector. This is because only the *direct* emissions are counted as sector emissions, whereas the *indirect* emissions from electricity production are included in the energy supply sector. However, the *potential* also contains the measures related to the *indirect* emissions. As can be seen from Table A.2, the PRIMES emission level is not always higher than the frozen technology level from GENESIS. Possible reasons include:

1. Inconsistency of sector definition between GENESIS and PRIMES;
2. Ad 2 PRIMES assumes a trend towards 'carbonisation' in some sectors

Ad 1 Inconsistency in sector definitions

During this study it became clear that certain PRIMES sub-sectors were not included in the GENESIS database. The next table contains a list of the sub-sectors, under both PRIMES and GENESIS, which are considered equal. The PRIMES sub-sectors that are not represented in the GENESIS data are coloured red. The PRIMES emission levels for these sectors were added to the sector total of the GENESIS emission levels. Table A.3 contains a list of sub-sectors and sectors under PRIMES and GENESIS that are considered equal. The PRIMES emission levels for these sectors were added to the sector total of the GENESIS emission levels (Table A.4). However, even with these adjustments, the PRIMES levels for the sectors agriculture, fossil fuel extraction, waste and other, are still higher than the GENESIS level. But this will not have significant effects on the results, because these differences are relatively small.

Ad 2 PRIMES assumes a trend towards 'carbonisation' in some sectors

As previously indicated, a main characteristic of the LREM baseline is the fact that the CO_2 emissions increase more rapidly than primary energy use consumption. This represents a structural change away from the historic trend towards 'decarbonisation'. This means that it's possible that the difference between frozen efficiency (GENESIS) and improved efficiency (PRIMES) is compensated by a shift towards a more carbon-intensive fuel mix.

TableA.3: Sector comparison PRIMES and GENESIS. The PRIMES sub-sectors that are not represented in the GENESIS data are coloured grey.

Pollutant	MAC-EU sector	Sub-sector PRIMES	Sub-sector GENESIS
CO_2	Energy supply	District heating	
		Energy branch	Refineries
		Electricity-steam production	Energy (incl. CHP)
		New fuels (hydrogen etc.) production	
	Households	Households	Households
	Industry	Food, drink and tobacco	Food, beverages and tobacco
		Engineering	Building materials
		Iron and steel	Iron and steel
		Non-ferrous metals	Non-ferro
		Non-metallic minerals	
		Other industries	Other industry
		Chemicals	Chemicals
		Textiles	
		Paper and pulp	Pulp and paper
	Services	Tertiary	Tertiary
	Transport	Inland navigation	
		Rail	
		Aviation	
		Road transport	Freight
			Cars
CH_4	Agriculture	ENTERIC FERMENTATION	Enteric
		OTHER AGRICULTURE	
		MANURE MANAGEMENT	Manure
	Energy supply	OTHER FUEL COMBUSTION	
	Fossil fuel extraction	FUGITIVE - OIL & GAS	Oil and gas
		FUGITIVE – COAL	Solid fuels
	Industry	INDUSTRIAL PROCESSES	
	Other	OTHER	
	Transport	TRANSPORT	
	Waste	WASTE-WATER	
		LANDFILL	LANDFILL
		WASTE INCINERATION	
		WASTE OTHER	
N_2O	Agriculture	MANURE MANAGEMENT	
		OTHER AGRICULTURE	
		SOILS	SOILS
	Energy supply	OTHER FUEL COMBUSTION	Energy (incl. CHP)
	Fossil fuel extraction	FUGITIVE	
	Industry	CHEMICAL INDUSTRY	Chemical industry
		INDUSTRIAL PROCESSES	
	Other	SOLVENT	
		OTHER	
		LUC	
	Transport	TRANSPORT	
	Waste	WASTE	
HFC	Industry	Foams-XPS	Foams-XPS
		Foams-PU	Foams-PU
		HFC-23 production	HFC-23 production
		Solvents	Solvents
		Refrigeration airco	Refrigeration airco
		MDI	MDI
	Other	Aerosols	Aerosols

Pollutant	MAC-EU sector	Sub-sector PRIMES	Sub-sector GENESIS
		Fire-fighting HFC	Fire-fighting HFC
	Transport	MAC	MAC
PFC	Industry	Aluminium production	Aluminium production
		Semiconductors	Semiconductors
	Other	Fire-fighting PFC	Fire-fighting PFC
SF_6	Industry	ElecT&D	ElecT&D
		GIS_gear	GIS_gear
		Magnesium production	Magnesium production

Table A.4: GHG emissions included in PRIMES but excluded in GENESIS for the 30 European countries.

Sector	2020			2030		
	Emission level GENESIS	Not included in GENESIS	Corrected emission level	Emission level GENESIS	Not included in GENESIS	Corrected emission level
Agriculture	468	29	497	441	28	469
Energy supply	1702	12	1714	1927	11	1938
Fossil fuel extraction	86	0	86	83	0	83
Households	538	0	538	531	0	531
Industry	671	171	842	667	176	843
Other	9	10	19	10	10	20
Services	273	0	273	289	0	289
Transport	1093	244	1337	1057	270	1327
Waste	87	26	113	65	26	91
Total	**4927**	**537**	**5464**	**5071**	**522**	**5593**

Table A.5: Reduction potentials after cutting off.

	2020 $MtCO_2$-eq.		2030 $MtCO_2$-eq.	
	From GENESIS	**After cutting off**	**From GENESIS**	**After cutting off**
Agriculture	53	52	50	49
Energy supply	650	584	742	673
Fossil fuel extraction	17	17	17	17
Households	919	894	880	854
Industry	184	97	187	102
Other	9	9	10	9
Services	252	224	254	226
Transport	266	161	256	174
Waste	61	61	46	46
TOTAL	**2411**	**2099**	**2441**	**2150**

Table A.6: Reduction potentials for 27 European countries.

	2020		2030	
	GENESIS potential	Potential after cut off	GENESIS potential	Potential after cut off
Sweden	62	39	75	53
Slovenia	10	8	10	8
Slovak Republic	24	19	25	20
Romania	65	55	66	55
Portugal	35	32	37	34
Poland	156	135	155	133
The Netherlands	95	90	102	97
Malta	2	2	2	2
Latvia	7	6	7	6
Luxembourg	5	4	5	5
Lithuania	13	12	14	13
Italy	265	238	263	242
Ireland	31	29	30	29
Hungary	40	36	44	41
Greece	52	48	51	48
Great Britain	318	280	323	293
France	307	280	302	274
Finland	37	22	38	24
Estonia	8	8	8	8
Spain	172	149	176	153
Denmark	29	26	29	27
Germany	474	404	465	404
Czech Republic	53	39	54	41
Cyprus	4	3	4	4
Bulgaria	36	31	35	30
Belgium	69	63	76	70
Austria	42	39	41	38
TOTAL	**2411**	**2099**	**2441**	**2150**

Step 3: creating the curves

The difference between the (corrected) GENESIS emission level and the PRIMES emission level is 208 $MtCO_2$.eq. (5464 minus 5211) in 2020. The GENESIS potential should therefore be decreased by 253 $MtCO_2$.eq., to the value of 2158 $MtCO_2$-eq. (2411 minus 253) following the 'cut off algorithm' mentioned in chapter 2. Table A.5 makes clear that the cut off method does not provide the expected reduction potential of 2158 $MtCO_2$-eq. in 2020. This is due to the reason mentioned above: if the GENESIS level is *below* the PRIMES level (which can be due to 'decarbonisation'), then a negative gap has to be cut off, which the algorithm does not take into account. Table A.6 summarises the results of this exercise for the individual countries.

The following overview includes a list of measures that were cut off for the year 2020.

Energy supply

Pollutant	Measure	GENESIS ($MtCO_2$-eq.)	Amount 'cut off' ($MtCO_2$-eq.)
CO_2	New capacity by natural gas-fired combined cycles	253.6	26.8
CO_2	Solid biomass	52.0	19.9
CO_2	CHP - Paper and pulp	4.7	3.3
CO_2	CHP - Residential - Small	5.7	2.4
CO_2	CO_2 removal	45.7	2.2
CO_2	CHP - Residential - Large	5.7	1.9
CO_2	CHP - Tertiary - Small	3.2	1.3
CO_2	Wind offshore	26.8	1.2

Households

Pollutant	Measure	GENESIS ($MtCO_2$-eq.)	amount 'cut off' ($MtCO_2$-eq.)
CO_2	Miscellaneous options (cheap tranche)	74.0	12.6
CO_2	Cold appliances: Best Practice	18.4	12.3

Industry

Pollutant	Measure	GENESIS ($MtCO_2$-eq.)	amount 'cut off' ($MtCO_2$-eq.)
CO_2	Miscellaneous I (Low cost tranche)	34.3	16.2
CO_2	Miscellaneous II (High cost tranche)	32.8	8.2
CO_2	Miscellaneous	9.2	7.3
SF_6	Magnesium production: use of SO2 as protection gas	15.6	6.1
HFC	Foams XPS: carbon dioxide	14.3	4.3
CO_2	Food. beverages and tobacco - micellaneuous I (Low cost tranche)	5.6	4.2
HFC	Foam PU-one component: hydrocarbons	12.6	4.0
N_2O	Industrial processes Adipic acid	6.8	4.0
CO_2	Miscellaneous - building materials	4.1	3.7
CO_2	Use of waste derived fuels	3.7	3.3
CO_2	Food. beverages and tobacco miscellaneous II (High cost tranche)	7.8	3.1
N_2O	Industrial processes Nitric acid	6.8	2.9
CO_2	Thin slab casting techniques	8.7	2.6
CO_2	Improved process control	1.5	1.4
CO_2	De-bottle-necking	1.3	1.2
HFC	Foam PU-spray: water	5.0	1.2
CO_2	Improving wet process kilns	1.3	1.1
CO_2	Other non-ferro metals - miscellaneous	3.8	1.1
HFC	Oxidation of HFC-23	2.3	1.1
HFC	Industrial refrigeration: hydrocarbons and NH3	1.6	1.1

Services

Pollutant	Measure	GENESIS ($MtCO_2$-eq.)	amount 'cut off' ($MtCO_2$-eq.)
CO_2	Lighting: Best Practice level 2	62.2	23.4
CO_2	Building Energy Management Systems (BEMS): electricity	3.7	3.5

Transport

Pollutant	Measure	GENESIS ($MtCO_2$-eq.)	amount 'cut off' ($MtCO_2$-eq.)
CO_2	Petrol to Diesel shift	47.7	17.9
CO_2	Engine improvement	28.0	16.6
CO_2	Driver Training - Heavy Goods Vehicles (HGV) Drivers	24.6	11.1
CO_2	Rolling Resistance	18.7	11.0
CO_2	Variable Valve Lift Timing + Cylinder Deactivation	23.9	10.3
CO_2	Aerodynamics - Cab Roof Fairing	18.2	9.5
CO_2	Advanced Gasoline Direct Injection (advanced: "DISC")	47.7	7.4
CO_2	Aerodynamics - Cab Roof Deflector	11.8	5.6
CO_2	Basic package - Diesel cars	11.9	4.8
HFC	Mobile air conditioning: recovery	10.0	3.6
HFC	Mobile air conditioning: leakage red.	6.3	2.4
HFC	Mobile air conditioning: carbon dioxide	3.3	1.4
CO_2	Lightweight Interior components - Petrol cars	2.9	1.3

Step 4: converting the curves for FAIR

The algorithms that determine those measures are already (partly) implemented in the PRIMES scenario and have been sketched out in the above section. With this knowledge the cost curves for the six FAIR sectors were created, both for Europe as a whole and for the 30 European countries individually. Costs are expressed in terms of ‘costs for the end user’.

Figure A.2 shows the results for eight different countries and Europe as a whole for the sector CO_2 industry and energy.

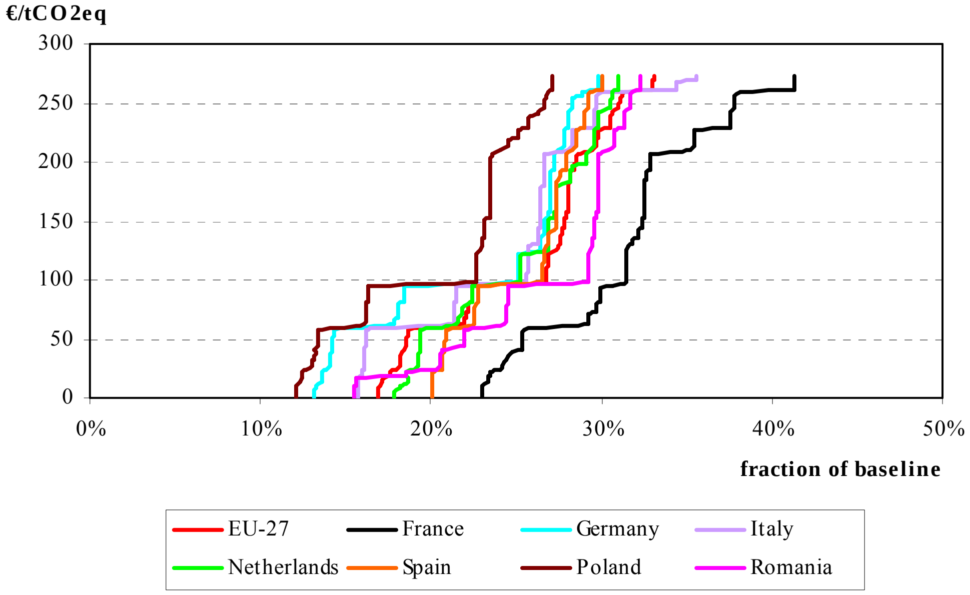

Figure A.2: MAC curves for seven European countries, CO_2 industry-energy sector in 2020.

The following items are worth noting:

1. A large amount of the reduction comes from 'no-regret' measures.
2. The different curves are similarly shaped.
3. Large reductions can be achieved with costs of around €220/tC-eq. and €360/tC-eq.

A large amount of the reduction comes from ' no-regret' measures

Even after the application of the 'cut off' algorithm a large number of the measures are 'no-regret' measures: 714 $MtCO_2$-eq. of CO_2, 31 $MtCO_2$-eq. CH_4 and 26 $MtCO_2$-eq. N_2O can be reduced in 2020 from the baseline, with costs that are equal to or less than zero. This corresponds with 15% of the baseline, and 38% of the total potential. Table A.7 lists the most significant costs for 'no-regret' measures. For a detailed description of these measures, see Blok et al. (2001).

Table A.7: Summary of the most important cost-effective measures in 2020 for Europe.

Sector	Sub-sector	Measure	Potential ($MtCO_2$-eq)	Pollutant	Reduction costs
Energy supply	Energy (incl. CHP)	New capacity by natural gas-fired combined cycles	207	CO_2	0
Households	Households	Miscellaneous options (moderate costs tranche)	74	CO_2	-170
Households	Households	Miscellaneous options (cheap tranche)	54	CO_2	-172
Services	Tertiary	Office equipment: Best Practice	52	CO_2	-101
Households	Households	Avoid standby consumption	51	CO_2	-157
Households	Households	Very energy-efficient refrigerators and freezers	37	CO_2	-149
Services	Tertiary	Lighting: Best Practice level 2	34	CO_2	-134
Services	Tertiary	Lighting: Best Practice level 1	32	CO_2	-97
Energy supply	Energy (incl. CHP)	Solid biomass	31	CO_2	-30
Services	Tertiary	Building Energy Management Systems: space heating and cooling	29	CO_2	-131
Agriculture	SOILS	Agriculture Common Agricultural Policy Reforms Set-Aside	26	N_2O	0
Households	Households	Lighting: Best Practice	23	CO_2	-160

The different curves are similarly shaped

The curves for the different countries are very similarly shaped. This is the consequence of the generic character of the GENESIS algorithms. Every country has the same set of measures and each measure has, globally, the same input values for each country. This means that every measure has the same costs for each country. The position of a curve in the graph is therefore mainly determined by the relative height of the emission to which the measures are applied.

Around €220/tC-eq. and €360/tC-eq. large reductions are defined

The measures that cause the large reductions around €220/*tCO_2-eq.* are:

Table A.8: Measures with costs approx. €200/tCO_2-eq. in 2020.

Sector	Measure	Reduction ($MtCO_2$)	Costs €/tC-eq. *(€/tCO_2-eq.)*
Households	Advanced heating systems: condensing boilers	96	221 (60)
Energy supply	Carbon Capture and Storage	40	212 (58)

<u>Description of 'Advanced heating systems: condensing boilers'. Source: Blok et al. (2001).</u>

A considerable amount of the fossil fuel combustion products consist of water vapour. Condensing boilers use a heat exchanger to condense that water vapour and extract the heat. Hence, the latent heat of the water vapour is usefully applied and the efficiency of the boiler is improved. The costs of this option vary considerably, depending on the market segment where the heat pump is applied (e.g. existing or new residence, within a project or not, large/small heat requirements of the residence).

<u>Description of 'Carbon Capture and Storage' Source: Blok et al. (2001).</u>

Carbon Capture and Storage is a technically feasible option. Nevertheless, substantial research is required to better understand the impact, environmental consequences and risks of underground storage. Improving recovery technology may substantially lower the costs of Carbon Capture and Storage. The technology can be applied to power plants and a broad range of industries. In this way hydrogen can also be produced carbon-free and subsequently used for various applications, e.g. to feed into the natural gas pipelines, to produce electricity, or in the longer term, can be used as a transport fuel. The measure that causes large reductions around €350/tC-eq. is:

Table A.9: Measures with costs approx. €350/tC-eq. in 2020

Sector	Measure	Reduction ($MtCO_2$-eq.)	Costs €/tC *(€/tCO_2-eq.)*
Energy Supply	Replacement of capacity by natural gas-fired combined cycles	178	356 (97)

Description of: 'Replacement of capacity by natural gas-fired combined cycles'. Source: Blok et al. (2001).

One way of reducing CO_2 emissions is to switch from a fuel with a high carbon content to one with a lower carbon content, e.g. from coal to natural gas. Capacity with higher efficiency can be installed at the same time. As both effects often occur at the same time, Ecofys defined this as one option: Substitution. Implementation of such a measure depends on many factors, such as costs, political willingness, but also on the availability of natural gas. In principle, power plants can be also be converted or replaced before the end of their technical lifetime. This option refers to: replacement of fossil-fuelled power plants (both early retirement of coal-fired plants and plants at the end of their lifetimes) by modern natural gas-fuelled combined cycles. The replacement is calculated on basis of the average yearly replacement rate and the period to go towards 2030.

Appendix B Contribution of the sectors to the total domestic abatement

		Emission 2020 ($MtCO_2$-eq.)	Reduction potential ($MtCO_2$-eq.)	EU 20% unilateral without CDM	EU 30% in a multilateral regime
Austria					
	Agriculture	8.10	0.90	9.0%	9.0%
	Energy supply	21.80	5.00	14.9%	14.9%
	Fossil fuel extraction	0.10	0.00	8.3%	8.3%
	Households	8.30	18.20	69.4%	80.4%
	Industry	14.70	3.50	21.4%	21.4%
	Other	0.60	0.30	44.8%	44.8%
	Services	3.30	3.30	76.9%	76.9%
	Transport	25.90	5.40	17.7%	17.7%
	Waste	4.20	2.20	16.4%	16.4%
Belgium					
	Agriculture	12.10	1.40	9.4%	9.4%
	Energy supply	35.10	8.70	12.3%	12.3%
	Fossil fuel extraction	0.90	0.20	17.0%	17.0%
	Households	18.30	32.30	60.4%	70.9%
	Industry	33.70	5.80	15.3%	15.3%
	Other	0.60	0.20	40.3%	40.3%
	Services	8.70	6.50	53.0%	53.0%
	Transport	34.40	6.80	15.4%	15.4%
	Waste	1.90	0.80	14.4%	14.4%
Bulgaria					
	Agriculture	21.30	1.60	7.1%	7.2%
	Energy supply	30.50	17.00	40.6%	41.0%
	Fossil fuel extraction	1.40	0.30	16.4%	17.9%
	Households	1.30	7.00	184.4%	193.8%
	Other	0.20	0.10	68.8%	68.8%
	Services	1.40	1.60	92.1%	95.7%
	Transport	8.30	1.40	5.4%	9.5%
	Waste	4.30	2.10	15.4%	17.1%
Cyprus					
	Agriculture	0.70	0.10	7.6%	7.6%
	Energy supply	3.60	1.50	22.5%	22.5%
	Households	0.30	0.90	170.4%	188.9%
	Other	0.00	0.00	50.0%	50.0%
	Services	0.20	0.30	100.0%	126.7%
	Transport	3.60	0.50	6.6%	11.0%
	Waste	0.40	0.30	19.5%	24.4%
Czech Republic					
	Agriculture	7.70	0.80	9.6%	9.6%
	Energy supply	48.60	12.60	11.7%	11.7%
	Fossil fuel extraction	4.20	0.60	11.8%	11.8%
	Households	6.10	13.80	64.0%	69.6%
	Industry	25.60	3.40	11.6%	11.6%
	Other	1.10	0.70	62.8%	62.8%
	Services	4.80	4.60	66.1%	66.1%
	Transport	17.20	2.20	9.4%	9.8%
	Waste	1.90	0.70	12.5%	12.5%

		Emission 2020 ($MtCO_2$-eq.)	Reduction potential ($MtCO_2$-eq.)	EU 20% unilateral without CDM	EU 30% in a multilateral regime
Denmark					
	Agriculture	11.50	1.20	9.7%	9.7%
	Energy supply	20.70	12.70	24.0%	24.0%
	Households	3.20	5.60	122.8%	122.8%
	Industry	6.20	0.60	9.7%	9.7%
	Other	0.20	0.20	75.0%	75.0%
	Services	3.20	2.50	63.2%	63.8%
	Transport	15.60	3.00	11.2%	11.5%
	Waste	0.80	0.50	20.7%	22.0%
Estonia					
	Agriculture	1.20	0.10	10.2%	10.2%
	Energy supply	8.50	4.70	34.4%	34.5%
	Fossil fuel extraction	1.30	0.30	15.9%	17.4%
	Households	0.30	1.20	193.9%	200.0%
	Services	0.30	0.50	135.7%	142.9%
	Transport	2.70	0.50	8.9%	9.2%
	Waste	1.10	0.60	15.2%	17.0%
Finland					
	Agriculture	5.70	0.60	9.4%	9.4%
	Households	2.90	7.90	137.5%	137.5%
	Industry	16.20	3.00	15.4%	16.9%
	Other	0.20	0.10	56.5%	56.5%
	Services	1.80	3.60	179.9%	179.9%
	Transport	15.50	2.00	3.3%	4.1%
	Waste	2.20	1.20	19.5%	19.9%
France					
	Agriculture	98.30	11.10	9.7%	9.9%
	Energy supply	103.80	32.70	21.4%	21.8%
	Fossil fuel extraction	3.20	0.70	15.6%	16.6%
	Households	60.30	131.90	100.2%	102.5%
	Industry	106.40	20.80	16.7%	18.0%
	Other	7.70	1.20	15.0%	15.0%
	Services	39.50	40.90	79.3%	79.3%
	Transport	183.60	35.20	10.2%	12.1%
	Waste	11.30	5.50	15.8%	17.6%
Germany					
	Agriculture	64.90	6.30	9.1%	9.1%
	Energy supply	375.60	127.20	12.5%	19.1%
	Fossil fuel extraction	15.00	2.50	14.4%	14.9%
	Households	110.00	188.80	66.0%	66.0%
	Industry	125.00	16.30	11.2%	11.3%
	Other	3.40	1.00	30.5%	30.5%
	Services	57.80	44.80	56.8%	61.4%
	Transport	7.60	4.70	22.0%	28.6%
	Waste	7.70	0.80	9.6%	9.6%
Greece					
	Agriculture	9.40	1.00	9.5%	9.6%
	Energy supply	60.90	20.80	22.3%	25.8%
	Fossil fuel extraction	1.60	0.20	9.4%	9.4%
	Households	7.80	18.10	97.4%	100.3%
	Other	0.20	0.10	50.0%	50.0%
	Services	5.70	2.90	29.4%	32.2%
	Transport	30.50	3.60	5.0%	5.5%
	Waste	3.60	1.90	16.9%	24.4%

		Emission 2020 ($MtCO_2$-eq.)	Reduction potential ($MtCO_2$-eq.)	EU 20% unilateral without CDM	EU 30% in a multilateral regime
Hungary					
	Agriculture	15.00	1.20	7.6%	7.6%
	Energy supply	24.10	10.90	31.9%	31.9%
	Fossil fuel extraction	6.60	1.30	15.0%	15.0%
	Households	9.30	14.40	39.4%	45.4%
	Other	0.30	0.20	65.4%	65.4%
	Services	6.80	5.00	46.2%	46.2%
	Transport	15.70	2.10	6.4%	6.4%
	Waste	3.00	1.20	12.5%	12.5%
Ireland					
	Agriculture	20.00	2.00	9.5%	9.5%
	Energy supply	17.30	8.60	26.6%	32.0%
	Fossil fuel extraction	0.30	0.00	3.2%	3.2%
	Households	5.60	10.30	84.2%	84.2%
	Industry	7.20	1.10	14.6%	15.1%
	Other	0.10	0.00	35.7%	35.7%
	Services	4.30	3.20	47.2%	51.2%
	Transport	17.80	2.90	8.8%	12.5%
	Waste	0.90	0.50	21.1%	27.8%
Italy					
	Agriculture	38.40	3.90	8.9%	8.9%
	Energy supply	151.30	53.10	21.0%	21.0%
	Fossil fuel extraction	7.80	1.70	15.4%	15.4%
	Households	79.40	134.50	32.6%	45.1%
	Other	0.50	0.30	64.6%	64.6%
	Services	10.00	16.50	147.1%	147.1%
	Transport	144.20	24.70	16.0%	16.0%
	Waste	8.80	3.80	14.1%	14.1%
Latvia					
	Agriculture	2.20	0.20	9.0%	9.0%
	Energy supply	4.10	2.50	40.8%	41.0%
	Fossil fuel extraction	0.30	0.00	3.3%	3.3%
	Households	0.60	1.20	88.7%	98.4%
	Industry	1.50	0.00	0.7%	1.3%
	Services	0.40	0.60	109.1%	115.9%
	Transport	3.90	0.80	10.4%	14.8%
	Waste	0.90	0.40	12.8%	14.0%
Lithuania					
	Agriculture	3.30	0.30	9.2%	9.5%
	Energy supply	11.40	5.90	37.2%	37.7%
	Fossil fuel extraction	0.60	0.20	25.0%	28.3%
	Households	1.70	2.30	47.4%	53.8%
	Industry	4.20	0.30	6.5%	6.5%
	Other	0.00	0.00	100.0%	100.0%
	Services	0.50	0.70	119.1%	125.5%
	Transport	6.40	1.20	7.2%	15.3%
	Waste	1.30	0.80	21.7%	25.6%
Luxem-burg					
	Agriculture	0.50	0.00	8.2%	8.2%
	Energy supply	1.70	0.40	11.4%	11.4%
	Households	1.50	2.30	19.9%	28.5%
	Other	0.10	0.00	50.0%	50.0%
	Services	0.10	0.20	250.0%	250.0%
	Transport	7.40	1.30	8.9%	8.9%
	Waste	0.10	0.00	14.3%	14.3%

		Emission 2020 ($MtCO_2$-eq.)	Reduction potential ($MtCO_2$-eq.)	EU 20% unilateral without CDM	EU 30% in a multilateral regime
Malta					
	Energy supply	2.10	0.90	22.9%	25.7%
	Households	0.10	0.20	158.3%	158.3%
	Industry	0.10	0.00	20.0%	20.0%
	Services	0.10	0.10	240.0%	240.0%
	Transport	1.50	0.10	4.8%	7.5%
	Waste	0.10	0.10	16.7%	25.0%
Poland					
	Agriculture	28.00	2.30	8.0%	8.0%
	Energy supply	188.20	58.90	17.9%	17.9%
	Fossil fuel extraction	18.50	2.90	13.4%	13.4%
	Households	31.10	40.50	34.1%	34.1%
	Industry	51.70	3.30	5.1%	5.1%
	Other	1.50	0.90	63.9%	63.9%
	Services	19.20	11.10	37.0%	37.0%
	Transport	46.50	5.50	0.6%	4.0%
	Waste	17.70	9.70	18.4%	19.6%
Portugal					
	Agriculture	12.00	1.40	9.2%	9.3%
	Energy supply	31.90	11.70	27.7%	29.1%
	Households	4.20	9.80	72.0%	72.0%
	Other	0.00	0.00	33.3%	33.3%
	Services	4.30	4.30	79.7%	82.3%
	Transport	30.20	3.60	5.2%	7.3%
	Waste	3.60	1.40	12.6%	17.1%
Romania					
	Agriculture	16.10	1.80	9.8%	9.8%
	Energy supply	49.70	25.50	39.2%	39.4%
	Fossil fuel extraction	11.20	2.30	16.4%	17.2%
	Households	14.10	17.00	33.5%	33.5%
	Industry	15.90	0.30	0.4%	0.9%
	Other	0.40	0.10	27.0%	27.0%
	Services	3.40	1.80	33.8%	36.2%
	Waste	13.20	6.70	18.1%	23.4%
Slovak Republic					
	Agriculture	4.20	0.40	9.0%	9.0%
	Energy supply	21.00	7.70	23.3%	26.7%
	Fossil fuel extraction	1.00	0.10	7.7%	7.7%
	Households	3.70	6.30	68.9%	68.9%
	Industry	8.10	0.50	3.5%	4.6%
	Services	1.30	2.40	141.7%	155.1%
	Transport	1.60	0.50	10.0%	14.4%
	Waste				
Slovenia		2.20	0.20	8.3%	8.3%
	Agriculture	7.10	3.40	35.1%	40.8%
	Energy supply	0.10	0.00	7.1%	7.1%
	Fossil fuel extraction	1.40	2.60	68.6%	68.6%
	Households	2.60	0.10	1.9%	2.3%
	Industry	0.10	0.10	53.8%	53.8%
	Other	1.10	0.90	50.9%	58.0%
	Services	1.10	0.60	18.9%	24.5%
	Waste	4.20	0.40	9.0%	9.0%

		Emission 2020 ($MtCO_2$-eq.)	Reduction potential ($MtCO_2$-eq.)	EU 20% unilateral without CDM	EU 30% in a multilateral regime
Spain					
	Agriculture	43.50	5.10	8.5%	9.5%
	Energy supply	119.10	58.90	33.2%	35.7%
	Fossil fuel extraction	1.60	0.30	15.1%	15.1%
	Households	27.40	43.50	54.0%	63.2%
	Industry	63.10	2.40	1.9%	2.0%
	Other	2.30	1.30	57.1%	57.1%
	Services	16.40	15.00	61.2%	68.0%
	Transport	138.00	18.70	12.5%	12.8%
	Waste	11.00	4.10	12.2%	12.2%
Sweden					
	Agriculture	9.40	0.90	9.2%	9.3%
	Households	2.50	22.90	621.7%	621.7%
	Industry	11.10	1.60	10.4%	11.5%
	Other	0.30	0.10	36.0%	36.0%
	Services	3.50	8.60	228.1%	228.1%
	Transport	25.80	3.90	5.4%	5.6%
	Waste	2.00	1.20	19.2%	19.7%
The Nether-lands					
	Agriculture	16.20	1.80	9.5%	9.7%
	Energy supply	68.20	23.90	19.8%	20.0%
	Fossil fuel extraction	4.20	0.90	16.1%	18.0%
	Households	22.10	28.30	49.8%	49.8%
	Industry	37.20	9.60	24.1%	24.4%
	Other	2.50	0.60	24.3%	24.3%
	Services	20.00	10.60	50.7%	52.0%
	Transport	56.40	10.10	10.0%	13.3%
	Waste	6.80	4.20	20.0%	22.2%
United Kingdom					
	Agriculture	52.20	5.30	9.7%	9.7%
	Energy supply	209.50	65.20	20.0%	20.0%
	Fossil fuel extraction	14.10	2.80	15.4%	16.1%
	Households	87.30	132.00	62.8%	62.8%
	Industry	92.20	24.20	25.3%	25.3%
	Other	2.10	1.40	67.6%	67.6%
	Services	27.90	31.60	88.2%	90.5%
	Transport	180.50	12.10	0.0%	0.5%
	Waste	10.00	5.10	18.3%	18.3%

Appendix C Contribution of the different reduction measures in total domestic abatement

Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM	Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM
Austria				***Finland***			
	CCS	2.4%	2.3%		Fuel shift		0.8%
	Fuel shift	6.6%	6.4%		Savings & CHP	77.2%	77.0%
	Non-CO_2	27.7%	26.6%		Non-CO_2	22.8%	22.2%
	Renewables	8.7%	8.4%				
	Savings & CHP	54.5%	56.3%				
Belgium				***France***			
	CCS	2.6%	2.5%		CCS	1.6%	1.5%
	Fuel shift	12.4%	11.7%		Fuel shift	10.6%	11.5%
	Non-CO_2	16.8%	15.9%		Non-CO_2	19.4%	19.2%
	Renewables	1.0%	0.9%		Renewables	0.4%	0.5%
	Savings & CHP	67.3%	69.1%		Savings & CHP	68.1%	67.2%
Bulgaria				***Germany***			
	CCS	4.0%	3.8%		CCS	5.3%	4.5%
	Fuel shift	22.6%	23.4%		Fuel shift	15.6%	25.0%
	Non-CO_2	14.0%	14.0%		Non-CO_2	11.6%	10.1%
	Renewables	37.4%	36.4%		Renewables	3.3%	2.8%
	Savings & CHP	22.0%	22.3%		Savings & CHP	64.1%	57.5%
Cyprus				***Greece***			
	CCS	5.0%	4.4%		CCS	5.6%	5.0%
	Fuel shift	29.1%	29.1%		Fuel shift	32.3%	36.4%
	Non-CO_2	9.5%	9.2%		Non-CO_2	8.3%	8.5%
	Renewables	9.5%	8.3%		Renewables	13.6%	12.2%
	Savings & CHP	46.9%	49.0%		Savings & CHP	40.2%	37.9%
Czech Republic				***Hungary***			
	CCS	6.7%	6.6%		CCS	3.4%	3.3%
	Fuel shift	10.0%	9.8%		Fuel shift	22.5%	21.8%
	Non-CO_2	22.0%	21.6%		Non-CO_2	15.5%	15.0%
	Renewables	13.3%	13.0%		Renewables	18.6%	18.1%
	Savings & CHP	47.9%	49.0%		Savings & CHP	40.0%	41.8%
Denmark				***Ireland***			
	CCS	3.5%	3.4%		CCS	2.7%	2.4%
	Fuel shift	12.4%	12.7%		Fuel shift	21.7%	20.6%
	Non-CO_2	17.9%	17.9%		Non-CO_2	16.4%	15.2%
	Renewables	12.0%	11.9%		Renewables	5.5%	10.1%
	Savings & CHP	54.3%	54.1%		Savings & CHP	53.7%	41.6%
Estonia				***Italy***			
	CCS	5.0%	4.9%		CCS	3.7%	3.4%
	Fuel shift	28.2%	27.8%		Fuel shift	25.6%	23.3%
	Non-CO_2	11.0%	11.6%		Non-CO_2	7.4%	6.7%
	Renewables	27.8%	27.2%		Renewables	6.7%	6.1%
	Savings & CHP	28.0%	28.5%		Savings & CHP	56.6%	60.5%

Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM
Latvia			
	CCS	3.5%	3.2%
	Fuel shift	19.6%	21.6%
	Non-CO_2	9.7%	9.2%
	Renewables	24.6%	22.7%
	Savings & CHP	42.5%	43.2%
Lithuania			
	CCS	3.7%	3.7%
	Fuel shift	23.5%	24.3%
	Non-CO_2	13.3%	13.0%
	Renewables	31.5%	28.4%
	Savings & CHP	28.0%	30.7%
Luxembourg			
	CCS	3.5%	3.2%
	Fuel shift	8.5%	7.7%
	Non-CO_2	11.3%	10.3%
	Renewables	0.7%	0.6%
	Savings & CHP	76.1%	78.1%
Malta			
	CCS	4.5%	5.1%
	Fuel shift	35.2%	38.4%
	Non-CO_2	3.4%	4.0%
	Renewables	12.5%	11.1%
	Savings & CHP	44.3%	41.4%
Poland			
	CCS	7.7%	7.5%
	Fuel shift	40.6%	41.7%
	Non-CO_2	16.7%	16.5%
	Renewables	2.4%	2.3%
	Savings & CHP	32.7%	31.9%
Portugal			
	CCS	4.3%	4.0%
	Fuel shift	30.9%	31.8%
	Non-CO_2	8.7%	8.9%
	Renewables	11.8%	13.3%
	Savings & CHP	44.3%	42.0%
Romania			
	CCS	3.7%	3.5%
	Fuel shift	20.8%	20.3%
	Non-CO_2	19.2%	21.3%
	Renewables	36.4%	35.3%
	Savings & CHP	20.0%	19.6%
Slovak Republic			
	CCS	5.5%	4.8%
	Fuel shift	27.8%	30.7%
	Non-CO_2	7.4%	7.1%
	Renewables	13.2%	11.6%
	Savings & CHP	46.1%	45.9%
Slovenia			
	CCS	4.0%	3.6%
	Fuel shift	22.7%	28.2%
	Non-CO_2	11.8%	11.9%
	Renewables	27.4%	24.4%
	Savings & CHP	34.1%	31.9%
Spain			
	CCS		2.9%
	Fuel shift	35.5%	32.8%
	Non-CO_2	12.2%	13.5%
	Renewables	11.4%	10.6%
	Savings & CHP	40.9%	40.2%
Sweden			
	Fuel shift		
	Non-CO_2	7.5%	7.7%
	Savings & CHP	92.5%	92.3%
The Netherlands			
	CCS	3.0%	2.9%
	Fuel shift	19.0%	20.7%
	Non-CO_2	24.0%	24.1%
	Renewables	0.6%	0.6%
	Savings % CHP	53.3%	51.7
United Kingdom			
	CCS	3.2%	3.1%
	Fuel shift	19.3%	19.4%
	Non-CO_2	17.4%	17.3%
	Renewables	4.0%	3.9%
	Savings & CHP	56.2%	56.3%

Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM
Austria			
	CCS	2.4%	2.3%
	Fuel shift	6.6%	6.3%
	Non-CO_2	27.7%	26.2%
	Renewables	8.7%	8.6%
	Savings & CHP	54.5%	56.7%
Belgium			
	CCS	2.6%	2.3%
	Fuel shift	12.4%	11.7%
	Non-CO_2	16.8%	15.9%
	Renewables	1.0%	0.9%
	Savings & CHP	67.3%	69.2%
Bulgaria			
	CCS	4.0%	3.2%
	Fuel shift	22.6%	31.0%
	Non-CO_2	14.0%	12.9%
	Renewables	37.4%	32.5%
	Savings & CHP	22.0%	20.4%
Cyprus			
	CCS	5.0%	3.9%
	Fuel shift	29.1%	35.7%
	Non-CO_2	9.5%	9.1%
	Renewables	9.5%	7.4%
	Savings & CHP	46.9%	43.9%
Czech Republic			
	CCS	6.7%	5.1%
	Fuel shift	10.0%	22.9%
	Non-CO_2	22.0%	17.2%
	Renewables	13.3%	10.0%
	Savings & CHP	47.9%	44.7%
Denmark			
	CCS	3.5%	2.9%
	Fuel shift	12.4%	23.9%
	Non-CO_2	17.9%	15.3%
	Renewables	12.0%	10.0%
	Savings & CHP	54.3%	48.0%
Estonia			
	CCS	5.0%	4.0%
	Fuel shift	28.2%	38.3%
	Non-CO_2	11.0%	10.7%
	Renewables	27.8%	22.3%
	Savings & CHP	28.0%	24.7%
Finland			
	Fuel shift	22.9%	4.2%
	Savings & CHP	77.1%	74.4%
	Non-CO_2		21.4%
France			
	CCS	1.6%	1.5%
	Fuel shift	10.6%	12.6%
	Non-CO_2	19.4%	19.0%
	Renewables	0.4%	0.5%
	Savings & CHP	68.1%	66.4%
Germany			
	CCS	5.3%	4.0%
	Fuel shift	15.6%	34.4%
	Non-CO_2	11.6%	8.9%
	Renewables	3.3%	2.4%
	Savings & CHP	64.1%	50.4%
Greece			
	CCS	5.6%	4.5%
	Fuel shift	32.3%	42.1%
	Non-CO_2	8.3%	7.8%
	Renewables	13.6%	11.1%
	Savings & CHP	40.2%	34.5%
Hungary			
	CCS	3.4%	2.8%
	Fuel shift	22.5%	23.6%
	Non-CO_2	15.5%	14.5%
	Renewables	18.6%	15.7%
	Savings & CHP	40.0%	43.3%
Ireland			
	CCS	2.7%	2.2%
	Fuel shift	21.8%	26.3%
	Non-CO_2	16.4%	13.5%
	Renewables	5.5%	11.4%
	Savings & CHP	53.7%	46.7%
Italy			
	CCS	3.7%	3.1%
	Fuel shift	25.6%	22.7%
	Non-CO_2	7.4%	6.9%
	Renewables	6.7%	6.1%
	Savings & CHP	56.6%	61.2%

Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM
Latvia			
	CCS	3.5%	3.0%
	Fuel shift	19.6%	25.1%
	Non-CO_2	9.7%	9.4%
	Renewables	24.6%	20.7%
	Savings & CHP	42.5%	41.9%
Lithuania			
	CCS	3.7%	3.4%
	Fuel shift	23.5%	30.1%
	Non-CO_2	13.3%	12.7%
	Renewables	31.5%	25.8%
	Savings & CHP	28.0%	27.9%
Luxembourg			
	CCS	3.5%	2.9%
	Fuel shift	8.5%	16.0%
	Non-CO_2	11.3%	9.7%
	Renewables	0.7%	0.6%
	Savings & CHP	76.1%	70.9%
Malta			
	CCS	4.5%	4.5%
	Fuel shift	35.2%	45.5%
	Non-CO_2	3.4%	3.6%
	Renewables	12.5%	9.8%
	Savings & CHP	44.3%	36.6%
Poland			
	CCS	7.7%	5.7%
	Fuel shift	40.6%	51.8%
	Non-CO_2	16.6%	13.9%
	Renewables	2.4%	1.8%
	Savings & CHP	32.7%	26.8%
Portugal			
	CCS	4.3%	3.8%
	Fuel shift	30.9%	32.7%
	Non-CO_2	8.7%	8.6%
	Renewables	11.8%	12.6%
	Savings & CHP	44.3%	42.4%
Romania			
	CCS	3.7%	
	Fuel shift	20.8%	
	Non-CO_2	19.2%	
	Renewables	36.4%	
	Savings & CHP	20.0%	

Country		EU 30% in a multilateral regime	EU 20% unilateral without CDM
Slovak Republic			
	CCS	5.5%	4.4%
	Fuel shift	27.8%	37.2%
	Non-CO_2	7.4%	6.4%
	Renewables	13.2%	10.5%
	Savings & CHP	46.1%	41.5%
Slovenia			
	CCS	4.0%	3.3%
	Fuel shift	22.7%	33.0%
	Non-CO_2	11.8%	11.4%
	Renewables	27.4%	22.7%
	Savings & CHP	34.1%	29.7%
Spain			
	CCS		2.7%
	Fuel shift	35.5%	34.7%
	Non-CO_2	12.2%	13.7%
	Renewables	11.4%	10.0%
	Savings & CHP	40.9%	38.8%
Sweden			
	Fuel shift		0.5%
	Non-CO_2	7.5%	7.8%
	Savings & CHP	92.5%	91.7%
The Netherlands			
	CCS	3.0%	2.7%
	Fuel shift	18.9%	23.3%
	Non-CO_2	24.0%	23.3%
	Renewables	0.6%	0.6%
United Kingdom			
	CCS	3.2%	2.8%
	Fuel shift	19.3%	24.5%
	Non-CO_2	17.4%	15.7%
	Renewables	4.0%	3.5%
	Savings & CHP	56.2%	53.6%

Appendix D Reduction measures in detail

The following tables present the detailed reduction measures in $MtCO_2$-eq. for the ‘EU 20% unilateral without CDM’ scenario. The other scenarios are not shown here.

EU-15

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
Agriculture	Enteric	Agriculture Enteric fermentation change composition concentrates by extra fat	0.06	0.07	0.05	0.03	0.55	0.39	0.06	0.2	0.23	0.01	0.05	0.27	0.13	0.36	2.46
		Agriculture Enteric fermentation change composition concentrates by Non-Structural Carbohydrates	0.02	0.02	0.01	0.01	0.14	0.1	0.01	0.05	0.06		0.01	0.07	0.03	0.09	0.62
		Agriculture Enteric fermentation improved level feed intake	0.13	0.15	0.11	0.06	1.1	0.78	0.11	0.39	0.46	0.01	0.1	0.54	0.27	0.72	4.93
		Agriculture Enteric fermentation proprionate precursors		0.02	0.01	0.01	0.14	0.1	0.01	0.05	0.06		0.01	0.07	0.03	0.09	0.6
		Agriculture Enteric fermentation replace roughage by concentrates	0.1	0.11	0.08	0.05	0.82	0.59	0.08	0.3	0.34	0.01	0.07	0.4	0.2	0.54	3.69
	Manure	Agriculture Manure farm scale anaerobic digestion (heat and power)	0.05	0.14	0.04	0.01	0.72	0.21	0.02	0.07	0.18		0.17	0.44	0.1	0.11	2.26
		Agriculture Manure slowing down anaerobic decomposition	0.07	0.19	0.06	0.02	1.01	0.3	0.03	0.1	0.26		0.23	0.62	0.14	0.16	3.19
	SOILS	Agriculture Common Agricultural Policy Reforms Set-Aside	0.3	0.46	0.76	0.35	5.21	3.43	0.58	0.74	1.9	0.01	0.47	1.8	0.67	3	19.68
Energy supply	Energy (incl. CHP)	Biogas	0.21	0.31	0.35		0.63	0.35	0.03	0.47		0.01	0.18	1.46	0.02	2.18	6.2
		Biomass heat	0.05		0.06			0.3	0.02				0.01	0.1	0.01	0.05	0.6
		Biowaste	0.15		0.06			1.27	0.04	0.14	0.95		0.03	1.16	0.04	0.3	4.14
		CHP - Engineering goods			0.01		0.06	0.13							0.02		0.22
		CHP - Food. drink and tobacco	0.01		0.08		0.18	0.23					0.02		0.11		0.63
		CHP - Non-ferrous metals					0.01	0.03							0.01		0.05

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		CHP - Other industries			0.01		0.04	0.04							0.02		0.11
		CHP - Paper and pulp	0.03		0.03		0.18	0.28					0.06		0.04		0.62
		CHP - Residential - Small	0.09		0.31		0.23	1.12					0.02		0.23		2
		CHP - Tertiary - Large	0.03		0.1		0.07	0.26					0.01		0.11		0.58
		CHP - Tertiary - Small			0.19		0.14	0.53					0.03		0.22		1.11
		CHP - Textiles					0.02	0.03					0.01		0.01		0.07
		Carbon Capture and Storage	0.53	0.84	0.5		2.67	9.47	1.44	0.44	3.77	0.05	0.79	2.83	1.61	4.96	29.9
		Combustion processes fluidised bed after burner		0.01			0.02	0.03	0.02	0.01	0.03			0.02		0.01	0.15
		Combustion processes fluidised bed reversed		0.01			0.02	0.03	0.02	0.01	0.03			0.02		0.01	0.15
		Geothermal electricity									0.22			0.01			0.23
		Geothermal heat			0.01			0.01			0.02						0.04
		Hydro large-scale	0.07				0.26	0.29		0.01	0.32		0.47	0.02		0.03	1.47
		Hydro small-scale	0.49				0.03			0.01	0.19			0.1			0.82
		New capacity by natural gas-fired combined cycles	0.65	2.93	1.79		17.52	27.67	8.35	3.26	20.81	0.12	5.68	29.07	10.06	30.29	158.2
		Solar thermal electricity							1.28		1.92		0.83				4.03
		Solid biomass	0.45		1.12			3.64	2.15		2.49		1.11	7.39	0.27	2.29	20.91
		Wind onshore	0.57		0.13					0.25	1.2			0.02		1.4	3.57
		Replacement of capacity by natural gas-fired combined cycles		0.26	1.93			54.56	5	1.66	1.51		0.57	4.15	2.54	13.18	85.36
		Wind offshore								1.44							1.44
	Refineries	CHP - Refineries		0.2	0.22		0.48	1.04	0.21	0.01	0.34	0.01	0.04	0.28	0.71	0.35	3.89
		Improved catalysts (catalytic reforming)		0.02			0.04	0.01			0.01			0.01	0.02	0.01	0.12
		Miscellaneous I (Low cost tranche)						0.01			0.02			0.02	0.03	0.02	0.1
		Miscellaneous II (High cost tranche)		0.03				0.01			0.02			0.02	0.03	0.02	0.13
		Power recovery (e.g. at fluid catalytic cracker)													0.01		0.01
		Reflux overhead vapour recompression (distillation)						0.01						0.02	0.03	0.02	0.08
Fossil fuel extraction	Oil and gas	Oil and Gas altering start-up procedure during maintenance of compressors		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		Oil and Gas associated gas (flared) mix other options		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas associated gas (vented) mix other options		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas electrical start-up (new) compressors		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas further increased utilisation		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas improved sealing compressors	0.01	0.04			0.14	0.41	0.01	0.01	0.35			0.05	0.19	0.57	1.78
		Oil and Gas increased gas utilisation		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas increasing the pipeline examination frequency		0.01				0.08			0.07			0.01	0.04	0.11	0.32
		Oil and Gas inspection and maintenance compressors		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas inspection and maintenance power equipment		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas no/reduced flushing at start-up compressors		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas offshore flaring instead of venting of process vents		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas recompressing of gas during maintenance compressors		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas replacement grey cast iron network low		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas use of gas turbines instead of reciprocating engines		0.01			0.03	0.08			0.07			0.01	0.04	0.11	0.35
		Oil and Gas inspection and maintenance system		0.01				0.08			0.07			0.01	0.04	0.11	0.32
	Solid fuels	Coal mining abatement from ventilation air						0.11	0.02					0.01		0.03	0.17
		Coal mining degasification (high recovery rate)						0.16	0.04					0.02		0.04	0.26
		Coal mining degasification (low recovery rate)						0.08	0.02					0.01		0.02	0.13
		Coal mining degasification (medium recovery rate)						0.27	0.06					0.03		0.07	0.43
Households	Households	Advanced heating systems: condensing boilers	2.21	3.55		1.35	14.37	21.39	1.55	1.1	18.94	0.28	0.77	2.56	1.98	13.68	83.73
		Avoid standby consumption	1.14	1.93	0.87	0.25	10.03	10.92	1.13	0.67	3.15	0.05	0.31	3.14	2.22	8.29	44.1
		Cold appliances: Best Practice							0.35	0.23	2.36		0.24				3.18

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		Lighting: Best Practice	0.26	0.43	0.33	0.79	3	2.22	0.52	0.17	2.28	0.01	0.23	3.28	0.59	4.96	19.07
		Miscellaneous options (cheap tranche)	0.84	2.37	0.73	0.3	11.67	13.33	1.52	0.87	4.48		0.41	0.81	1.27	8.35	46.95
		Miscellaneous options (moderate costs tranche)	1.6	3.01	1.23	0.35	14.42	15.25	1.69	0.97	4.98	0.08	0.46	4.77	3.12	11.7	63.63
		Very energy efficient refrigerators and freezers	0.6	1.21	0.47	0.9	5.7	6.62	0.78	0.51	5.23	0.03	0.54	1.96	1.16	5.59	31.3
		Wet appliances: Best Practice	0.27	0.46	0.21	0.06	2.39	2.6	0.27	0.16	0.75	0.01	0.07	0.75	0.53	1.98	10.51
	Refrigeration/ airco	Domestic refrigeration: hydrocarbons	0.02	0.02	0.01	0.01	0.07	0.06	0.01		0.02			0.08	0.04	0.08	0.42
		Stationary air conditioning DX (distributed technology): leak reduction	0.04	0.04	0.03	0.02	0.18	0.16	0.01	0.01	0.05			0.2	0.09	0.22	1.05
Industry	Building materials	Application of multi-stage pre-heaters and pre-calciners					0.02	0.03								0.01	0.06
		Batch and cullet preheating	0.01	0.03		0.01	0.08	0.11							0.01	0.02	0.27
		Electricity savings													0	0	0
		Improved melting technique and furnace design	0.01	0.02	0.01	0.01	0.07	0.1							0.01	0.02	0.25
		Improving wet process kilns				0.01										0.05	0.06
		Miscellaneous				0.07										0.33	0.4
		Miscellaneous - building materials				0.04									0.02	0.22	0.28
		Optimisation of heat recovery of clinker cooler		0.01												0.02	0.03
		Raising cullet percentage in raw material				0.01											0.01
		Reduce clinker content of cement														0.03	0.03
		Use of waste derived fuels		0.08		0.03										0.14	0.25
	CHEMICAL INDUSTRY	Industrial processes Adipic acid	0.06	0.42		0.13	0.5								0.72	0.7	2.53
		Industrial processes Nitric acid	0.1	0.42		0.13	1.33								0.72	0.7	3.4
	Chemicals	Cracking furnace - various options		0.01				0.01							0.01		0.03
		Fractionation - various options		0.02											0.01		0.03
		Gas turbine integration		0.01				0.01							0.01		0.03
		Miscellaneous I (Low cost tranche)				0.01									0.58	0.79	1.38
		Miscellaneous II (High cost tranche)	0.07	0.35	0.02	0.06	0.76	0.76		0.07					0.49	0.7	3.28
		Process integration. e.g. by applying pinch													0.02		0.02

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		technology															
		Replacing of mercury and diaphragm processes with membrane electrolysis (chlorine)		0.03											0.03	0.16	0.22
		Advanced reforming													0.01		0.01
	Foams-PU	Foam PU-appliances: pentane		0.02	0.02	0.01	0.11	0.1						0.12	0.06	0.13	0.57
		Foam PU-blocks: pentane	0.11	0.11	0.07	0.05	0.49	0.44		0.02				0.54	0.26	0.59	2.68
		Foam PU-continuous panels: pentane	0.03	0.03	0.02	0.01	0.12	0.11		0.01				0.14	0.06	0.15	0.68
		Foam PU-discontinuous panels: pentane	0.08	0.08	0.05	0.04	0.36	0.32		0.01				0.05	0.19	0.43	1.61
		Foam PU-flexible faced laminate: pentane	0.09	0.09	0.06	0.04	0.41	0.37		0.02					0.22	0.5	1.8
		Foam PU-one component: hydrocarbons	0.42	0.41		0.2	1.87	1.69							0.99	2.26	7.84
		Foam PU-pipe in pipe: pentane	0.01	0.01			0.04	0.04							0.02	0.05	0.17
		Foam PU-spray: water	0.17	0.16	0.11	0.08	0.74	0.67		0.03					0.39	0.9	3.25
	Foams-XPS	Foams XPS: carbon dioxide	0.47	0.47	0.05	0.23	2.13	1.92		0.09					1.12	2.57	9.05
	Food. beverages and tobacco	Application of efficient evaporation processes (dairy)		0.02	0.01		0.17	0.02		0.05					0.03	0.01	0.31
		Food. beverages and tobacco - miscellaneous I (Low cost tranche)				0.05									0.36	0.53	0.94
		Food. beverages and tobacco - miscellaneous II (High cost tranche)	0.07	0.12	0.1	0.07	1.18	0.71		0.15					0.49	0.73	3.62
		Miscellaneous	0.02	0.04	0.02	0.01	0.36	0.13		0.02				0.04	0.09	0.05	0.78
	GIS-gear	Recovery of SF_6 from gas insulated switchgears	0.05	0.01			0.14	0.27							0.02	0.11	0.6
	HFC-23_prodn	Oxidation of HFC-23					0.45								0.24	0.54	1.23
	Iron and steel	Miscellaneous I (Low cost tranche)	0.16	0.34	0.01	0.13	1.16	1.92							0.32	0.59	4.63
		Miscellaneous II (High cost tranche)		0.32													0.32
		Oxygen en fuel injection in electric arc furnaces (secondary steel)				0.01									0.01	0.05	0.07
		Pulverised coal injection up to 30% in the blast furnace (primary steel)		0.06		0.01										0.04	0.11
		Recovery of process gas from coke ovens. blast furnaces and basic oxygen furnaces (primary steel)	0.02	0.07		0.02	0.16	0.27						0.06	0.02	0.08	0.7

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		Scrap preheating in electric arc furnaces (secondary steel)				0.01										0.03	0.04
		Thin slab casting techniques		0.51		0.25	1.16	1.87						0.43	0.18	0.63	5.03
	Magnesium production	Magnesium production: use of SO_2 as protection gas	0.91	0.15		0.07	2.83	0.84							0.36	2.22	7.38
	Non-Ferro	Other non-ferrous metals - miscellaneous	0.09	0.3	0.01	0.03	0.59	0.7		0.48					0.02	0.12	2.34
	Other industry	Miscellaneous I (Low cost tranche)														2.09	2.09
		Miscellaneous II (High cost tranche)		0.8		0.37									0.17	3.15	4.49
	Pulp and paper	Heat recovery in thermal mechanical pulping	0.01	0.02		0.24	0.5	0.04						0.02		0.03	0.86
		Improved drying. e.g. condensing belt drying				0.01											0.01
		Miscellaneous II (High cost tranche)				0.06	0.03									0.01	0.1
		Miscellaneous I (Low cost tranche)		0		0									0	0.04	0.04
		Miscellaneous II (High cost tranche)	0.03	0.01	0.01	0.07	0.18	0.11						0.17	0.03	0.07	0.68
		Pressing to higher consistency, e.g. by extended nip press (paper making)	0.09		0.01	0.06	0.46	0.07							0.02	0.04	0.75
		Reduced air requirements, e.g. by humidity control in paper machine drying hoods	0.03	0.01		0.04	0.2	0.05						0.08	0.01	0.03	0.45
		Refiner improvements				0.02		0.01								0.01	0.04
	Refrigeration/ airco	Industrial food refrigeration: hydrocarbons and NH_3	0.01	0.01	0.01	0.01	0.06	0.05							0.03	0.07	0.25
		Industrial refrigeration: hydrocarbons and NH_3		0.05		0.02									0.12	0.27	0.46
	Semiconductors	Semiconductors: Chemical vapour deposition (CVD). NF_3	0.01	0.06	0.01	0.01	0.53	0.25		0.1				0.13	0.49	0.24	1.83
		Semiconductors: etch - alternative chemicals		0.01											0.07	0.04	0.12
		Semiconductors: etch – oxidation		0.02				0.08		0.03				0.04	0.15	0.07	0.39
Other	aerosols	Aerosols: hydrocarbons	0.26	0.25	0.18	0.13	1.16	1.05	0.09	0.05	0.31	0.03	0.01	1.29	0.61	1.4	6.82
Services	Refrigeration/ air co	Commercial refrigeration: leakage reduction	0.22	0.22	0.15	0.11	0.99	0.9	0.08	0.04	0.27	0.02	0.01	1.11	0.52	1.2	5.84
		Stationary air conditioning chillers: HC and NH_3	0.1	0.1	0.07	0.05	0.45	0.4	0.04	0.02	0.12	0.01		0.5	0.24	0.54	2.64
	tertiary	Building Energy Management Systems: electricity											0.04				0.04
		Building Energy Management Systems: space	0.26	1.12	0.15	0.26	7.15	7.26	0.38	0.59	0.29	0.01	0.25	1.22	1.38	4.3	24.62

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		heating and cooling															
		Efficient space cooling equipment	0.2	0.82	0.48	0.71	1.85	0.7	0.2	0.11	2.38	0.02	0.21	1.62	0.52	1.08	10.9
		Lighting: Best Practice level 1	0.4	0.81	0.5	0.48	5.4	4.94	0.14	0.29	3.9	0.05	0.63	2.23	1.23	4.81	25.81
		Lighting: Best Practice level 2		0.65	0.48	0.49	6.32	6.48		0.38	6.69	0.01	1.15	0.21	0.48	4.31	27.65
		Office equipment: Best Practice	1.3	0.69	0.17	1.21	8.5	10.85	0.72	0.57	0.92	0.08	1.06	3.93	5.59	8.23	43.82
		Retrofit services buildings: improving building shell: roof insulation	0.08	0.2	0.01		0.65	1.3	0.1	0.05	0.08		0.07	0.33	0.17	0.13	3.17
		Retrofit services buildings: improving building shell: wall insulation		0.32	0.02			2.66	0.16	0.17	0.13		0.11	0.55	0.26	1.56	5.94
Transport	Freight	Aerodynamics - cab roof deflector	0.2	0.27	0.11		1.39		0.15	0.12	1.28	0.05	0.16	0.67	0.37		4.77
		Aerodynamics - cab roof fairing	0.31	0.41	0.17		2.14		0.23	0.19	1.19	0.08	0.25	1.03	0.57		6.57
		Driver training - Heavy Goods Vehicles (HGV) drivers	0.42		0.23		2.89			0.26	2.67	0.11		1.39	0.77		8.74
		Engine improvement	0.48	0.64	0.26		3.3		0.35	0.3		0.12	0.38	1.59	0.88		8.3
		Rolling resistance	0.32	0.42	0.17		2.2		0.23	0.2		0.08	0.26	1.06	0.58		5.52
	MAC	Mobile air conditioning: carbon dioxide		0.13	0.09	0.07	0.6		0.02	0.02	0.07	0.01		0.27	0.32		1.6
		Mobile air conditioning: leakage red.	0.2	0.2	0.14		0.91		0.09	0.04	0.29	0.02	0.01	1.21	0.48		3.59
		Mobile air conditioning: recovery	0.32	0.32	0.22	0.16	1.45		0.14	0.06	0.47	0.03	0.01	1.94	0.77		5.89
	Passenger cars	Advanced Gasoline Direct Injection (advanced: 'DISC')	0.81	1.05	0.43	0.04		4.4		0.45	5.09		0.59	2.56	1.45	6.21	23.08
		Basic package - diesel cars	0.2	0.26	0.11	0.13	1.38		0.14	0.11	1.27	0.05	0.15	0.64	0.36		4.8
		Basic package - petrol cars		0.53							2.55			1.28			4.36
		Lightweight interior components - diesel cars	0.05	0.06	0.03	0.03	0.33			0.03	0.31		0.04	0.15	0.09	0.37	1.49
		Lightweight interior components - petrol cars	0.05	0.06	0.03		0.33		0.03	0.03	0.31	0.01	0.04	0.15	0.09		1.13
		Petrol to diesel shift	0.81	1.05	0.43	0.52	4.47			0.45	5.09	0.16	0.59	2.56	1.45	0.51	18.09
		Variable valve lift timing + cylinder deactivation	0.4	0.53	0.21	0.14	2.75		0.28	0.23	2.55	0.11	0.3	1.28	0.72		9.5
	Refrigeration/ air co	Transport refrigeration: leak reduction	0.02	0.02	0.01	0.01	0.08		0.01		0.02			0.09	0.04		0.3
Waste	LANDFILL	Landfill diversion: composting		0.03	0.02	0.04	0.2	0.17	0.07	0.02	0.14		0.05	0.15	0.15	0.18	1.22
		Landfill diversion: paper recycling	0.08	0.03	0.02	0.04	0.2	0.17	0.07	0.02	0.14		0.05	0.15	0.15	0.18	1.3

Sector	Subsector	Measures	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Portugal	Spain	The Netherlands	United Kingdom	EU total
		Landfill electricity generation	0.12	0.05	0.03	0.07	0.32	0.27	0.11	0.03	0.22		0.08	0.24	0.24	0.29	2.07
		Landfill flaring	0.15	0.06	0.04	0.09	0.39	0.33	0.14	0.04	0.27		0.1	0.3	0.3	0.37	2.58
		Landfill heat production	0.02	0.01		0.01	0.04	0.03	0.01		0.03		0.01	0.03	0.03	0.04	0.26
		Landfill increased oxidation	0.3	0.11	0.07	0.18	0.79	0.67	0.27	0.08	0.54	0.01	0.2	0.59	0.6	0.73	5.14
		Landfill upgrade to SNG (synthetic natural gas)	0.02	0.01		0.01	0.04	0.03	0.01		0.03		0.01	0.03	0.03	0.04	0.26
		Landfill diversion mechanical-biological pre-treatment (MBT)		0.08	0.06			0.5	0.2	0.06	0.41		0.15	0.44	0.45	0.55	2.9
		Landfill diversion anaerobic digestion								0.02							0.02
Grand Total			22.28	36.2	17.59	12.29	172.51	239.21	31.9	20.42	121.01	1.76	20.97	103.34	60.58	177.81	1037.87

EU-10 and EU-2 new countries

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
Agriculture	Enteric	Agriculture enteric fermentation change composition concentrates by extra fat			0.03	0.01		0.01	0.04		0.17	0.11	0.02	0.01	0.89
		Agriculture enteric fermentation change composition concentrates by non-structural carbohydrates			0.01				0.01		0.04	0.03	0.01		0.22
		Agriculture enteric fermentation improved level feed intake		0.01	0.06	0.02		0.03	0.08		0.35	0.23	0.04	0.02	1.82
		Agriculture enteric fermentation propionate precursors	0.01		0.01		0.01		0.01		0.04	0.03	0.01		0.24
		Agriculture enteric fermentation replace roughage by concentrates		0.01	0.05	0.01		0.02	0.06		0.26	0.17	0.03	0.02	1.36
	Manure	Agriculture manure farm scale anaerobic digestion (heat power)	0.03		0.03	0.01	0.03		0.01		0.04	0.1	0.01	0.01	0.51
		Agriculture manure slowing down anaerobic decomposition	0.04	0.01	0.05	0.01	0.04	0.01	0.02		0.06	0.14	0.01	0.01	0.73
	SOILS	Agriculture Common Agricultural Policy Reforms Set-Aside	1.45	0.02	0.51	0.06	1.07	0.13	0.08		1.29	0.77	0.25	0.11	8.95
Energy supply	Energy (incl. CHP)	Biogas	0.48	0.04	0.66	0.2	0.39	0.21	0.28	0.01	0.18	1.75	0.33	0.17	6.52
		Biomass heat							0.03			0.14			5.7
		Bio waste	0.16	0.03		0.05	0.04	0.01	0.05	0.02		0.4		0.11	1.1
		CHP - Engineering goods	0.01		0.01		0.01				0.04	0.01	0.01		0.12
		CHP – Food, drink and tobacco	0.02		0.03	0.01	0.02		0.01		0.12	0.03	0.01		0.32
		CHP - Non-ferrous metals									0.01				0.02
		CHP - Other industries			0.01						0.02	0.01			0.05
		CHP – Paper and pulp	0.05	0.01	0.08	0.01	0.04	0.01	0.02		0.29	0.07	0.03	0.01	0.81
		CHP - Residential - Small	0.07	0.01	0.12	0.02	0.06	0.01	0.03	0.01	0.46	0.11	0.05	0.02	1.27
		CHP - Tertiary - Large	0.02		0.03	0.01	0.02		0.01		0.13	0.03	0.01		0.34
		CHP - Tertiary - Small	0.04		0.07	0.01	0.03	0.01	0.02		0.25	0.06	0.03	0.01	0.69
		CHP - Textiles									0.01				0.02
		Carbon Capture and Storage	0.75	0.09	1.31	0.23	0.61	0.12	0.29	0.05	4.85	1.14	0.55	0.18	13.29

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		Combustion processes fluidised bed after burner	0.01								0.01				0.02
		Combustion processes fluidised bed reversed air staging	0.01								0.01				0.02
		Geothermal electricity	0.42								0.04	0.03			0.61
		Hydro large-scale	1.46				0.2	0.1	0.11		0.47	1.34	0.66	0.61	5.86
		Hydro small-scale	0.05		0.05		0.01	0.02				0.06	0.14	0.04	0.51
		New capacity by natural gas-fired combined cycles	4.28	0.52	1.34	1.31	3.46	0.67	1.66	0.31	25.41	6.48	2.79	1.02	66.98
		Solar thermal electricity									0.83				2.11
		Solid biomass	0.96	0.08		0.64	2.55	0.16	1.73	0.01		4.62		0.22	11.2
		Wind onshore	3.97	0.02	1.88	0.4	0.18	0.34	0.03	0.07		3.04	0.2	0.08	12.05
		Replacement of capacity by natural gas-fired combined cycles	2.55	0.22	3.97	0.83	1.01	0.22	0.69	0.18	17.06	4.85	1.91	0.77	36.83
		Wind offshore										0.01			0.01
		CHP – Food, drink and tobacco (implemented in situation of overcapacity)												0	0
	Refineries	CHP - Refineries	0.09	0.01	0.16	0.03	0.08	0.01	0.04	0.01	0.61	0.14	0.07	0.02	1.66
		Improved catalysts (catalytic reforming)			0.01						0.01	0.01			0.04
		Miscellaneous I (Low cost tranche)										0.01			0.02
		Miscellaneous II (High cost tranche)			0.02						0.02	0.01	0.01		0.07
		Reflux overhead vapour recompression (distillation)										0.01			0.02
Fossil fuel extraction	Oil and gas	Oil and Gas altering start-up procedure during maintenance compressors	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas associated gas (flared) mix other options	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas associated gas (vented) mix other options	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas electrical start-up (new) compressors	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas further increased utilisation	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas improved sealing compressors	0.03		0.05	0.04	0.23	0.01	0.03		0.38	0.46	0.01		1.7

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		Oil and Gas increased gas utilisation	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas increasing the pipeline examination frequency	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas inspection and maintenance compressors	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas inspection and maintenance power equipment	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas no/reduced flushing at start-up compressors	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas offshore flaring instead of venting of process vents	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas recompressing of gas during maintenance compressors	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas replacement grey cast iron network low	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas use of gas turbines instead of reciprocating engines	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas inspection and maintenance system	0.01		0.01	0.01	0.05		0.01		0.08	0.09			0.35
		Oil and Gas electrical start-up (retrofit) compressors										0.05			0.1
		Oil and Gas flaring instead of venting of unused associated gas										0.09			0.18
	Solid fuels	Coal mining abatement from ventilation air	0.01		0.06	0.01	0.03				0.18	0.02	0.01		0.32
		Coal mining degasification (high recovery rate)	0.02		0.09	0.01	0.04				0.28	0.03	0.02		0.49
		Coal mining degasification (low recovery rate)	0.01		0.04	0.01	0.02				0.14	0.02	0.01		0.25
		Coal mining degasification (medium recovery rate)	0.04		0.14	0.02	0.07				0.46	0.05	0.03	0.01	0.82
Households	Households	Advanced heating systems: condensing boilers	0.68	0.06	1.42	0.09	1.48	0.06	0.11		3.85	1.32	0.49	0.25	14.71
		Avoid standby consumption	0.31	0.08	0.87	0.09	0.47	0.09	0.13	0.04	1.02	0.49	0.32	0.12	8.35
		Cold appliances: Best Practice		0.03		0.04		0.04	0.06			0.22			2.21
		Lighting: Best Practice	0.28	0.03	0.27	0.08	0.43	0.08	0.11	0.03	1.42	0.44	0.29	0.11	5.48
		Miscellaneous options (cheap tranche)	0.36	0.11	0.31	0.12	0.65	0.11	0.17	0.04	0.78	0.77	0.48	0.11	11.08
		Miscellaneous options (moderate costs tranche)	0.46	0.12	1.3	0.13	0.81	0.12	0.19	0.05	2.16	0.86	0.54	0.19	14.78
		Very energy-efficient refrigerators and freezers	0.31	0.06	0.87	0.09	0.47	0.09	0.13	0.02	1.02	0.49	0.32	0.12	8.05

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		Wet appliances: Best Practice	0.07	0.02	0.21	0.02	0.11	0.02	0.03	0.01	0.24	0.12	0.08	0.03	1.99
	Refrigeration/ air co	Domestic refrigeration: hydrocarbons			0.02		0.01				0.03				0.07
		Stationary air conditioning DX (distributed technology): leak reduction	0.01		0.06		0.01				0.08	0.01	0.01	0.01	0.23
Industry	Building materials	Application of multi-stage pre-heaters and pre-calciners									0.01				0.01
		Batch and cullet preheating			0.01										0.03
		Electricity savings													0
		Improved melting technique and furnace design			0.01						0.05				0.08
		Improving wet process kilns													0.02
		Miscellaneous													0.13
		Miscellaneous - building materials													0.07
		Optimisation of heat recovery of clinker cooler													0.01
		Raising cullet percentage in raw material													0.01
		Reduce clinker content of cement													0.01
		Use of waste derived fuels													0.06
	CHEMICAL INDUSTRY	Industrial processes Adipic acid			0.11										0.16
		Industrial processes Nitric acid			0.11				0.15						0.43
	Chemicals	Miscellaneous I (Low cost tranche)													0.22
		Miscellaneous II (High cost tranche)			0.44						0.51		0.13		1.41
		Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)			0.06										0.09
	foams-PU	Foam PU-appliances: pentane			0.02						0.02				0.06
		Foam PU-blocks: pentane			0.09						0.11		0.01	0.01	0.3
		Foam PU-continuous panels: pentane			0.02						0.03				0.08
		Foam PU-discontinuous panels: pentane			0.06						0.08		0.01		0.22
		Foam PU-flexible faced laminate: pentane			0.07						0.1		0.01		0.25
		Foam PU-one component: hydrocarbons			0.33				0.01						0.67

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		Foam PU-pipe in pipe: pentane			0.01										0.02
		Foam PU-spray: water			0.13						0.17		0.02		0.46
	foams-XPS	Foams XPS: carbon dioxide			0.37				0.01	0.01					0.77
	Food. beverages and tobacco	Application of efficient evaporation processes (dairy)			0.01						0.05				0.08
		Food, beverages and tobacco - miscellaneous I (Low cost tranche)													0.29
		Food, beverages and tobacco - miscellaneous II (High cost tranche)			0.26				0.06		0.07				0.82
		Miscellaneous			0.04			0.01	0.01		0.19		0.02		0.33
	GIS-gear	Recovery of SF_6 from gas insulated switchgears			0.01										0.08
	Iron and steel	Miscellaneous I (Low cost tranche)			0.31						0.48				1.23
		Oxygen en fuel injection in electric arc furnaces (secondary steel)			0.01										0.03
		Pulverised coal injection up to 30% in the blast furnace (primary steel)													0.07
		Recovery of process gas from coke ovens, blast furnaces and basic oxygen furnaces (primary steel)			0.04						0.06		0.02		0.18
		Scrap preheating in electric arc furnaces (secondary steel)			0.01										0.02
		Thin slab casting techniques			0.03			0.01			0.05	0.07	0.15		0.71
	Magnesium production	Magnesium production: use of SO_2 as protection gas			0.07										1.38
	Non-Ferro	Other non-ferrous metals - miscellaneous			0.02										0.24
	Other industry	Miscellaneous I (Low cost tranche)													5.85
		Miscellaneous II (High cost tranche)			0.22										7.53
	Pulp and paper	Heat recovery in thermal mechanical pulping			0.01						0.08				0.11
		Miscellaneous I (Low cost tranche)													0
		Miscellaneous II (High cost tranche)			0.02				0.01		0.13			0.02	0.21
		Pressing to higher consistency, e.g. by extended			0.02				0.01		0.11				0.17

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		nip press (paper making)													
		Reduced air requirements, e.g. by humidity control in paper machine drying hoods			0.01						0.06			0.01	0.1
		Refiner improvements									0.01				0.01
	Refrigeration/ air co	Industrial food refrigeration: hydrocarbons and NH_3			0.02										0.03
		Industrial refrigeration: hydrocarbons and NH_3			0.07										0.1
	Semiconductors	Semiconductors: Chemical vapour deposition (CVD). NF_3							0.01		0.26			0.01	0.73
		Semiconductors: etch - alternative chemicals													0.02
		Semiconductors: etch - oxidation									0.08	0.07		0.01	0.3
Other	aerosols	Aerosols: hydrocarbons	0.11	0.01	0.71		0.17		0.01		0.94	0.1		0.07	2.37
Services	Refrigeration/ air co	Commercial refrigeration: leakage reduction	0.05	0.01	0.32		0.07				0.42	0.04	0.04	0.03	1.2
		Stationary air-conditioning chillers: HC and NH_3	0.02		0.14		0.03				0.19	0.02	0.02	0.01	0.53
	tertiary	Building Energy Management Systems: space heating and cooling	0.11	0.08	0.61	0.04	0.85	0.08	0.07		1.15	0.19	0.39	0.19	5.27
		Efficient space cooling equipment	0.1		0.23	0.03	0.17	0.03	0.04	0.02	0.52	0.08	0.11	0.03	2.73
		Lighting: Best Practice level 1	0.27		0.61	0.07	0.44	0.08	0.1	0.03	1.37	0.21	0.28	0.08	6.37
		Lighting: Best Practice level 2	0.31			0.12	0.54	0.14	0.17	0.04	0.95	0.21	0.38	0.02	7.39
		Office equipment: Best Practice	0.4	0.03	1.05	0.11	0.85	0.13	0.16	0.03	2.22	0.34	0.49	0.16	9.74
		Retrofit services buildings: improving building shell: roof insulation	0.03	0.03	0.18	0.01	0.21	0.02	0.02		0.28	0.05	0.09	0.05	1.15
		Retrofit services buildings: improving building shell: wall insulation	0.05	0.04	0.31	0.02	0.36	0.03	0.03		0.49	0.08	0.17	0.08	2
Transport	Freight	Aerodynamics - cab roof deflector		0.02		0.02		0.03	0.06	0.01					1.06
		Aerodynamics - cab roof fairing		0.03		0.03		0.05	0.04	0.01					1.58
		Driver training - Heavy Goods Vehicles (HGV) drivers	0.16	0.04		0.04		0.07	0.13	0.01					2.37
		Engine improvement		0.04		0.05		0.08		0.01					1.69
		Rolling resistance		0.03		0.03		0.05		0.01					0.12
	MAC	Mobile air conditioning: carbon dioxide													0.03

sector	Sub sector	Measure	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovak Republic	Slovenia	EU total
		Mobile air conditioning: leakage red.		0.01					0.01						0.16
		Mobile air conditioning: recovery	0.03	0.01		0.01		0.01	0.01						0.29
	Passenger cars	Advanced Gasoline Direct Injection (advanced: ‘DISC’)	0.32	0.08	0.6	0.08	0.61	0.13	0.25	0.02	1.83		0.35		8.25
		Basic package - diesel cars	0.08	0.02	0.15	0.02	0.15	0.03	0.06	0.01	0.29				1.8
		Basic package - petrol cars			0.3		0.3								2.59
		Lightweight interior components - diesel cars	0.02		0.04		0.04	0.01	0.02		0.11				0.48
		Lightweight interior components - petrol cars	0.02					0.01	0.02						0.29
		Lightweight structure - petrol cars													0.07
		Petrol to diesel shift	0.32	0.08	0.6	0.08	0.61	0.13	0.25	0.02	1.83				7.9
		Variable valve lift timing + cylinder deactivation	0.16	0.04	0.3	0.04	0.2	0.07	0.13	0.01					2.94
	Refrigeration/ air co	Transport refrigeration: leak reduction													0.01
Waste	LANDFILL	Landfill diversion composting	0.07	0.01	0.03	0.02	0.04	0.01	0.03		0.35	0.24	0.02	0.02	1.35
		Landfill diversion paper recycling	0.07	0.01	0.03	0.02	0.04	0.01	0.03		0.35	0.24	0.02	0.02	1.35
		Landfill electricity generation	0.12	0.01	0.04	0.03	0.07	0.02	0.05		0.55	0.38	0.03	0.03	2.14
		Landfill flaring	0.15	0.02	0.05	0.04	0.08	0.03	0.06	0.01	0.69	0.48	0.04	0.04	2.7
		Landfill heat production	0.01		0.01		0.01		0.01		0.07	0.05			0.26
		Landfill increased oxidation	0.3	0.04	0.1	0.08	0.17	0.05	0.12	0.01	1.38	0.95	0.07	0.09	5.39
		Landfill upgrade to SNG (synthetic natural gas)	0.01		0.01		0.01		0.01		0.07	0.05			0.26
		Landfill diversion mechanical-biological pre-treatment (MBT)	0.22	0.03	0.08	0.06	0.12	0.04	0.09	0.01	1.04	0.71	0.05	0.06	4.03
		Landfill diversion anaerobic digestion										0.24		0.02	0.28
Grand Total			23.18	2.31	25.88	5.82	21.58	4.07	8.67	1.13	86.12	37.53	12.71	5.45	373.37