Ecofys UK
1 Alie Street
London E1 8DE

tel +44 (0)20 7423 0970
fax +44 (0)20 7423 0971
e-mail info@ecofys.co.uk

DEVELOPING AN EU CARBON BUDGET

Final report

Alyssa Gilbert
Gemma Reece
Sara Moltmann
Ann Gardiner

May 2007
PECSGB062976

Supported by Friends of the Earth and Christian Aid

EXECUTIVE SUMMARY

This paper follows on from a discussion paper by Ecofys supported by Friends of the Earth UK, "Developing a Carbon Budget for the UK: with opportunities for EU action"[1]. It explores the concept of introducing a carbon budget at the EU level, as a tool that can be used by governments, alongside targets, to define the emissions pathway needed to reach the desired long-term level of stabilisation of greenhouse gases in the atmosphere.

The aim in creating a carbon budget would be to ensure that the long-term greenhouse gas emissions reductions that the EU has committed to achieving are realised. A well-designed carbon budgeting system should help to achieve this aim by:

1. Raising the profile of greenhouse gas emissions reductions by apportioning ultimate responsibility to the highest levels;
2. Embodying a clear, sensibly devised emissions reduction profile for the long-term, which in turn would provide direction and certainty to business and policy makers;
3. Providing a structure for regular monitoring and review of targets; and
4. Providing flexibility for achieving reductions in different sectors of the economy and over time.

> A **carbon budget** is a set amount of carbon that can be emitted in a given amount of time, either by the whole economy, or a pre-selected sub-population or set of activities.

The research presented here first uses the Evolution of Commitments Tool (EVOC), developed by Ecofys, to present the scale of a carbon budget for the EU-25 [2] to 2050. This budget is presented under various potential international agreements to reduce emissions in the post-Kyoto period: contraction and convergence; common but differentiated convergence; multistage; Global Triptych; and greenhouse gas (GHG) intensity targets. The carbon budget here is based on reaching a global greenhouse gas stabilisation level in the atmosphere of 450 ppmv CO_2e (400 ppmv CO_2). The European Commission state that by stabilising long-term concentrations at around 450 ppmv CO_2e

[1] Gilbert, A. and Reece, G. (2006). Developing a Carbon Budget for the UK: with opportunities for EU action. Report by Ecofys UK supported by Friends of the Earth UK. Available from: www.foe.co.uk/resource/reports/carbon_budgetting.pdf

[2] Data was not yet available in the EVOC model for Romania and Bulgaria, the newest Member States, when this report was commissioned. It is estimated that inclusion of Romania and Bulgaria in an EU carbon budget would increase the budget out to 2050 by around 1% to 4%.

there is a 50% chance of keeping average global temperature increase to within 2 degrees Celsius[3].

Importantly it was found that the emissions reductions required by the EU as a whole are determined much more strongly by the required greenhouse gas stabilisation level than by the form of the international burden sharing agreement. This is particularly true to reach a global stabilisation level of 450 ppmv CO_2e (400 ppmv CO_2) which requires very strong action to be taken to reduce emissions in the short term.

The contraction and convergence approach has been used to calculate the EU's overall carbon budget here, as it is a simple, transparent approach which also leads to an intermediate level of emissions targets for the EU-25 in both 2020 and 2050 when compared to the other approaches studied. The contraction and convergence approach was then further used to divide the carbon budget between Member States.

The overall carbon budget for the EU-25 from 2005 to 2050 to reach stabilisation at 450 ppmv CO_2e would be **134 GtCO_2e**. This translates approximately to a carbon dioxide only budget of around 109 GtCO_2e. The budget for all greenhouse gases compares to a median "BAU carbon budget" of around 280 GtCO_2e, and is equivalent to a -45 to -55% reduction in emissions compared to cumulative BAU emissions by 2050.

Data modelled here suggest that to reach the required GHG stabilisation level of 450 ppmv CO_2e the EU as a whole will have to achieve average annual emissions reductions of 3% per year between 2010 and 2020 or 4% per year over the whole period 2010 to 2050.

For the EU as a whole (under C&C) a total emissions reduction of 35% by 2020 and 81% by 2050, compared to 1990, would be required to meet the given stabilisation level. The -35% in 2020 figure compares to -20% already committed to by the EU, with an agreement to increase that to -30% if other countries will also agree to binding emission reduction action.

The study also sets out the key economic reasons for taking action on climate change and provides a description of current renewable energy and energy efficiency policies in place to achieve such reductions at the EU-level.

[3] COM(2007)2: Limiting Global Climate change to 2 degrees Celsius. The way ahead for 2020 and beyond. 10 January 2007. http://ec.europa.eu/environment/climat/future_action.htm
Note that Friends of the Earth and Christian Aid believe that atmospheric concentrations should be stabilised considerably below 450 ppmv CO_2e in order to decrease the risk of exceeding a two degree increase, but for the purposes of modelling target from the Commission's Communication is maintained.

According to a growing body of scientific literature:

- If global emissions go unchecked average global temperatures could increase by up to 5°C, having a profound affect on the global climate, with far reaching impacts.
- The cost of taking action to mitigate climate change is outweighed by the costs of not taking action.
- The cost of taking action to mitigate climate change today is lower than taking steps to mitigate that change in the future.
- Climate change actions bring opportunities in both mitigation and adaptation, as reducing carbon emissions will create new jobs and foster innovation and technology.
- Climate change is a global problem and the response must be international but the EU is well placed to take the lead.

In the final section of the report, recommendations are given for how a carbon budget could work within existing EU infrastructures and processes and suggested first steps towards the development and implementation of an EU carbon budget are described.

In the early stages a carbon budget could be introduced simply as a means to raise the profile of decisions which affect greenhouse gas emission within the EU and the need for significant long term emissions reductions. At a later stage, a long-term carbon budget could be set formally for the EU and concepts such as borrowing within periods incorporated. Initial steps towards the introduction of a carbon budget for the EU are:

- Endorsement by the European Union of the carbon budget approach as a tool to monitor and reduce cumulative emissions from the EU
- Use of the approach to raise the profile of carbon emissions to the highest levels within the EU governance structure to ensure they are factored in to key policy decisions. This might be achieved most effectively if the country holding the presidency promotes the use of a carbon budget.
- A Member State trial of the approach to show its effectiveness as a policy tool at the national level could be helpful in gain acceptance before broadening the scheme to the EU

Table of contents

1 Introduction

1.1 Introduction

There is currently much debate at the international level on global agreements to reduce greenhouse gases post-2012, when the first Kyoto commitment period will have come to an end. As part of these debates, calculations have been made of the possible trajectories, or *emissions pathways*, that could be followed to achieve given stabilisation levels of greenhouse gases in the atmosphere.

To secure particular stabilisation levels of greenhouse gases in the atmosphere in the longer-term countries and regions participating in a global agreement will need to adhere to these emissions pathways. Another way to look at the emissions pathways is to consider the total carbon that is “available” to a given economy - referred to here as a *carbon budget.* A carbon budget figure gives an indication of the total carbon available to an economy over a given timeframe, and can allow for flexibility in adhering to emissions pathways. Such budgets should be set out and reviewed at the highest levels of government, incorporating the true long-term perspective inherent in the emissions pathways agreed internationally, but coupled to high-profile regular review at a national government level to ensure that deviations from the pathway can be remedied within the total budget available.

Recently, Friends of the Earth published several studies at the UK level to promote the carbon budget approach. This study extends that thinking further to investigate the application of a carbon budget approach at the EU-level. This section of the report describes the concept of a carbon budget in more detail, and within the context of the international climate change agenda.

1.2 International Climate Change Agenda

The Kyoto Protocol, which officially entered into force in 2005, is the first international agreement aiming to reduce atmospheric greenhouse gas levels. During the first commitment period, 2008-12, signatories must meet internationally agreed reductions in greenhouse gas emissions.

The Kyoto Protocol falls within the scope of the United Nations Framework Convention on Climate Change (UNFCCC). Countries are currently exploring potential mechanisms for ensuring that global reductions in greenhouse gases continue beyond 2012, both through the UNFCCC and independently. Discussions on such a so-called “post-2012 approach” involve an understanding of the scale of global reductions of greenhouse gas emissions that relate to appropriate levels of stabilisation of greenhouse gases in the atmosphere, and the ways in which these reductions or limits could appropriately be distributed between countries.

Under the Kyoto Protocol the EU-15 originally signed up to an average reduction of greenhouse gas emissions of 8% during the period 2008 to 2012, compared to 1990 levels. The EU's burden-sharing agreement divided this average cut between Member States in a way that took into account the stage of economic development of the 15 EU Member States at that time. New EU Member States, who have ratified the Kyoto Protocol both individually and as part of an enlarged EU, have emission reduction targets of -8% compared to 1990 levels in 2008 to 2012 (with the exception of Poland that has a reduction target of -6%).

Looking towards the post-2012 period, the EU is interested in taking an international leadership position on climate issues. The EU has made a firm commitment to reduce greenhouse gas emissions by 20% compared to 1990 levels by 2020, with an interest in considering a target of 30% in the context of international agreement. The nature of the EU's aspirations in the climate field is outlined in more detail in section 4.3.

1.3 Targets versus total emissions

Commitments at an international, EU, and national level often focus on targets in particular years. These targets, as well as the associated policies and measures, are important indicators that climate change is being taken seriously. There is a real need for the international community to work together to set EU and global targets for emissions reduction post-2012 to show clearly how the future emissions reduction path will have to be. Furthermore, targets serve as helpful goals and points for taking stock of emissions reduction progress.

However, by placing too great an emphasis on a targets-based approach, there is a risk that the total volume of emissions released into the environment will be out of line with the goal of achieving certain stabilisation levels of greenhouse gases. It is not only the target, but also the way in which it is reached, that determines the total impact of emissions on the environment. This point is particularly important if only very long term emissions reduction targets are set.

It is the total cumulative emissions, as well as the profile over time, that are important in terms of adherence to given stabilisation levels. Carbon dioxide remains stable in the atmosphere for a time within the order of magnitude of 100 years. This assumption can be used therefore in calculating initial approximations of cumulative emissions, irrespective of the time of emission, which can be used to define the concentration levels of greenhouse gases in the atmosphere.

Figure 1 and Figure 2 relate to global emissions of CO_2 and illustrate the importance of understanding cumulative emissions graphically. The pink shaded area in both graphs, labelled SRES, shows the business as usual levels of emissions based on the standard set of emissions scenarios from the Special Report on Emission Scenarios (SRES) of the IPCC [4]. These scenarios assume that no further emission reduction efforts will take place in the future. The yellow shaded area in Figure 1 shows the area within which a 400 ppmv CO_2 (450 ppmv CO_2e) stabilisation level could be achieved. Note that the carbon budget in this report is calculated assuming a stabilisation level of 400 ppmv CO_2 (the yellow shaded area in Figure 1). This level was chosen as the European Commission state that by stabilising long-term concentrations at around 450 ppmv CO_2e (400 ppmv CO_2) there is a 50% chance of keeping average global temperature increase to within 2 degrees Celsius[3]. The green shaded area in Figure 2 shows the area in which a 450 ppmv CO_2 stabilisation level could be achieved, and the blue shaded area back in Figure 1 shows the area within which a 550 ppmv CO_2 stabilisation level could be achieved.

In the terminology commonly used at the level of international negotiations, the shaded area is known as an *emission corridor*.[5] Within this corridor, a range of different emissions trajectories could be followed with time, all of which adhere to the given stabilisation level. These trajectories are known as *emissions pathways*. Figure 2 illustrates two example pathways for the 450 ppmv CO_2 stabilisation level. In one global emissions increase rapidly, peak and then decrease rapidly whist in the other emissions decrease moderately from the start. Both paths lead to the same concentration level by the end of the century. Many alternative pathways are possible, differing in terms of the timing of required emissions reductions. If reductions are not made now, then more extreme reductions will be necessary in the future.

The difference between the emissions pathways evident in the pink “business as usual” area and those in the shaded areas for the different stabilisation levels in Figure 1 and Figure 2 shows the degree of effort that the global community must make in order to achieve each stabilisation level. There is a large difference evident in the emissions corridors for the different stabilisation levels. It can be seen that to achieve the lowest stabilisation level of 400 ppmv CO_2 (yellow shaded area in Figure 1), the emissions corridor is relatively narrow and there is little choice of emissions pathways available. Global emissions would have to start a significant decrease from 2010.

---

[4] Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E. Emilio la Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooyen, N. Victor and Z. Dadi. (2000). *Special report on emissions scenarios*. IPCC Special Reports. Cambridge, UK: Cambridge University Press. As presented by Höhne, N. (2006). *What is next after the Kyoto Protocol? Assessment of options for international climate policy post 2012*. Amsterdam, the Netherlands: Techne Press http://www.technepress.nl/publications.php?id=13

[5] The emissions corridors displayed here were derived using a simple climate model and two key assumptions: annual global emissions cannot decrease more than 3% per year and the annual trend cannot change more than 0.5% per year (Höhne 2006)

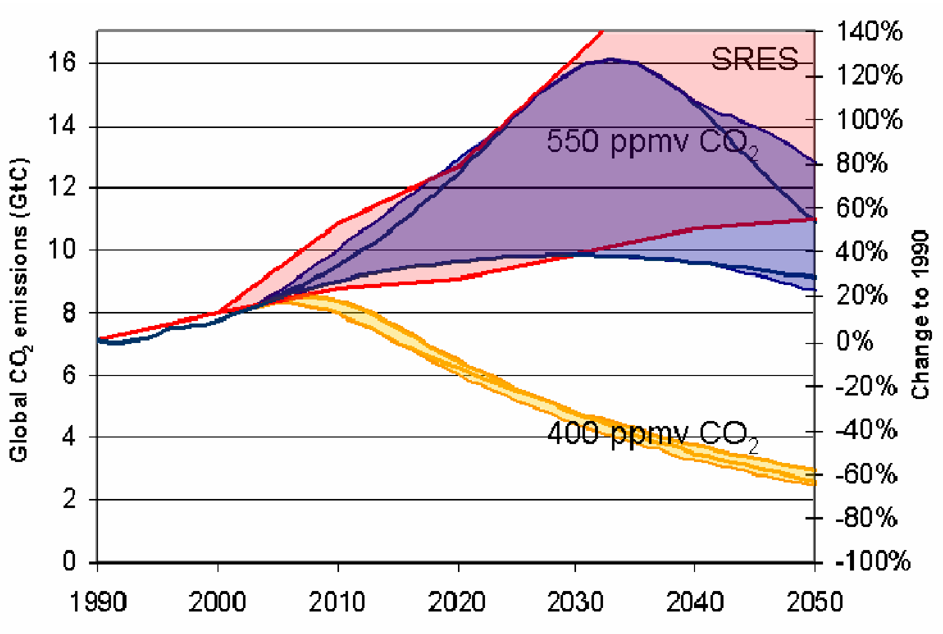

Figure 1 Possible global CO_2 emission pathways to 2050: Reference emissions and emissions corridors towards stabilisation at 400 ppmv CO_2 (450 ppmv CO_2e) and 550 ppmv CO_2 (650 ppmv CO_2e)

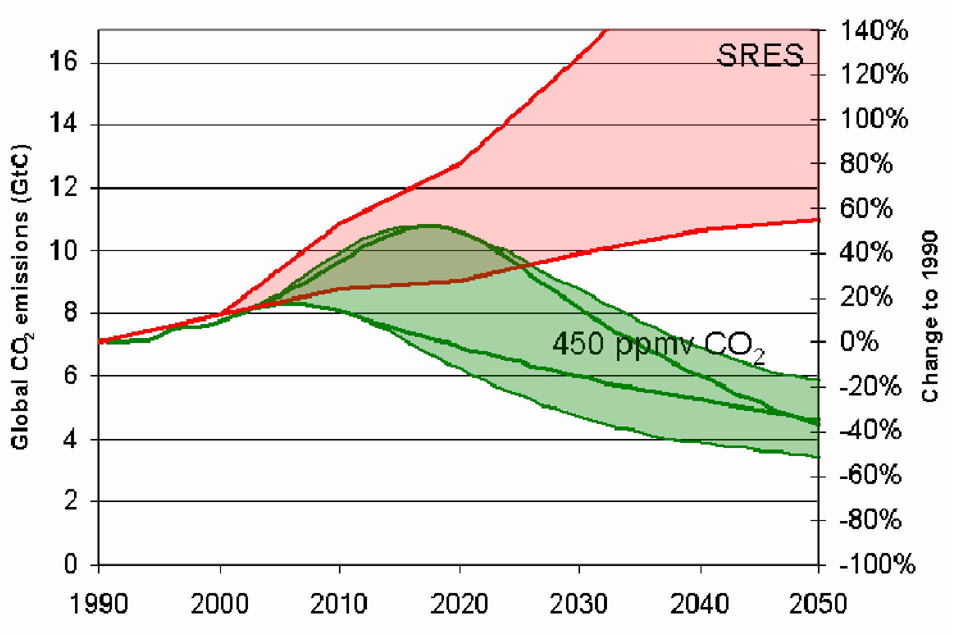

Figure 2 Possible global CO_2 emission pathways to 2050: Reference emissions and emissions corridors towards stabilisation at 450 ppmv CO_2 (550 ppmv CO_2e)

An understanding of the emissions corridor concept illustrates the importance of setting more frequent targets than ones for e.g. 2010, 2020 and 2050, and monitoring and reviewing these aspirations regularly – even annually.

A carbon budget is a complementary tool that can be used by governments, alongside targets, to define the appropriate emissions pathway towards a pre-defined long-term stabilisation goal. A carbon budget incorporates the consideration of cumulative emissions, but enables slightly more flexibility. A carbon budget could be structured within budgeting periods, for example, to enable compensation for the inevitable fluctuations in emissions between years as a result of e.g. economic cycles.

A carbon budget can be used by governments as a tool to help to manage emissions reduction targets, to check compliance with the targets and to readjust policy if necessary. A carbon budget should be firmly placed within a national or international emissions reduction framework in which long term target setting still remains a priority.

1.4 What is a carbon budget?

The concept of a carbon budget can be understood in many different ways. In this report, the following definition is used.

> A **carbon budget** is a set amount of carbon that can be emitted in a given amount of time, either by the whole economy, or a pre-selected sub-population or set of activities.

Setting the budget

The budget can be set according to a variety of different approaches. Approaches include estimating the maximum tolerance of the environment to different concentrations of greenhouse gases or estimating the technical potential to achieve emissions reductions. In this report, the potential carbon budget for the EU has been calculated for a pre-defined stabilisation rate of CO_2 in the atmosphere, accompanied by some assumptions about the rate at which it is possible to make emissions reductions. These assumptions are described in more detail in Appendix A.

Units

This report discusses the concept of a carbon budget measured in terms of the volume of carbon dioxide equivalent (CO_2e) emitted. This is calculated using the global warming potential (GWP) over a defined period for the different greenhouse gases, and expressing their climate change impact relative to the effect of carbon dioxide. Although there are always developments in this field of science and there are certain other important considerations, such as the differential impacts of gases emitted at different altitudes or in different temperatures, the UNFCCC uses a standard set of GWPs and expresses greenhouse gas emissions in terms of carbon dioxide equivalent (over a 100 year time period). It is logical to set any carbon budget according to this internationally agreed standard, and it is considered the most practical option in terms of monitoring emissions, understanding changes and considering the overall environmental impact of all greenhouse gases.

One alternative option would be to monetise the carbon values and express the budget as a financial value, thus increasing the profile of greenhouse gas emissions. However, the direct CO_2e reporting approach has been chosen here for two reasons. Firstly, to maintain the focus on the actual volume of greenhouse gas emitted to the atmosphere, which is the key environmental parameter. Secondly, at the time of writing this report, assigning a robust value to carbon is difficult. Existing carbon markets show extreme price volatility, making monetisation both impractical and confusing. In the future, this uncertainty should be reduced allowing financial reporting of a carbon, although for environmental effects, monitoring of the volume of CO_2e would still be paramount.

Scale

The concept of a carbon budget itself does not automatically relate to a certain scale. In theory a carbon budget could be set on a global, regional, national government, company or individual level. The choice of scale relates to the system within which a carbon budget is used.

In this report, the term carbon budget is used in its most general sense. Information and data is given at the European level (EU-25), which is then further disaggregated to the level of European countries. The figures generated for this report, however, have been generated within the context of a broader set of international commitments and therefore related to budgets of other nations and regions around the world.

Scope

Figures in this report cover all greenhouse gas emissions within the Kyoto basket (i.e. CO_2, CH_4, N_2O, HFCs, PFCs, SF_6). Environmentally, emissions of a longer list of greenhouse gases contribute to climate change. However, for policy purposes it is important that gases are attributable to clear actors, which is the case with the Kyoto basket of gases.

The calculations of a carbon budget at an EU-level include international transportation, and therefore also cover emissions from marine and aviation activities. These figures exclude land use change and forestry. The figures in this report have been calculated for the full basket of six Kyoto gases, using an approximation to indicate the figures for carbon dioxide only.

Control

One of the advantages of a carbon budget approach is that it would potentially give a high profile to carbon. To achieve such a high profile responsibility for the carbon budget would need to be taken at the highest possible level. For Europe, political responsibility for the carbon budget would have to be agreed. Key figures would include the European Presidency, the Council of Ministers, the European Parliament and the European Commission.

System Design
If a carbon budget were set for the EU, there are various ways in which the responsibility and break down for this budget could be divided to manage emissions in the European economy as a whole. This approach needs to be consistent with the policy approaches that already exist in Europe, and those that are planned, as outlined further in this report.

Trading versus budgets
Carbon budgets have been in the headlines most recently in relation to trading-type mechanisms. It is important to distinguish between budgets and trading at the outset of this report. A budget refers to the actual amount of carbon that is available – be it to a region, nation, firm or individual. A trading mechanism is a way in which division of this budget can be made more flexible.

This report is concerned primarily with the scale of a potential carbon budget for the EU, and how this relates to current European policies and approaches. The relationship of such a budget with trading options could be considered as a potential next step, once a budgetary system is established. Trading can be a way to make international and national targets more palatable, whilst trading would make budgeting at the small-scale (e.g. individual level) more practical and more appealing. However, setting a budget does not necessarily mean having a trading system.

1.5 Advantages of a carbon budget

As outlined above, a carbon budget is a policy tool that could be used as a means of expressing and managing the European approach to greenhouse gas reductions.

The carbon budget approach, as a part of a long term emissions reduction framework, has several advantages to managing emissions reductions over an approach based exclusively on target-setting. These include:

- The use of stronger terminology, indicating strict limits to emissions, which cannot be overshot;
- A tight relationship with a long-term emissions reduction pathway, to be monitored over time, ensuring a closer adherence to stabilisation goals than may be possible with traditional target-based approaches;
- A long-term perspective that can aid policy-makers, rather than put them under pressure at certain junctures (e.g. 2010, 20 and 50);
- Transparency of progress to the overall stabilisation goals that can help in the setting of particular European policies e.g. EU ETS caps, which are dependent on an understanding of national progress towards meeting certain goals (currently Kyoto);
- A carbon budget should be closely linked to the type of regular monitoring and review currently carried out by the European Environment Agency (EEA). This close linkage of a clear pathway and targets should help with strategic policy setting in the EU;

- The carbon budget approach could help to provide direction and certainty for businesses and investors in emissions reduction technologies across Europe. This could be particularly true if translated, at some point, into a carbon price signal;
- As the carbon budget effectively sets a cap on emissions for the whole economy for a given period of time, it could enable new trading opportunities within or between sectors across Europe. Such an approach could in turn lead to clearer price signals and thus contribute further to certainty for businesses.

1.6 Challenges of developing a Carbon Budget

It is important to note that although the concept of a carbon budget has many advantages, it is likely to also come under criticism.

Setting absolute emission reduction targets at the EU, and subsequently national level, is only likely to be supported in the context of international agreements, as has been made clear by the recent policy announcements in the EU Energy Package. It is for this reason that the carbon budgets presented in this report relate to models of international climate change agreements.

Furthermore, experience with the EU ETS cap-setting exercise has shown that setting an overall budget at the European level can be a very contentious process in itself, as is the sub-division of this budget further to the sector and company/installation level.

Therefore, the links between the headline carbon budget approach and the downstream policies and measures which lead to the necessary reductions have to be carefully considered. On the one hand these could be totally unrelated, with a carbon budget just acting as a profile-raising exercise. Alternatively, a carbon budget could be used to monitor progress along an emissions pathway, to add flexibility to achieving annual emissions targets and to enable policies and measures to be targeted more specifically towards areas where policies and measures are not working. It is this latter approach that would take the greatest advantage of an understanding of a carbon budget.

It is possible that the degree to which an EU carbon budget dictates high level policies and measures at the European level could be different from the way in which it is used at the individual Member State level.

1.7 Coverage of this report

The following section of this report presents the scale of a carbon budget for the EU-25 [2] under various potential international agreements to reduce emissions in the post-Kyoto period. The study also sets out the key economic reasons for taking action on climate change and provides a description of the current policies in place to achieve such reductions at the EU-level. The final section of the report describes how best to take the carbon budget concept further at the European level.

2 Setting a Carbon Budget for the EU

2.1 Introduction

This part of the report looks at the scale of a carbon budget for the EU-25 [6], following the assumptions laid out in Section 1.4 of this report. The carbon budget presented here is based on staying below a 450 ppmv CO_2e (400 ppmv CO_2) global stabilisation level from 2005-2050 and covers all sectors of the EU economy. This stabilisation level was chosen as the European Commission state that by stabilising long-term concentrations at around 450 ppmv CO_2e there is a 50% chance of keeping average global temperature increase to within 2 degrees Celsius[7]. The budget is calculated on the basis of the Kyoto basket of six greenhouse gases, and an approximation has been made to also provide figures for carbon dioxide only.

The calculations on reduction targets and the resulting emission budgets per country are based on the Evolution of Commitments Tool (EVOC) developed by Ecofys. (For a detailed description see Appendix A.)

The results are given both in terms of absolute carbon figures and indicative emissions reductions, as compared to a business as usual scenario. Taken together, these two sets of figures give a clear total emissions budget as well as an indication of the degree of effort necessary to reach stabilisation goals.

As future developments of emissions are uncertain, the reductions are calculated for each of the IPCC SRES scenarios (A1B, A1Fl, A1T, A2, B1, B2) and the median is represented in the results.[8]

Historic emissions for all EU-25 countries are based mainly on their national inventories as submitted to the UNFCCC. It has also been assumed that all EU-25 countries reach their Kyoto targets by 2010. To determine the emission reduction pathways, calculations for all of the emission reduction approaches have to meet set reference points in 2020 and

[6] Data was not yet available in the EVOC model for Romania and Bulgaria, the newest Member States, when this report was commissioned. It is estimated that emissions from these countries were around 65 and 133 Mt respectively in 2000.

[7] COM(2007)2: Limiting Global Climate change to 2 degrees Celsius. The way ahead for 2020 and beyond. 10 January 2007. http://ec.europa.eu/environment/climat/future_action.htm
Note that Friends of the Earth and Christian Aid believe that atmospheric concentrations should be stabilised considerably below 450 ppmv CO_2e in order to decrease the risk of exceeding a two degree increase, but for the purposes of modelling target from the Commission's Communication is maintained.

[8] The range of differences over the six scenarios are shown as error bars in the graphical representations.

2050. These points set global emissions at 10% above 1990 emissions in 2020 and 40% below 1990 emissions in 2050.

Ideally to minimise adverse impacts on the global climate the required stabilisation level of atmospheric greenhouse gases would be met by always staying below the target level, gradually approaching it from below and then levelling off. However it is also possible in theory to "overshoot" the required stabilisation level and then bring global greenhouse gas concentration back down to the required level (as illustrated in Figure 3). The final level of global greenhouse gas emissions would be similar in both cases.

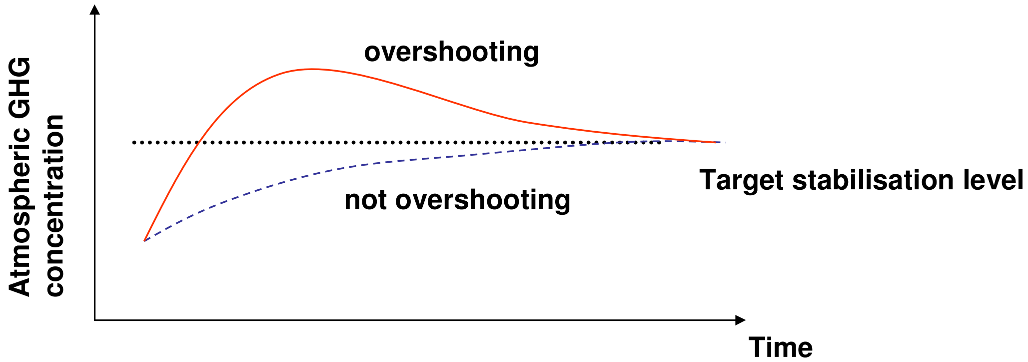

Figure 3 Illustration of how global greenhouse gas stabilisation level could be reached, with or without overshooting the target level

This possibility of overshooting is sometimes considered in literature (e.g. den Elzen and Meinshausen 2005), and in others it is excluded (e.g. Höhne et al. 2005a)[9]. For a detailed analysis of how the global concentration of greenhouse gases in the atmosphere relates to the risks of exceeding a global temperature increase of 2 degrees Celsius, and the concept of overshooting see also a report published in November 2006 by the Institute for Public Policy Research[10].

Given the current concentration of greenhouse gases in the atmosphere of around 380 ppmv CO_2, overshooting is considered particularly likely to occur if aiming for the lower global stabilisation levels studied in the climate literature. Within EVOC it would be possible to overshoot the reference point of +10% global emissions (compared to 1990) in 2020 and still be able to reduce emissions to reach the 400 ppmv CO_2 stabilisation level around 2100.

[9] For full references see Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for the Department for Environment Food and Rural Affairs (DEFRA), UK, prepared by Ecofys
http://www2.defra.gov.uk/research/project_data/More.asp?I=GA01093&M=CFO&V=ECOFYS

[10] Baer P, and M Mastrandrea (2006) High Stakes: Designing emissions pathways to reduce the risk of dangerous climate change, report published by Institute for Public Policy Research. http://www.ippr.org/publicationsandreports/publication.asp?id=501

2.2 Approaches to burden sharing

The EVOC model is based on different agreements on the burden-sharing related to reductions of greenhouse gases at the international level and results are presented on the basis of several different principles:

1. Contraction and convergence by 2050;
2. Common but differentiated convergence;
3. Multistage;
4. Global Triptych; and
5. GHG intensity targets.

The difference between these allocation methodologies and a technical description of the assumptions used in the model can be found in Appendix B to this report. Alternative approaches to burden sharing that are not modelled in EVOC are described briefly in section 2.2.1.A brief description of each approach modelled here is given below:

1. Contraction and convergence by 2050

Under Contraction and convergence (C&C)[11], all countries participate in the regime with quantified emission targets. Firstly, all countries agree on a path of future global emissions that leads to an agreed long-term stabilisation level for greenhouse gas concentrations ('Contraction'). As a second step, the targets for individual countries are set in such a way that per capita emissions converge from the countries' current levels to a level equal for all countries within a given period ('Convergence').

To reach a stabilisation of approximately 450 ppmv CO_2e convergence to about 2 tCO_2 per capita is necessary. In this case, contraction to average per capita emissions in 2020 of around 4 tCO_2 per capita is needed.

2. Common but differentiated convergence

Common but differentiated convergence (CDC)[12] is a modified version of C&C. In this approach, developed (or Annex I) countries' per capita emission allowances converge within e.g. 40 years (2010 to 2050) to an equal level for all countries. Individual non-Annex I countries' per capita emissions also converge within the same period to the same level. However, for this latter group of countries convergence only starts from the date when their per capita emissions reach a certain percentage threshold of the (gradually declining) global average. Those countries who do not pass this percentage threshold do not take on binding emission reduction requirements. However, they have the option to become involved in the scheme either through CDM projects, or by voluntarily taking on positively binding emission reduction targets. Under the latter, emission allowances may be sold if the target is overachieved, but no emission allowances have to be bought if the target is not reached.

---

[11] Meyer, A. (2000) *Contraction & convergence. The global solution to climate change.* Schumacher Briefings, No. 5. Bristol, UK; GCI (2005) *GCI Briefing: Contraction & Convergence.* Retrieved April, 2006. Global Commons Institute. http://www.gci.org.uk/briefings/ICE.pdf

[12] Höhne, N, M.G.J. den Elzen and M. Weiss. (2006) Common but differentiated convergence (CDC), a new conceptual approach to long-term climate policy. *Climate Policy (accepted)*

3. Multistage
Under the Multistage approach countries participate in several stages, with differentiated types and levels of commitments[13]. Countries engage gradually through the stages as they exceed certain thresholds (e.g. emissions per capita or GDP per capita). Under this model four stages are considered, going from the lowest level of commitment to the highest: no commitments, enhanced sustainable development, moderate absolute targets, and absolute reduction targets. Each of these stages has stage-specific commitments associated with them.

The parameters needed for the 450 ppmv CO_2e are very demanding, requiring almost all developing countries to participate in stages 2 and 3 almost from the outset. The levels of emissions reductions required at each stage are very demanding (see Appendix B).

4. Global Triptych
The global Triptych approach allocates emission allowances to countries on the basis of several national indicators.[14] It takes into account the key differences in national circumstances relevant to emissions and emission reduction potentials. In this model it is assumed that all countries participate and take on equal levels of commitment.

The parameters for the 450 ppmv case are demanding, requiring 70% to 95% renewable and emission-free electricity in 2050, 70% to 95% reduction in electricity generation from coal and oil, and convergence to an industrial energy efficiency that is 50% to 70% better than best available technology in 1995.

5. GHG intensity targets
A variety of greenhouse gas intensity targets could be used here and expressed as dynamic variables e.g. as a function of the GDP ("intensity targets") or variables of physical production (e.g. emissions per tonne of steel produced)[15]. Dynamic targets provide more flexibility to countries, allowing for unpredicted changes to economic, and therefore emissions, development. Such targets are set in a manner that does not limit the economic growth of countries, but requires that economic development takes place in a carbon-efficient way.

---

[13] E.g. Claussen and McNeilly 1998; Gupta 1998; Berk and den Elzen 2001; USEPA 2002; Blanchard et al. 2003; CAN 2003; Criqui et al. 2003; den Elzen et al. 2003; Gupta 2003; Höhne et al. 2003; Ott et al. 2004; Blok et al. 2005; den Elzen 2005; den Elzen et al. 2005b; Höhne et al. 2005a; Höhne and Ullrich 2005; Michaelowa et al. 2005; den Elzen et al. 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

[14] Unlike e.g. the Multistage approach which is more a framework of stages that can be filled with different allocation methods for the several stages or C&C which is based only on per capita emissions.

[15] E.g. Hargrave et al. 1998; Baumert et al. 1999; Lutter 2000; Müller et al. 2001; Bouille and Girardin 2002; Chan-Woo 2002; Lisowski 2002; OECD/IEA 2002; Ellerman and Wing 2003; Höhne et al. 2003; Müller and Müller-Fürstenberger 2003; Jotzo and Pezzey 2005; Pizer 2005; Kolstad 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

2.2.1 Alternative approaches not modelled

In addition to the five described above and modelled within EVOC, there are a number of alternative approaches that could be considered to divide the greenhouse gas emissions budgets internationally. Three alternatives that are not modelled here are described below for reference.

The Sectoral Approach

Different sectoral approaches are discussed actively in various international fora. Sector-specific approaches aim to reduce emissions by applying the same rules for a particular sector across all countries, thus avoiding many competitiveness concerns.

One such approach[16] proposes that developed (i.e. Annex I) countries would continue to receive absolute emission reduction targets. At the same time, key developing countries would pledge to achieve a voluntary sector "no lose" GHG intensity target (e.g. emissions per tonne of steel) in major energy and heavy industry sectors (e.g. electricity, cement, steel, oil refining, pulp/paper, metals, etc). The inclusion of the top 10 largest GHG emitting developing countries in each sector would ensure coverage of 80-90% of developing country GHG emissions in each of the selected sectors.

The Brazilian historical responsibility proposal

The approaches described here so far quantify the capacity for greenhouse gas emissions remaining in the global atmosphere (the carbon budget), and divide these emissions between countries according to current and projected country or sector-specific characteristics. It would also be possible however to consider alternative approaches which take into account countries' contribution to the volume of greenhouse gas that has already been emitted.

During the negotiations of the Kyoto Protocol in 1997, the delegation of Brazil proposed to share the burden of emission reductions according to the historical responsibility of countries for climate change. With the adoption of the Kyoto Protocol in 1997, the so-called "Brazilian Proposal" has essentially been overtaken, but the consideration of its methodological and scientific aspects has been subject to continued debate within the international negotiations and in the scientific literature[17].

According to the Brazilian Proposal, reduction obligations between countries should be differentiated in proportion to a country's relative share of responsibility for climate change. How far back historical responsibility is defined is a matter of debate. Suggestions could range from pre-industrialisation to the much more recent past, for

[16] Developed into a global regime by the Center for Clean Air Policy (CCAP) (Schmidt et al. 2006)

[17] UNFCCC 1997; Rose et al. 1998; Meira Filho and Gonzales Miguez 2000; Pinguelli Rosa and Ribeiro 2001; den Elzen and Schaeffer 2002; den Elzen et al. 2002; La Rovere et al. 2002; Andronova and Schlesinger 2004; Pinguelli Rosa et al. 2004; Trudinger and Enting 2004; den Elzen et al. 2005a; den Elzen et al. 2005c; Höhne and Blok 2005; Rive et al. 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

example at the formation of the UNFCCC when the limits of the atmosphere were officially acknowledged by the international community.

The further back in time historical responsibility is measured, in general, the greater the responsibility many Annex I countries would take and potentially the more stringent their emissions budgets would be in the coming years. Difficulties to consider when defining country-specific burdens under such an approach would be the availability and robustness of historic emissions data, particularly in the more distant past, and the implementation of very stringent emissions cuts.

Greenhouse Development Rights (GDRs)

The GDR framework is currently being developed by Christian Aid and US-based EcoEquity. As with the Brazilian Proposal, the GDR framework also takes historic emissions into account and calls for developed countries to take on a much increased responsibility for emissions reductions. The focus of the GDR framework is the concept of equity.

The GDR approach suggest that those countries with the greatest responsibility for the current atmospheric concentration of greenhouse gases and with the highest levels of human and economic development must take on the majority share of the global emissions reduction burden. This means that industrialised countries with a high standard of living would not only have to carry out mitigation activities nationally, but would also take on responsibility for a share of those activities globally, which could amount to more than 100% of their national emissions.

The basis for the approach has been proposed as cumulative emissions since 1990 and current capacity in terms of ppp (purchasing power parity) adjusted wealth per capita.

Under GDRs, the focus is not on the automatic acquisition of one's rights to pollute but on the sharing of the global burden to reduce pollution on the basis of responsibility for the crisis and capacity to deal with it. This, Christian Aid believes, reflects the current reality of severe resource constraints and extreme poverty.

2.2.2 Assessing cumulative emissions

As an example, the EU carbon budget is calculated under the contraction and Convergence (C&C) approach (see section 2.4). Data are used for C&C as it is implemented in the Evolution of Commitments (EVOC) model developed by Ecofys. (For more detailed information on EVOC see Appendix A.) The implementation of C&C is comparatively simple. Each year's emissions are reduced on a global scale to meet the long-term reduction path. The emissions allowances for the single countries are distributed according to their per capita emissions as described above. Therefore, a clear assessment of cumulative emissions and thus a transparent carbon budget for the years from 2005-2050 can be provided under this approach. As illustrated in Figure 4 below, C&C also leads to intermediate emission reduction requirements from the EU-25 compared to other approaches, and as such a carbon budget calculated under C&C is a useful illustration of the magnitude that a European carbon budget out to 2050 should take.

Allocation of emissions to different countries at the global scale is more complicated for all of the other approaches, as they are by their nature more complicated to implement. The methodology to implement them in EVOC is therefore also more complicated. Two separate reduction paths, with different sets of parameters, are defined in EVOC for the different approaches, one to +10% global greenhouse gas emissions in 2020 and one to -40% in 2050. As a result of the different parameters interpolation between the two years is not possible. Clear targets for the EU-25 are therefore given for 2020 and 2050 for all approaches, and a semi-qualitative assessment of the implications for an EU carbon budget, as compared to the contraction and convergence approach is given.

2.3 Setting the carbon budget in context

As explained earlier, it is both the EU's cumulative emissions until 2050 and the defined emissions reduction pathway that are important to achieve a given stabilisation level of greenhouse gases in the atmosphere. However, the relevant 2020 and 2050 obligations under each of the international allocation approaches give an important indication of the scale of effort required. Any carbon budget for the EU-25 will be closely linked to these internationally agreed reduction obligations.

Figure 4 shows the percentage change in emissions required from the EU-25 in 2020 and 2050, compared to 1990 levels, across the different allocation methodologies, and in comparison to overall Annex I and non-Annex I countries internationally.

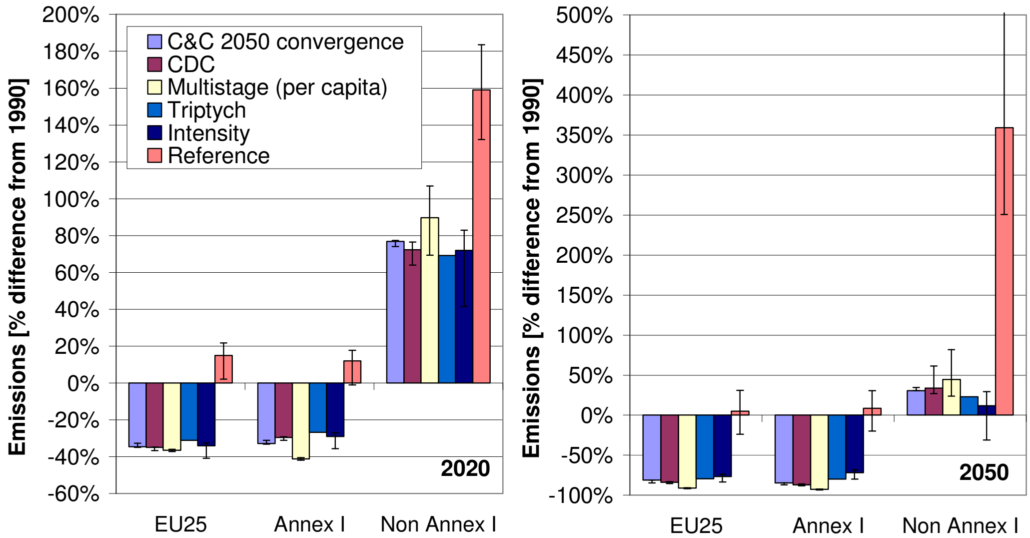

Figure 4 Changes in Emission allowances for EU-25, Annex I and non-Annex I in 2020 (left) and 2050(right) according to the different emission reduction approaches to achieve a 450 ppmv CO_2e stabilisation level

Figure 4 shows the initial allocation of emissions targets before any potential trading takes place between countries. The final emission levels after trading could be different from those shown.

Figure 4 shows that significant reductions below 1990 levels are necessary for all approaches and stabilisation levels from developed (Annex I) countries in addition to early deviation from the business as usual case in developing countries (non-Annex I). Table 11 and Table 12 in Appendix C (Emissions data) show the percentage emissions reduction (compared to 1990) for each European country and the EU as a whole under the different burden sharing approaches by 2020 and 2050 respectively.

For the EU as a whole greenhouse gas emissions reductions of between 31% (Triptych approach) and 36% (Multistage) compared to 1990 would be required in 2020 to meet the required stabilisation level (Table 11). This compares to a 20% emissions reduction already committed to by the EU, with an agreement to increase that to 30% if other countries will also agree to binding emission reduction action.

By 2050 it is estimated that emissions reductions between 76% (intensity approach) and 91% (Multistage) compared to 1990 would be required for the stabilisation level to be met (Table 12).

Table 1. Average annual emission reductions under all considered approaches (Figure 4)

	Annual reduction under Contraction and Convergence			
	2010-2020		2010-2050	
	min	max	Minmin	max
EU 25	-3% (Triptych)	-4% (Multistage)	-3% (Intensity)	-6% (Multistage)
Annex I	-3% (Triptych)	-5% (Multistage)	-3% (Intensity)	-6% (Multistage)
Non-Annex I	0% (Multistage)	-1% (Triptych)	-1% (Multistage)	-1% (Intensity)

Table 1 shows the minimum and maximum annual percentage emissions reduction required in the EU-25 and overall Annex I and non-Annex I countries in the period 2010 to 2020 and over the whole period 2010 to 2050. The minima and maxima refer to the different burden sharing approaches represented in Figure 4. For example, in the EU-25 an average 3% emissions reduction per year would be required between 2010 and 2050 to reach the required stabilisation level if the greenhouse gas intensity approach to burden sharing is taken. If the multistage approach to burden sharing were chosen, the EU's contribution to emissions savings over the period would be relatively higher and an average 6% emissions reduction per year would be required over the period to reach the required stabilisation level.

Importantly, the difference in effort required between the allocation approaches is comparatively small, particularly for the EU-25. Different emission reduction approaches focus on different parameters, such as emissions per GDP, emissions per capita or emission intensity in energy and industry. Thus, the results for single countries, especially for smaller non-average countries, can diverge among the approaches. (Average annual emission reductions for each EU country under the C&C approach are detailed in Table 15 in Appendix C.) In the global context however the EU is a comparatively homogeneous group. Therefore, for the EU as a whole these effects compensate quite well, as can be seen in Figure 4. There is a span of less than ten percentage points in 2020 and less than 20 percentage points in 2050 across the methods. For most individual Annex I countries the resulting reductions below 1990 levels under all approaches are dominated by the starting point (the Kyoto target). The key element in determining the scale of effort is the stabilisation level to be achieved.

Although the emissions reductions required are relatively similar across the allocation approaches, some observations can be made about how the different methodologies distribute a constant level of global emissions over the regions.

Under C&C, all countries participate and developing countries with high per capita emissions may need to reduce substantially. For the EU-25, C&C results in comparatively average reduction obligations compared to all other approaches, and as such a carbon budget calculated under C&C gives a useful illustration of the magnitude that a European carbon budget out to 2050 should take. Under C&C the EU as a whole would be required to make average annual emissions reductions of 3% per year between 2010 and 2020 or 4% per year over the whole period 2010 to 2050 (Table 15).

The CDC approach assumes action by developed countries first and delayed action by developing countries. In Annex I countries the per capita emissions have to converge comparatively soon, in a similar but more stringent way to under C&C. Therefore, some developing countries (non-Annex I) would have more possibilities to develop and might reduce their per capita emissions later than under C&C. Hence, the reductions necessary for the EU-25 under this approach are slightly higher in than for most of the other approaches.

The assumptions used for the Multistage approach lean even further toward reductions by Annex I countries and delayed reductions by non-Annex I countries than the CDC approach, accentuating this effect. This is illustrated in Table 1, which shows that the maximum annual percentage emissions reductions from Annex I are required when the multistage approach to burden sharing is used, and conversely the minimum percentage emissions reduction is required from non-Annex I countries. The major reason for this is that most developing countries participate later in the reduction stage compared to the other approaches to reach reasonable thresholds for the different stages.

The Triptych approach makes a relatively greater demand on developing countries (particularly the coal-intensive countries in Africa and South Asia in 2050) than for other cases, resulting in less stringent obligations for the EU-25 and Annex I as a whole. In this approach all countries participate after 2010. Sectors that have a major impact on emissions are the electricity and the industry sectors, as well as the domestic sector, which here includes transport. As the reduction settings have to be very stringent to reach the target reduction path these have a comparatively higher impact on many developing countries than other approaches.

Under the greenhouse gas intensity targets approach reduction efforts are more stringent for most Annex I countries, at least in the short term. It has to be kept in mind, though, that this approach is strongly linked to the assumptions of GDP development. The growth rates are assumed to be similar for all EU-25 countries currently in EVOC and are lower than for developing countries and economies in transition. Therefore, the results under the intensity targets approach are also very stringent for the EU countries, compared to other approaches.

2.4 A carbon budget for the EU

The scale of a potential carbon budget is calculated here for the EU-25 [18] as a whole out to 2050 under a stabilisation goal of 450 ppmv CO_2e. As a simple, transparent approach which also leads to an intermediate level of emissions targets for the EU-25 in both 2020 and 2050, the contraction and convergence approach has been used to calculate the EU's overall carbon allocation and to divide the carbon budget between Member States. Data is presented here in several different steps:

1. An overview of annual absolute emissions for the EU-25, showing an error margin according to the six SRES scenarios;
2. An overview of annual absolute emissions for individual European countries;
3. A calculation of the change in per capita emissions to 2050 for individual European countries and Europe as a whole;
4. A calculation of the maximum level of greenhouse gas emissions required from each EU country in the years 2010, 2020, 2030, 2040 and 2050,
5. An overview of cumulative emissions from 2005-2050 for the EU-25, the "carbon budget", showing an error margin according to the six SRES scenarios; and
6. An overview of the carbon budget for the EU-25 and for individual European countries, including an estimate of the carbon dioxide element of the cumulative emissions for individual countries and Europe as a whole.

Each of the different representations of the data is useful in understanding the scale of reductions necessary to meet a stabilisation value of 450 ppmv CO_2e; however it is the cumulative figures that relate directly to the carbon budget concept. It is this cumulative volume of emissions that could be used as a "budget" with more flexibly as part of a regional or national policy tool in order to achieve the contraction and convergence targets.

[18] Data was not yet available in the EVOC model for Romania and Bulgaria, the newest Member States, when this report was commissioned. It is estimated that inclusion of Romania and Bulgaria in an EU carbon budget from 2005 to 2050 would increase the EU-25 budget by between 1% and 4% (see page 21).

1. **Overview of annual absolute emissions for the EU-25**

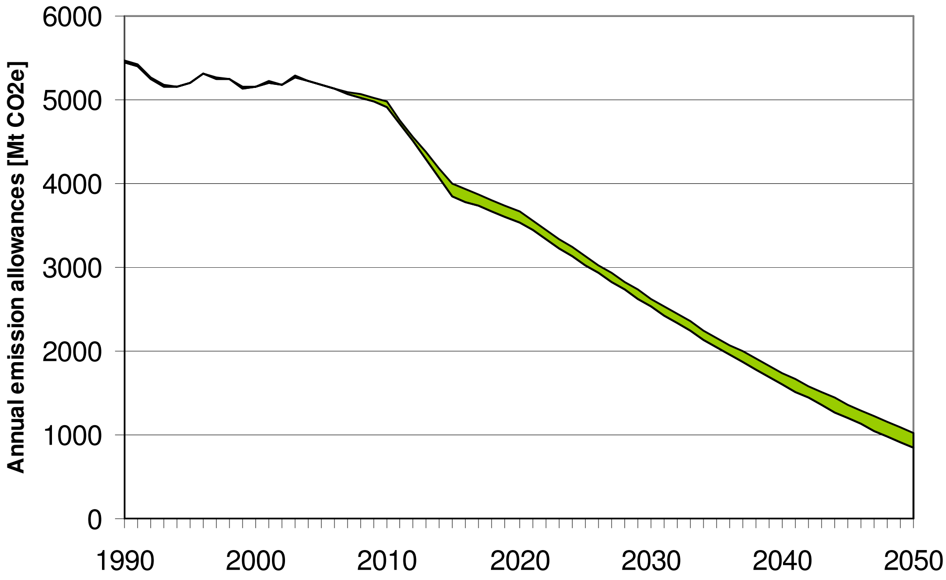

Figure 5 Absolute annual emission allowances according to C&C for the EU-25 as a whole between 2005 and 2050 (showing range according to consideration of 6 SRES scenarios)

Figure 5 shows the absolute level of greenhouse gas emissions in the EU-25 each year to 2050, and hence the change in emissions necessary within Europe as a whole (under the international contraction and convergence scenario) to meet the 450 ppmv CO_2e stabilisation level. The figure shows the very rapid reduction in emissions necessary from 2010 onwards. The annual emissions reductions illustrated in Figure 5 translate to an average annual emissions reductions of 3% per year between 2010 and 2020 or 4% per year over the whole period 2010 to 2050 for the EU as a whole (Table 15 in Appendix C).

For the EU as a whole (under C&C) a total emissions reduction of 35% by 2020 and 81% by 2050, compared to 1990, would be required to meet the given stabilisation level of 450 ppmv CO_2e (see Table 11 and Table 12 in Appendix C). The -35% in 2020 figure compares to 20% already committed to by the EU, with an agreement to increase that to 30% if other countries will also agree to binding emission reduction action.

The contraction and convergence model used relies on an assumption that the per capita emissions required globally in 2050 to reach the stabilisation level of 450 ppmv CO_2e are approximately 2 tCO_2e per capita. Further calculations have been carried out within the model, based on population estimates, to show the change in per capita emissions per EU country over time according to the emissions pathway that results from the model. Emissions per capita over the time period and population projection assumptions are detailed in Table 8 and Table 9 in Appendix C. The overall level of ambition per capita reflects the steep change in emissions behaviour required by the EU as a whole.

2. Overview of annual absolute emissions for individual European countries

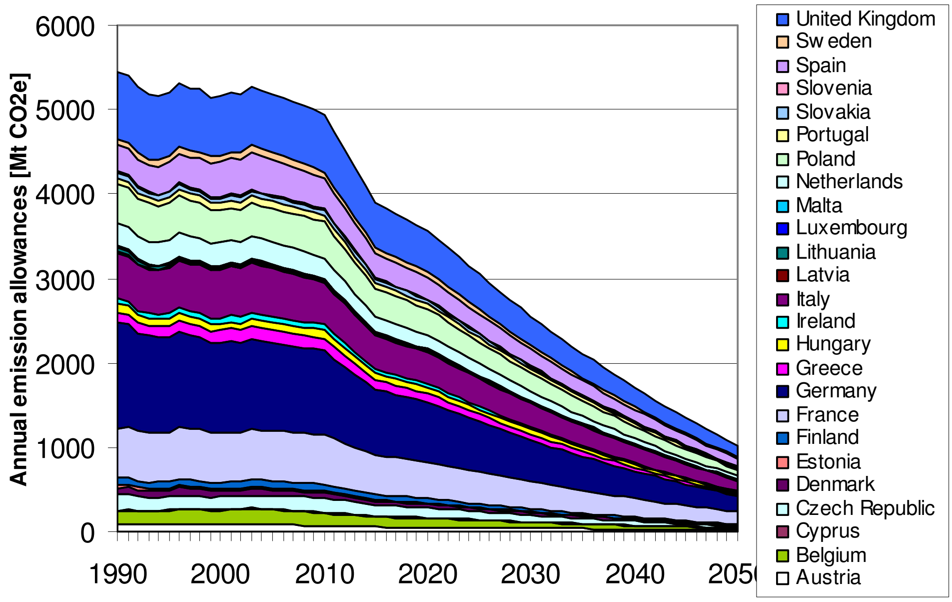

Figure 6 Absolute annual emission allowances according to C&C for individual EU countries between 2005 and 2050 (median values)

Figure 6 shows the absolute annual emissions from Figure 5 (median value) divided between the 25 EU Member States, using the contraction and convergence approach within Europe. The highest shares of EU emissions relate to Germany, France, the UK and Italy. As already indicated above, these figures show that substantial emission reductions will be necessary immediately after the Kyoto Protocol[19] to have a good chance to achieve stabilisation at 450 ppmv CO_2e.

3. Change in per capita emissions to 2050

A calculation of the change in per capita emissions to 2050 if a C&C approach is used to reach the 450 ppmv CO_2e stabilisation level is shown in Table 8 in Appendix C, for individual European countries and the EU as a whole. (Table 9 in Appendix C shows the underlying population projection assumptions for each EU country.) Per capita emissions contract and converge to 2 $MtCO_2e$ for all countries by 2050.

4. Maximum level of greenhouse gas emissions required from each EU country in specific years

Table 10 in Appendix C shows the level of greenhouse gas emissions from each European country and the EU as a whole in each of the years 2010, 2020, 2030, 2040 and 2050 if the emissions pathway shown in Figure 6 is followed.

[19] The model assumes here that all countries meet their Kyoto Protocol target in 2010, hence a step change in emission levels required is witnessed after 2010.

5. Overview of cumulative emissions from 2005-2050 for the EU-25, the "Carbon Budget"

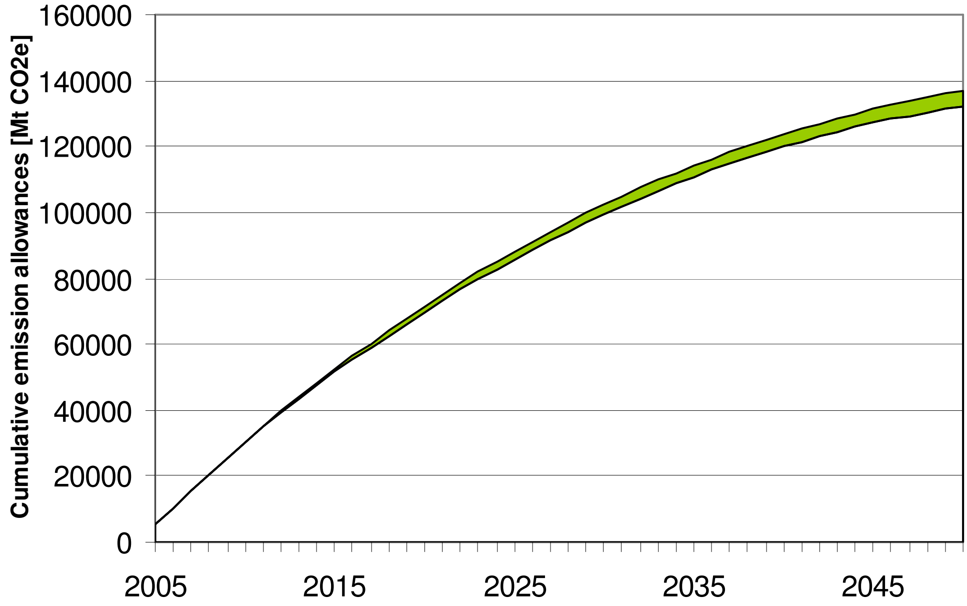

Figure 7 Cumulative emission allowances for the EU-25 between 2005 and 2050 according to C&C (range according to 6 SRES scenarios)

Figure 7 shows that the overall EU-25 carbon budget.[20] According to the results of this modelling using a contraction and convergence approach, with an intermediate level of emissions reductions from the EU-25 to reach stabilisation at 450 ppmv CO_2e (see Figure 4), the carbon budget for the EU-25 from 2005 to 2050 would be **134 GtCO_2e**. This translates approximately to a carbon dioxide only budget of around 109 GtCO_2e. The budget for all greenhouse gases compares to a median "BAU carbon budget" of around 280 GtCO_2e, and is equivalent to a -45 to -55% reduction in emissions compared to cumulative BAU emissions by 2050 (see Table 14 in Appendix C).

This conclusion assumes an emissions reduction pathway as shown in Figure 5 (median value) and therefore it is important how this budget is distributed and used over the years. However, a carbon budget tool could enable a degree of flexibility between absolute annual volumes of emissions within small timeframes e.g. a three to six year cycle. This type of cycle would enable policy makers to keep a clear watch on the progress along the emissions reduction pathway and in relation to cumulative emissions and to modify climate policies accordingly.

[20] Under C&C cumulative emissions allowances for the EU 27 would include Bulgaria (2 Gt CO_2e between 2005 and 2050) and Romania (5 Gt CO_2e between 2005 and 2050). This would increase the EU carbon budget by 1% to 4%.

6. Overview of the carbon budget for the EU-25 and for individual European countries

Figure 8 shows the same data as Figure 7, cumulative emissions to 2050, but divided up between the individual European countries. This illustrates how a European carbon budget could be further divided to the national level.

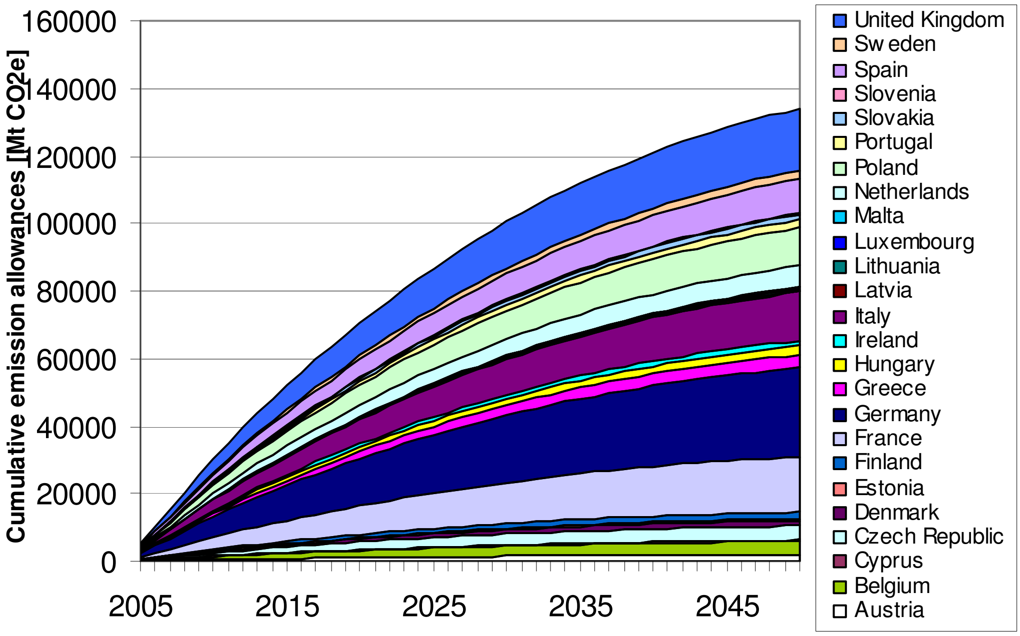

Figure 8 Cumulative emission allowances for individual European countries between 2005 and 2050 according to C&C (median values for all countries)

Table 2 "Carbon Budget": Cumulative emission allowances between 2005 and 2050 for the EU25 (according to C&C) in $MtCO_2e$

Country	Carbon Budget all GHG ($MtCO_2e$, median)	Error (± %)	Share of CO_2 in total emissions (% in 2000)	Carbon Budget estimate CO_2 only ($MtCO_2$)[21]
Austria	2,050	2	81	1,661
Belgium	3,856	2	86	3,316
Cyprus	338	4	88	297
Czech Republic	4,218	6	86	3,627
Denmark	1,624	2	79	1,283
Estonia	572	4	87	498
Finland	1,898	2	82	1,556
France	16,442	2	73	12,003
Germany	26,261	3	86	22,584
Greece	3,852	2	80	3,082
Hungary	2,602	4	71	1,847
Ireland	1,609	3	65	1,046
Italy	14,409	2	83	11,959
Latvia	432	5	69	298
Lithuania	718	4	66	474
Luxembourg	231	2	93	215
Malta	106	4	88	93
Netherlands	6,242	2	82	5,118
Poland	11,274	3	82	9,245
Portugal	2,358	2	78	1,839
Slovakia	1,593	6	82	1,306
Slovenia	485	2	80	388
Spain	10,269	2	80	8,215
Sweden	2,246	2	79	1,774
United Kingdom	18,293	2	82	15,000
EU-25	133,980	2	81	108,524

Table 2 provides the cumulative emissions data, the "carbon budget", for all EU-25 [20] countries and for the EU-25 as a whole for the period 2005 and 2050. In keeping with the emission reduction pathways shown in the earlier figures, the countries with the biggest carbon budgets would be Germany (26 Gt CO_2e), the UK (18 Gt CO_2e), France (16 Gt CO_2e), Italy (14 Gt CO_2e), Poland (11 Gt CO_2e) and Spain (10 Gt CO_2e) as these are the countries with the largest projected populations.

[21] Based on the assumption that the shares of CO_2 in total emissions stay constant (at 2000 level) over the whole period.

These figures have all been provided for the Kyoto basket of six greenhouse gases. Estimates of the carbon budget in terms of carbon dioxide alone are also provided in Table 2 on the basis of the share of carbon dioxide in 2000. As the model provides flexibility in the approach with respect to achieving the targets under the C&C models, no assumptions are made about how the percentage shares of different greenhouse gases might change.

2.5 A Carbon budget under different allocation methodologies

A carbon budget, in terms of cumulative emissions from 2005 to 2050, can only be estimated with a reasonable degree of accuracy under the C&C approach using the EVOC tool (see section 2.4). However, it is possible to make a qualitative assessment of how the carbon budget might change between the allocation approaches.

Taking C&C as a reference the differences between the approaches result in a divergence in the absolute greenhouse gas emissions for the EU-25 in 2020 of +5% (Triptych, less stringent emission target for EU-25) and -3% (Multistage, more stringent emission target for EU-25) . In 2050 the approaches diverge by extremes of +25% (Triptych) and -53% (Multistage) compared to the C&C allocation. Assuming a linear behaviour of these divergences from 2020 to 2050, it is estimated that the overall carbon budget (i.e. the cumulative emissions between 2005 and 2050) should lie in the range of -12% to +7% compared to the carbon budget under C&C, depending on the approach chosen. In absolute figures the carbon budget for the EU-25 carbon budget would lie between 119 and 144 $GtCO_2e$ across all of the approaches. To reiterate, the more stringent carbon budget for the EU-25 (119 $GtCO_2e$) would represent a carbon budget under the Multistage approach, and the less stringent carbon budget for the EU-25 (144 $GtCO_2e$) would represent a carbon budget under the Triptych approach.

The relatively small difference in relation to C&C reflects the observation in section 2.4 that the scale of emissions reductions required for the EU-25 differs very little between the different allocation approaches, and is far more greatly affected by the level of greenhouse gas stabilisation desired. It is also important to note that the scale of the carbon budget will be dependent on the assumptions used in the model under each approach (see Appendix B), however, these have been carefully chosen in order to achieve the given stabilisation level of 450 ppmv CO_2e (400 ppmv CO_2).

3 Why take action?

3.1 Introduction

To argue for binding targets and the use of a carbon budget approach in the EU it is important to justify clearly why action should be taken now to reduce greenhouse gas emissions. This section of the report sets out these arguments, as they exist in the current literature.

3.2 Evidence is growing

Scientific consensus on the global impacts of climate change is building. Due to the nature of predicting large scale impacts on the global climate over large periods of time, the precise scale and timing of many of these impacts are subject to a degree of uncertainty. However there is a large and growing body of research into the potential magnitude of climate change impacts and recommendations as to our response to avert or adapt to these impacts.

Towards the end of 2006 several major reports were published which pull together a consensus from the literature to estimate the likely costs of climate change impacts and the potential costs of action to mitigate climate change. In particular the reports highlight the pros and cons of action taken now to mitigate climate change versus a delay in the international community taking action to mitigate climate change.

In November 2006 the Stern Review was published in the UK. The review, commissioned by the UK Government and led by former World Bank Chief Economist Sir Nicholas Stern, is the most comprehensive to date on the economics of climate change. The review collated a large body of material on the economics of climate change, including several studies carried out by leading scientists and economists for the purposes of the review. The final report published a simple conclusion: “the benefits of strong and early action [to combat climate change] far outweigh the economic costs of not acting.”

Just prior to this in October 2006, Friends of the Earth UK published “The Costs of Inaction” prepared by Tufts University Global Development and Environment Institute (GDAE) in the United States. The report, by researchers Frank Ackerman and Liz Stanton, is a survey of over one hundred economic and scientific papers on climate change. The report aims to compile the most recent work on the science and economics of climate change to outline the costs of inaction on climate change both at a global level and at a UK level.

In December 2006, the German Advisory Council on Global Change (WBGU) issued another analysis of climate change economics[22]. Stern estimates that the costs of a pro-active climate policy aimed at stabilising greenhouse gas concentration at 550 ppm CO_2e by the year 2050 will manifest themselves through a reduction of annual global GDP by 1% against the reference case during the next one hundred years. However the WBGU says that to stay within a 2°C average global temperature increase, the target must be stabilisation at 450 ppm CO_2e or below (Meinshausen, 2006), in concurrence with the European Commission Communication released on 10 January 2007 [3]. The WBGU analysis shows that this ambitious stabilisation target could be achieved at costs of less than 1.5% of global GDP. These estimates are based on the assumption that a stringent and reliable climate policy will indeed be adopted, and highlights the fact that staying below the 2°C temperature increase rail is worthwhile from a macro-economic perspective as well.

3.3 The economic arguments for action

If global emissions go unchecked average global temperatures could increase by up to 5 degrees Celsius.

An increase in average global temperature of 5 degrees Celsius (relative to pre-industrial times) would have a profound affect on the global climate, with far reaching impacts.

The Stern Review highlights five broad areas in which climate change is likely have social and economic impacts: food, water, ecosystems, extreme weather events and risk of abrupt and major irreversible change. The impact of climate change on society will depend on the scale of any changes in the physical environment, but also on vulnerability to those changes. So for example, health effects of high summer temperatures will be exacerbated by air pollution and by poor delivery of health care systems.

Even within these categories impacts are wide ranging. For example, a temperature increase of around 0.5-2°C would see the increased melting of mountain glaciers in many regions, which could disrupt local water supplies in very localised regions. An increase in temperature of the magnitude 2-4.5°C would exacerbate this problem and is likely to lead to major water shortages in many regions, also caused by increased frequency of drought in some regions. The summer 2003 heat wave and drought conditions in Europe already caused significant economic impacts in agriculture and forestry, with losses estimated at 13 billion euros[23].

[22] WBGU (2006) *New impetus for climate policy: making the most of Germany's dual presidency*. German Advisory Council on Global Change. http://www.wbgu.de/wbgu_pp2007_engl.pdf
[23] Assessment of the impact of the heat wave and drought of the summer 2003 on agriculture and forestry http://www.copa-cogeca.be/en/dossiers.asp

Equally, with the same magnitude of temperature increase some regions will see increased rates of flooding at certain times of the year. Increased melting of Arctic and Antarctic ice sheets with higher temperature increases will lead to increasing sea level rise around the globe, with the permanent loss of large areas of low-lying land. The impacts of which are estimated to affect 75-200 million people around the world, depending on the adaptive capacity. In Europe, one third of the population is estimated to live within 50km of the coast. There are already areas with significant populations who live below normal high-tide levels in countries such as the Netherlands, England, Denmark, Germany and Italy.

Increases in temperature of 1.5°C or more would begin to cause decreasing crop yields due to drought - this effect would be felt much earlier particularly in developing countries, where water shortages can already be a problem. With the Stern Report associating a stabilisation level of 550 ppm CO_2e with a temperature range of 1.5°C to over 4.5°C, and the IPCC 4th Assessment Report indicating that temperature increases of between 2.4°C and 6.4°C are possible by the end of the century under high emission scenarios, concerns regarding decreased crop yields appear well-founded.

As temperature increases, there is predicted to be a rising frequency and intensity of extreme weather, leading to events such as floods, drought and forest fires. The economic effect of such events is already being felt, with 2004 marked by the occurrence of natural events extreme in both their number and the economic losses they caused. Approximately 650 natural events were recorded, causing economic loss of €120 bn (compared to €50 bn in 2003) and insured losses of €36 bn (compared to €12 bn in 2003) [24]. Losses for hurricane Katrina are estimated as high as US$135 bn (Tufts 2006).

The potential global impacts of climate change are increasingly well understood, although the true extent and timing of impacts is less certain. There are also still large areas of uncertainty that scientists are working to better understand, such as small changes that could lead to abrupt and potentially catastrophic impacts. One example of this which could severely affect Northern Europe could be an increase in fresh water in the North Atlantic caused my melting glaciers, causing the North Atlantic Gulf Stream to shut down, cutting off the flow of warm water and air to North Western Europe that keeps the temperature mild. Complex feedback mechanisms are also at work within the global climate that could speed up such affects. For example, ice sheets are a very good reflector of the sun's rays. As they melt and expose the rock underneath, the sun's rays are increasingly absorbed by the dark rock, speeding up the melting process.

[24] Climate change and natural events: Insurers contribute to face the challenges. Comité Européen des Assurances (CEA), 2006

The cost of taking action to mitigate climate change is outweighed by the costs of not taking action

The Stern Review suggests that it would cost around 1% of global GDP every year to keep climate change at manageable levels. In contrast, the report warns that inaction could trigger damaging climate change impacts that could cost the global economy at least 5% of GDP each year, and up to 20% in the worst-case scenario.

The Stern Review takes two overall approaches to estimate the cost of keeping temperature increase within this range – a bottom up and a top down approach – then marrying the two to estimate the cost. The bottom up approach analyses the costs of technology options to mitigate climate change[25], and the top down approach which analyses existing macroeconomic models and their approaches to estimating cost[26]. Bottom up estimates are that keeping global temperatures within a manageable range would cost 1% of global GDP in 2050 with a range -1% to +3.5%. The top down approach estimates this cost to be 1% of global GDP in 2050 with a range +/-3%. For most scenarios, the effects on GDP in the EU tend to be higher than the average.

Predicting the costs of damages to the climate out in to the future necessarily involves uncertainties. Climate modellers tend to take an approach where the model different scenarios to predict future impacts. The Stern Review examines a range of models, attempting to aggregate their results and assessing the most likely assumptions to define a definitive range on the likely cost of climate change. The review concluded that total costs could be a reduction in global per-capita consumption of between 5% and 20% by 2050. The higher estimates include impacts on human health, amplifying feedbacks in the climate and weighting of the impacts to reflect the disproportionate share of the climate burden on poor regions of the world. The Tuft report refers to losses of 6% to 8% of global economic output by 2100.

The German Advisory Council on Global Change argues that a target of 450ppm CO_2e is both necessary and viable from an economic standpoint, with modelling presented in a recent report suggesting that stabilisation at 450 ppmv would be achieved at a cost of approximately 1.5% of GDP. Stern does not explicitly model the cost of achieving stabilisation at 450 ppmv, however the report is sceptical regarding whether stabilisation at this level is achievable – 450 ppmv is likely to be reached within ten years, and Stern argues that "costs rise significantly as mitigation efforts become more ambitious or sudden. Efforts to reduce emissions rapidly are likely to be very costly."

[25] Anderson, D (2006) Costs and finance of abating carbon emissions in the energy sector, Imperial College London.
[26] Barker, T et al (2006) The costs of greenhouse gas mitigation with induced technological change: a meta-analysis of estimates in the literature, 4CMR, University of Cambridge.

The cost of taking action to mitigate climate change today is lower than taking steps to mitigate that change in the future.

The longer the global community delays taking real steps to mitigate the impacts of climate change, the stronger action in the future will have to be to adapt to and mitigate against climate change, increasing the costs of action.

To stabilise concentrations at a particular level, delays in action mean that the rate of reduction in emissions would need to be higher. This increases the costs significantly. In addition, it exposes the world to the potential for greater levels of climate change.

Climate change actions bring opportunities: mitigation and adaptation.

The overall conclusions of the Stern Review were not all pessimistic. According to the report, "The world does not need to choose between averting climate change and promoting growth and development." Tackling climate change is "a pro-growth strategy for the longer term" as reducing carbon emissions will create new jobs and foster innovation and technology.

The 2007 Communication on a European Energy Policy[27] recognises that there are real benefits in placing the EU at the forefront of the growth in the low carbon technology sector and realising the benefits of a secure and sustainable energy supply.

Renewable energy is one of the few supply-side options that can make a major difference to greenhouse gas emissions in the short term and the Stern Review was welcomed by the renewable energy industry and environmental groups. Maria McCaffery, Chief Executive of the British Wind Energy Association said, "The move to a low-carbon economy is as much about opportunity as cost. Renewable energy, and wind power in particular, can be a massive benefit to the prosperity of this country, providing secure, stably-priced energy supplies in the short term. In the future, UK companies could be generating significant export revenues in the emerging technologies of wave and tidal power."

Both the Stern Review and the EC Communication emphasises the need for global support for energy research and development. The Stern Review recommends that it should be at least doubled and support for the deployment of low-emissions technologies needs to be stepped up by up to five times the existing level. The EC budget for environment, energy and transport research in the period 2007-2013 has already been increased to € 8.4 billion. In addition, Strategic Energy Technology and Environment Technology Action Plans are being implemented and public-private partnerships further promoted.

[27] European Commission: http://ec.europa.eu/energy/energy_policy/index_en.htm

Climate change is a global problem and the response must be international but the EU is well placed to take the lead

In its January communication "An Energy Policy for Europe"[28], the European Commission states, "The European Union is already the global leader in renewable technologies, accounting for a turnover of €20 billion and employing 300,000 people. It has the potential to lead the rapidly growing global market for low carbon energy technologies. In wind energy, for example, EU companies have 60% of the world market share."

EU industry also potentially stands to benefit if they can seize the opportunity to reduce and manage their emissions and be prepared for the impacts of climate change.

3.4 The economics and an EU carbon budget

As the economic argument for action to mitigate climate change becomes clearer and consensus from the international community grows, the potential parallels between a carbon budget and the economic budget are strengthened and the advantages of linking a carbon budget to a monetary budget becomes clearer.

A carbon budget could be defined, communicated, managed and reviewed alongside the financial budget. As emissions are likely to reflect the economic cycle to a large extent, reporting of the two together could be instructive.

[28] COM(2007) 1 final. Communication: "An Energy Policy for Europe". http://ec.europa.eu/energy/energy_policy/doc/01_energy_policy_for_europe_en.pdf, 10 January 2007

4 Achieving the carbon budget

4.1 Introduction

The carbon budget has the potential to be a key high level policy tool. The budget level would be defined by climate science and used to set the framework under which the international community can work. To achieve emissions savings, concrete and targeted policies and measures are needed. A carbon budget would be used to ensure that the overall greenhouse gas emissions targets are really met and to stimulate frequent monitoring of the effectiveness of the policies and measures. This section of the report focuses on some of the potential solutions to climate change, investigating the different policy package approaches that could be taken and describing some best practice examples of successful policy implementation.

4.2 Policy packages and approaches

The carbon budget approach sets the long-term framework under which specific policy packages are developed. The design of the most effective package at a national or regional level will depend on local circumstances. In determining this, policy makers will draw on knowledge of the sources of emissions and relative costs of abatement and on the success of policy approaches in other regions.

The stabilisation wedges approach[29] focuses on the ability of current technology to deliver the necessary global carbon dioxide reductions over the next 50 years (originally written in 2004). This initial timescale allows for the use of current technologies, or technologies with a known development trajectory. The approach assumes that to meet long-term climate change targets i.e. well beyond the 50 year horizon, an initial stabilisation of global emissions is required, followed by a reduction in emissions.

The 50 year horizon focuses on the stabilisation element, which requires significant work when compared to the business as usual emissions trajectory expected. By simplifying the difference between a stabilisation of emissions and the BAU trend, the degree of reduction required can be visualised.

The wedges approach proposes dividing the reduction required into a set of wedges of reductions that increase with time, from zero reductions achieved now, to 1 GtC/year reduction achieved in approximately 2055. A range of technologies, in combination with

[29] Stabilisation Wedges: Solving the Climate Problem for the Next 50 years with Current Technologies. S. Pascala and R.Socolow; Science 13 August 2004. Volume 305 p 968-72

a given ambition level, are able to achieve one, or in some cases more than one, wedge of reduction over that time period.

These include: more efficient vehicles, reduced use of vehicles, more efficient buildings, carbon capture and storage options, efficient baseload coal plants, wind power to substitute coal power, biomass fuels to substitute fossil fuels, and conservation tillage, amongst others.

The core message of this approach is that, although new technology is important, the climate problem for the next 50 years can be solved through a scaling-up of existing technology.

The EU provides a real opportunity for Member States to pool resources, for example in research and development, to focus reduction efforts where they will be most effective and to share best practice in policy making. Joint EU action could also help to create a large enough market for key technologies, such as renewables – that could therefore achieve greater economies of scale.

4.3 Future direction of EU policies

In January 2007, the EC published a Communication outlining the need to adopt the necessary domestic measures and take the lead internationally to ensure that global average temperature increases do not exceed pre-industrial levels by more than 2°C [3]. The Commission's proposals were finally passed by EU Heads of State at the Spring Summit on 8-9 March. The European Commission proposes that the EU pursues, in the context of international negotiations, the objective of 30% reduction in greenhouse gas emissions (GHG) by developed countries by 2020 (compared to 1990 levels). Until an international agreement is concluded, the EU should already take on a firm independent commitment to achieve at least a 20% reduction of GHG emissions by 2020.

Proposals for a new Energy Policy for Europe to combat climate change and boost the EU's energy security and competitiveness have also been developed.

- Energy efficiency should deliver reductions of 780 $MtCO_2$ by increasing energy efficiency by 20% by 2020 (energy efficiency action plan, originally published in October given a new, core role)
- A proposed binding target for the EU to achieve a 20% share of **renewable energy** by 2020, including a minimum 10% target for **biofuels**.
- Reaffirmation of the central role of **emissions trading** as a key mechanism for reducing greenhouse gases and the basis for international efforts to fight climate change.
- A commitment to install **carbon capture and storage** in several fossil fuel power stations by 2015 and phase out plants without it.

Altogether, the package consists of ten main papers plus a host of supporting documents:

- The overarching “energy policy for Europe”
- Post 2012 climate policy
- Strategic energy technology plan
- Renewable energy road map
- Renewable electricity progress report
- Biofuels progress report
- Sustainable fossil fuel power generation
- Nuclear illustrative programme
- Internal market for gas and electricity
- Gas and electricity infrastructure

The future of EU policy renewables and energy efficiency policy is likely to bring some degree of harmonisation where practicable across the region to share best practice and ensure a level playing field in terms of intra-community competition. However any policy changes should be designed to ensure as high a degree of stability and certainty for business and investors as possible.

4.4 Success to date

4.4.1 Focus on renewables

In 1997 the European Commission set a target for the EU to reach a 12% share of renewable energy in total primary energy consumption by 2010 [30]. The target refers to renewable energy as a whole, therefore including renewable electricity, heating and cooling and transport fuel, and corresponds to a doubling of overall renewable energy by 2010 compared to 1997.

By the end of 2005, renewable energy in the EU had increased by 55% compared to 1997[31]. However despite this progress, current projections suggest that the EU as a whole will miss the 12% overall target. The European Commission have stated that it is currently unlikely that the EU will exceed 10% renewable energy in 2010. However the story is very different when you consider different Member States, different renewable energy sectors (electricity, heating and cooling, and transport fuel) and different renewable energy technologies.

[30] COM(1997)599 final “Energy for the Future – Renewable Sources of Energy. White paper for a Community Strategy and Action Plan”
[31] COM(2006) 848 final. “Renewable Energy Road Map. Renewable energies in the 21st century: building a more sustainable future” 10 January 2006.
http://ec.europa.eu/energy/energy_policy/doc/03_renewable_energy_roadmap_en.pdf

Renewable electricity

In 2001 the EU Renewable Electricity Directive[32] set an EU target of 21% renewable electricity in 2010, with differentiated targets for each of the Member States. Targets vary dramatically between Member States depending on current installed renewable energy capacity and available natural resources, with major differences often due to differences in natural large hydro power resources.

The European Commission have stated that nine Member States are on track to reaching their target[33]. Electricity generation from non-hydro renewable sources has increased by 50% in the EU-25 in the period 2003 to 2005. Figure 9 shows electricity generation from non-hydro renewable sources in the EU-25 from 1990 to 2005. With current policies and measures in place across the region the EU is looking likely to fall just short of the target, achieving around 19% renewable electricity in 2010.

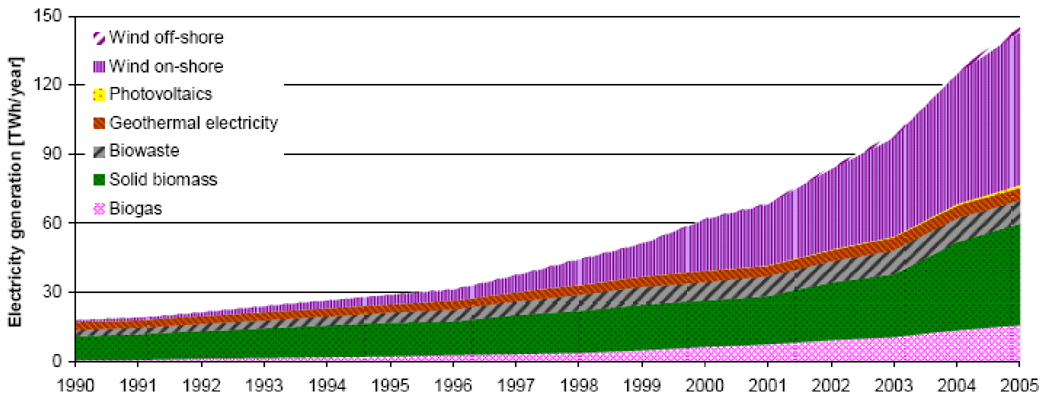

Figure 9 Non-hydro renewable electricity in the EU-25 (1990-2005). Source: EU Renewable Energy Road Map (2006)[31]

Renewable transport fuel

The EU adopted a Biofuels Directive in 2003[34], which aimed to increase both the production and consumption of biofuels in the EU. The Directive set indicative targets for Member States to achieve a 2% biofuels share in total transport fuel in 2005 and a 5.75% biofuels share in 2010. Many Member States started from a very low percentage share of biofuels in 2003, and the EU therefore allowed deviation from these indicative targets stated in the Directive.

[32] Directive 2001/77/EC on the promotion of the electricity produced from renewable energy source in the internal electricity market. http://ec.europa.eu/energy/res/legislation/electricity_en.htm

[33] Denmark, Germany, Finland, Hungary, Ireland, Luxembourg, Spain, Sweden and the Netherlands

[34] Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels and other renewable fuels for transport. http://ec.europa.eu/energy/res/legislation/biofuels_en.htm

Only two Member States (Germany, Sweden) achieved the 2005 indicative target and only three Member States (those above plus France) even achieved over a 1% biofuels share in 2005.

Nevertheless many Member States have set themselves the goal to achieve the 2010 indicative target, although the Commission has stated in the January Renewable Energy Road Map[31] that with the current policies and measures in place they do not believe that the 5.75% target will be achieved across the EU.

Heating and Cooling

Renewable heating and cooling has to date only had an indirect policy target in the EU, derived from the overall renewable energy target of 12% renewable energy in 2010 minus the electricity (21% in 2010) and biofuels (5.75% in 2010) targets. This leads to an indirect target of achieving 80 million tonnes of oil equivalent (Mtoe) of heating and cooling from renewable energy sources in 2010.

It is estimated that renewable heating and cooling accounts for less than 10% of energy for heating and cooling currently in the EU, with approximately half of EU final energy consumption going to provide heating or cooling[31].

Various Member States do have significant installed renewable heating and cooling capacity. For example many Scandinavian countries make extensive use of biomass as a fuel to provide both electricity and heat; solar thermal energy has reached significant capacities in Germany, Greece, Austria and Cyprus[31]. Sweden is being particularly ambitious in the heating sector, exploring ways to phase out fossil fuels for heating entirely by 2020.

However despite the successes in some countries and despite the fact that renewable heating and cooling can be a very cost-effective means of achieving renewable energy, there are very few targeted and implemented policies, and the approach to the sector is not coordinated across the region.

The heating sector represents 48% of European final energy consumption, compared to 20% for electricity and 32% for transport. The share of renewable heating today in Europe is about 9% of total heat demand. According to the European Renewable Energy Council, this share could be at least doubled, and potentially reach up to 25% by 2020[35].

EU best practice

Despite the picture presented above, there are several examples of policies that are working well throughout Europe and the wider world that show how much more could be achieved in the EU if the best policies were adopted throughout Europe or at least applied more widely.

[35] EREC, Renewable Heating, and Action Plan for Europe, 2006

Renewable electricity: Denmark (wind)

Denmark has a renewable electricity target of 29% of gross electricity consumption in 2010, and they are close to achieving this, with around 26% of electricity coming from renewable sources in 2005. Wind power alone contributes to around 20% of Denmark's electricity consumption[36].

No other country has a higher percentage share of wind power in their national electricity mix or a higher wind capacity per capita, and Denmark can claim to be a world leader particularly in terms of offshore wind power, with more than 400 MW offshore wind currently installed.

Renewable energy technology has experienced strong growth in Denmark since the beginning of the 1980s. Denmark's general approach has been to target the most appropriate policies towards different renewable energy technologies, and evolve these support schemes over time to suit the stage of technological development and commercialisation.

Currently Denmark offer a fixed feed-in tariff for most renewable electricity technologies, which is paid for every unit of electricity generated. This tariff is guaranteed for the first ten years of operation and a lower tariff is guaranteed for the next ten years. Onshore wind originally had this kind of fixed tariff guarantee, but in the late 1990s this was changed to a premium that is paid on top of the market price of electricity for every unit of electricity generated (guaranteed for 20 years). There is now also a "repowering" scheme for onshore wind which encourages old wind turbines to be replaced with larger capacity turbines, therefore increasing the overall capacity without increasing the necessary area for wind farms. Large offshore wind projects are however tendered by the Government. Two new offshore farms, each 200 MW, will come online within the next few years. Subsequent offshore wind farms are to be developed under market conditions.

Renewable electricity and transport fuel: Germany (onshore wind, PV, biofuels)

Germany has renewable electricity targets of 12.5% of gross electricity consumption in 2010 and 20% in 2020. Germany's renewable electricity sector has shown remarkable growth and the country is well on track to reaching its target for 2010, having already achieved a 9.5% share of overall electricity consumption in 2004. Germany was also the only EU country to exceed its 2005 biofuels target, achieving a share of 3.75% of transport fuel, well above the indicative target of 2%.

In the period 1997 to 2004, average annual growth in electricity from onshore wind in Germany was 36%. This impressive growth is beaten only by the growth in electricity from solar photovoltaics in the country which showed average annual growth over the

[36] European Commission: http://ec.europa.eu/energy/energy_policy/facts_en.htm

period of 53%. In absolute terms onshore wind however achieved the largest growth in capacity and about half of European wind energy capacity is in fact installed in Germany.

Germany leads the EU in terms of use of wind power, solar PV, solar thermal and biofuel production. The overriding feature of German renewables policy believed to have caused this impressive and sustained renewables growth is the presence of a stable and predictable policy framework.

Renewable electricity receives guaranteed fixed feed-in tariffs for every unit of renewable electricity generated. Tariffs are differentiated by technology and guaranteed for 20 years. Tariffs for new investments are reduced annually, both to encourage early investment from companies to take advantage of the higher tariffs, and also to reflect the reduction in the cost of renewable electricity generation assumed with experience and the development of a technology over time. For example the tariff for onshore wind is reduced by 2% every year. Solar PV, which is a less mature technology expected to see faster cost reduction currently receives a much higher tariff, but this tariff is decreased by 6.5% per year.

The German Market Incentive Programme offers investment incentives are for renewable heating. The programme has been particularly effective in boosting solar thermal and small scale biomass heat generation.

Renewable electricity and heat: Spain (solar thermal, wind)
Spain has a target to achieve 29.4% renewable electricity and 12% renewable energy in 2010. In 2004 renewable electricity only accounted for 19.6% of total electricity use and the country therefore still has a long way to go to meet these targets, but the renewables sector in Spain has begun to grow rapidly in recent years.

Spain has a strong, stable and transparent support programme to support renewable electricity, which has created a market with high investment certainty. Renewable electricity producers choose annually between a fixed feed-in tariff and a premium price on top of the market price for electricity. There is no time limit to the support, but fixed tariffs are reduced after either 15, 20 or 25 years depending on technology. Additional investment support is also available.

Onshore wind has shown particularly impressive growth, with an average annual growth rate in 1997 to 2004 of 54%. Spain currently has the second highest installed wind capacity in the EU-27, after Germany and installed wind capacity increased by 21% from 2004 to 2005 alone.

In March 2006 Spain introduced a new Technical Buildings Code (CTE, Codigo Tecnico de la Edificacion - Royal Decree 314/2006), which includes an obligation to provide 30-70% of the domestic hot water demand of all new and renovated buildings from solar thermal energy (depending on hot water demand and geographical location of the building). The solar thermal obligation is expected to be a strong stimulus for the solar thermal market in the country. Large buildings in the tertiary sector will also be obliged to install solar PV systems to generate electricity.

Renewable transport fuel: France
France has made a conscious decision to support the production of biofuels. In 2006 the country established an ambitious biofuels plan, setting targets to achieve a 5.75% share of biofuels by 2008 (two years earlier than the EU target), 7% by 2010, and 10% by 2015. Tax exemptions and capital grants are in place to promote biofuels. France currently has the second highest biofuel production and use in the EU, behind Germany. Although it did not meet the 2005 target of achieving a 2% share of biofuel in total transport fuel, the country was one of only three in the EU to use over 1% of biofuels in total transport fuel in 2005.

Targets to 2020
The EU has set a target for the block as a whole to achieve a 20% share of renewables in overall energy by 2020. Member States will have to develop their own "National Action Plan" which sets their own specific country targets for renewable electricity, heating and cooling, and transport fuel and will all have to be approved by the European Commission.

This new European target does not differentiate between the different renewable energy sectors, leaving Member States free to choose the best approach for their country, depending on national circumstances (economic structure, renewable resource potential, existing infrastructure, energy demand) and what they would like to focus on. However in recognising that renewable transport fuel is often a more expensive renewable option than electricity or heat but that it is also one of the only available options for tacking emissions from the growing transport sector, the EU has set a minimum European target of 10% renewable transport fuel in 2020.

High potential renewables
Renewable energy and renewable electricity generation in particular is increasing rapidly in the EU at the moment, but there is still a very large additional potential for renewable energy not yet exploited.

The OPTRES project[37] for the European Commission used the Green-X model to estimate the additional potential for renewable electricity from the different renewable electricity technologies and furthermore estimate the additional *realisable* potential before 2020, bearing in mind the total potential and the current status of the renewables markets in each country.

---

[37] *OPTRES: Assessment and optimisation of renewable support schemes in the European electricity market.* Report commissioned by European Commission Directorate General Energy and Transport. http://www.optres.fhg.de/

Of the additional realisable renewable electricity in the EU-15, offshore wind and solid biomass each account for about one quarter. Onshore wind makes up just under 20% of the additional realisable potential. In the new Member States just over half of the additional realisable potential is from solid biomass, with onshore wind representing 16% and offshore only 3% due to the geographical location.

Wave and tidal has a very large potential to contribute to renewable electricity, although the technology is at a relatively early stage of development. In October 2006, the first commercial wave energy project began delivering electricity to the grid off the north coast of Portugal. This first stage of the project involved the installation of 2.25 MW of "Pelamis" wave electricity devices designed by Scottish company Ocean Power Delivery.

Research and development activity is consistently lowering the cost of renewable energy. Innovative solutions like combining wind turbines with underwater tidal flow turbines, or combining solar thermal heat and solar photovoltaic modules in one panel, are also helping to lower the cost of realising renewable energy.

Contribution to emissions reductions

Exploitation of renewable energy resources leads to either zero near zero greenhouse gas emissions. The installation of the additional renewable energy required to meet the EU's 20% renewable energy target in 2020 is estimated to lead to an annual carbon dioxide reduction of 600-900 Mt in 2020. The range of emission savings can be explained by the variation of technologies used and the different shares of electricity, heat and biofuels considered under the different scenarios. If a carbon price of €25 per tonne CO_2 is assumed this corresponds to €150-200 billion in total savings between now and 2020 [38].

4.4.2 Focus on Energy efficiency

The EU has set a target to improve energy efficiency by 20% by 2020. A European Energy Efficiency Action Plan is currently under development. The "Green Paper on Energy Efficiency: or Doing More with Less" was published in 2006 and there are already five EU Directives that have been implemented on energy efficiency[39]: End-use Efficiency & Energy Services; Energy Efficiency in Buildings; Eco-design of Energy-Using Products; Energy Labelling of Domestic Appliances; and Combined Heat and Power.

A number of voluntary agreements have also been implemented in the EU, with differing degrees of success. Setting a minimum standard for the efficiency of some electrical appliances on the market has proven to be effective in improving the average energy

[38] Green-X model, balance scenario and Energy Economics Group, Fraunhofer ISI, Ecofys and PRIMES model. See Commission Staff Working Document: Renewable Energy Road Map: Impact Assessment – SEC(2006) 1719

[39] European Commission: http://ec.europa.eu/energy/demand/index_en.htm

performance of appliances available on the European market. Voluntary agreements can however have drawbacks in that, by definition, they are not legally binding. A voluntary agreement with ACEA (Association des Constructeurs Européen d'Automobiles – the European Automobile Manufacturers Association) to achieve a reduction in the emissions of the average new passenger car by 25% by 2008 (compared to 1995) has caused extensive debate within the European Commission. Some bodies within the Commission have called for legally binding legislation to be put on the car manufacturing industry as they are currently not on track to deliver the 2008 target. The 25% reduction aim of the ACEA Agreement corresponds to an average reduction of CO_2 emissions from new passenger cars from 186 gCO_2/km to 140 gCO_2/km with an additional 20g reduction being achieved through fuel consumption labelling of cars and fiscal measures[40].

Best practice examples

Several examples of energy efficiency policies and measures that have proven to be very effective are described below:

Energy Efficiency Commitment (EEC), UK

- Introduced in 2002, making it one of the longest running and largest energy efficiency obligations in place in the EU.
- Obligation on gas and electricity suppliers to achieve targets for the promotion of energy savings in the residential sector (potential extension to non-domestic sector being considered). There is an approved list of eligible activities and technologies that are included under each phase of the EEC, although obligated parties do have flexibility and it is ultimately the duty of the energy supplier to prove the additionality of their activities.
- First phase of the EEC (2002 to 2005) set a target of -62 TWh (223 PJ) in terms of TWh energy saved (around 1% improvement per year). The second phase (2005 to 2008) requires around double the level of energy savings to be instigated by electricity and gas suppliers, with a total energy saving target of -130 TWh (468 PJ), just over 2% energy saving per year[41].
- There was a high overachievement in phase 1, delivering 140% of the energy saving target in the 2002 to 2005 period. However suppliers have been allowed to carry over the excess energy savings into the second phase.
- Emissions savings due to achievement of the EEC1 target (not including carry over to phase 2) have been estimated at 1.47 $MtCO_2$ per year in 2010, around 1% of domestic sector emissions in the UK. Emissions savings from phase 2 are expected to be an additional 2.2 $MtCO_2$ per year in 2010, and the UK Government believes that a third phase of the EEC (2008-2011) would be able to deliver

[40] Bongardt, D and Kebeck, K (April 2006) Evaluation of the ACEA Agreement, within the framework of the AID-EE Project. http://www.aid-ee.org/documents.htm

[41] Lees, E. (2006), Evaluation of the Energy Efficiency Commitment 2002-2005, report by independent consultant Eoin Lees commissioned by Defra http://www.defra.gov.uk/ENVIRONMENT/energy/eec/pdf/eec-evaluation.pdf

between 3.3 to 4.4 $MtCO_2$ per year[42]. A consultation on the detailed development of EEC3 is scheduled for spring 2007.

- Future phases of the EEC will aim to stimulate more innovative energy efficiency delivery mechanisms.

Rational Use of Energy (RUE) public service obligation, Flanders, Belgium[43]

- Obligation on electricity grid companies to save energy at the end-use level.
- Sensitising and informing action and stimulating action (financial support) towards target groups.
- Targets households, services and industry sectors.

Tradable White Certificate scheme, France

- System of energy saving obligations combined with tradable white certificates introduced in January 2006.
- Aim is to increase the activities on energy demand side management
- Overall objective is to reduce French energy intensity by 2% by 2015 and 2.5% by 2030 (compared to current energy intensity).
- A national energy saving target has been set of 54 TWh reduction in final energy for the first three years (2006-2008). On average this will result in a reduction of around 1% of annual final energy demand.
- Obligations are set for energy suppliers delivering electricity, gas, domestic fuel (not transport), and heating and cooling for stationary applications. Obligated parties have targets in proportion to their market sales in the residential and tertiary sectors. Annual adjustments are made to take account of variations in the market (rising or lowering of the market quota, new entrants, etc.).
- The obligation must be fulfilled over the whole 3 year period (2006-2008) and at the end of the period a quantity of certificates corresponding to the obligation must be delivered.
- The average price of certificates is published regularly by the certificate registry. An upper limit for the price of certificates is established at 0.02 €/KWh (costs of penalty).

Tradable White Certificate scheme, Italy

- The Italian system of energy efficiency obligations and tradable white certificates started in January 2005.
- The target is to achieve an annual energy saving of 2.9 millions tonnes oil equivalent by the end of the first five years of the scheme (2005-2009), which would result in an annual energy demand reduction of about 0.5%
- Obligation is on electricity and gas grid distribution companies and is individual targets are set according to the market share of the company in terms of primary energy.

[42] Defra (2006), UK Climate Change Programme 2006 http://www.defra.gov.uk/ENVIRONMENT/climatechange/uk/ukccp/pdf/ukccp06-all.pdf
[43] AID-EE Project http://www.aid-ee.org/documents.htm

- Companies comply with the obligation by:
    - Developing "in-house" energy efficiency projects,
    - Developing energy efficiency projects jointly with third parties (e.g. Energy Service Companies - ESCOs),
    - Purchasing certificates on the market or via bilateral contracts with third parties who can prove achievement of energy savings (i.e.: other distributors, companies controlled by distributors or energy service companies), or
    - Paying the sanction for non compliance with the obligation.
- Energy efficiency projects can be realised in all energy end-use sectors.
- Eligible energy efficiency measures are grouped into 14 categories that range from electric motors to high efficiency appliances and office equipment to education, information and training.
- White Certificates are valid for five years after being issued (with the exception of those related to insulation or double glazing which are valid for 8 years).

Top Runner, Japan[44]

- Regulatory scheme designed to stimulate continuous improvement of energy efficiency in the use-phase of products within selected segments of the market.
- Started in 1999 covering ten product categories. Now been expanded to cover at least 18 product categories, typically household and office appliances, vehicles etc.
- Sets product-specific energy performance requirements and therefore focuses on supply side of the market, rather than the demand side.
- Manufacturers and importers are obliged to comply. No obligation on retailers or product owners.
- Standards are pre-defined as the use-phase energy performance of the best technology available on the market and are upgraded over time. Exact standard levels and target years, however, are agreed through an extensive consultation processes with stakeholders.
- Voluntary "e-Mark" product label introduced for five Top Runner product categories in 2000 and by 2005 this had been increased to 13 of the categories. Manufacturers can, if they choose, display the labels on their products to show that the product either does or does not meet the standard. Use of labels varies between products, but the vast majority of manufacturers have now taken up.
- So far, Japanese stakeholders agree that the Top Runner programme has been successful and there is little criticism for the model. The standards set are being met, although it has been argued that sometimes they seem to have been met too easily. The effectiveness of target setting procedures might therefore gain from closer scrutiny.
- Although standards are being met, however, there is little quantitative information available about actual energy savings from the programme.

[44] Nordqvist, J. (July 2006). Evaluation of Japan's Top Runner Programme, within the framework of the AID-EE Project. http://www.aid-ee.org/documents.htm

5 Next steps

5.1 What is needed at the political level?

On 10 January 2007 the European Commission made a commitment to, as a region, head towards a binding 20% reduction in greenhouse gas emissions by 2020 (compared to 1990 levels), with an intention to increase this target to 30% in 2020 if an international agreement on greenhouse gas emissions can be met [3].

The package of European Commission statements (see section 4.3) was discussed at the meetings of the EU Energy Council on 15 February and the EU spring Summit (Heads of State) on 8-9 March. The proposals of the European Commission were accepted in these meetings, committing the EU now to achieve at least a 20% reduction in greenhouse gas emissions (compared to 1990) by 2020, with a commitment to extend this to a 30% as part of a global agreement on emissions reductions. The EU has also agreed to a binding target for the region as a whole of a 20% share of renewables in overall energy by 2020, including a minimum 10% share of biofuels in transport fuel.

The EU has also stated that by 2050 global emissions will have to be reduced by up to 50% (compared to 1990). This implies greenhouse gas emissions reductions of between 60 and 80% by 2050 in developed countries including, of course, the EU. Many developing countries will also have to significantly reduce their emissions over this timescale for the goal of minimising climate change to 2 degrees Celsius to be achievable.

On the research side, the European Environment Agency published a report in June 2006 looking at long-term greenhouse gas emission reduction scenarios in Europe investigating scenarios of -20% by 2020, -30% by 2030 and -65% by 2050.

Several individual Member States have also made commitments to aim for significant long term emissions reductions, for example the UK, France and Germany.

However the EU lacks clarity and focus as to how to achieve these long term goals. Also, as yet not all Member States are fully committed to the concept of aiming for significant long term emissions cuts, particularly without the consensus from the international community that major countries will take part in future international climate change agreements post Kyoto. There is clearly a role for the EU to play in leading the international community towards longer term emissions commitments, yet there is also work to be done at home in the region to build commitment from all Member States on the way forward.

In terms of measuring and monitoring the necessary emissions data to manage a carbon budget approach, the EU already has many of the relevant infrastructures in place. Each Member State reports annually on their greenhouse gas emissions and the policies and measures in place to reduce them to both the UNFCCC and to the EU via the Monitoring Mechanism. The European Community itself also submits its own National Communication to the UNFCCC, which collates emissions data for the region and details Community level policies and measures. A cumulative emissions approach that would be needed to manage a carbon budget approach is already taken under the Monitoring Mechanism.

The EU also already has experience of introducing innovative and sometimes complex policy mechanisms, in particular through the design and implementation of the EU Emissions Trading Scheme. The EU has designed and implemented the scheme, which involves many of the kind of budget setting, budget approval, emissions quotas and trading rules that could be required under some designs of a carbon budget, showing that it is perfectly possible within the EU to implement what would have sounded like impossible schemes to achieve in practice.

Before a carbon budget approach would be implemented however endorsement of the approach would however be needed throughout the community. Any European wide approach would have to be sensitive to the Subsidiarity Principle of the European Union, which ensures that the EU only legislates at the appropriate level and that Member States retain legislative rights where it is most appropriate. However, it would be fitting and logical for the EU to stimulate a co-ordinated approach to tackling greenhouse gas emissions, through a common high-level reporting procedure.

A carbon budget should be presented in this manner. It is not intended that the EU would control the allocation of carbon budgets within a country – rather that each country should do so nationally, but with a centralised approach.

5.2 A Carbon Budget within existing EU processes

The way the EU is governed internally is unique: 27 individual Member States retain national sovereignty whilst working together and being governed on some issues by the EU. The main EU governance structure is explained in Appendix D.

As was previously discussed in the "Developing a Carbon Budget for the UK"[45], for maximum effectiveness a carbon budget should be high profile and should be central to all policy decisions. A carbon budget could be implemented in parallel to the main monetary budget. These same principles that were put forward for the UK should also be applied at the EU level.

---

[45] Gilbert, A. and Reece, G. (2006). Developing a Carbon Budget for the UK: with opportunities for EU action. Report by Ecofys UK supported by Friends of the Earth UK. Available from: www.foe.co.uk/resource/reports/carbon_budgetting.pdf

Logically an EU carbon budget would be agreed in co-decision between the Council of the European Union and the Parliament. Although, the annual budget could be announced at the highest level by the Council of EU Heads of State annually at one of the four EU Summits, to ensure a high profile is maintained. This would directly parallel the proposed role of the Prime Minister in announcing the annual budget in the UK scheme[45].

However in the UK model it was proposed that individual government departments then be given responsibility for the section of the budget that affects their area of policy. To parallel this it could be that individual Directorate Generals have responsibility for their section of an EU carbon budget. However this may be seen as being against the Subsidiarity Principle.

A more likely scenario might be that the Council of the European Union and the Parliament define the long term carbon budget for the EU, and within that define the EU level budgets for a number of years into the future, as would be done with a monetary spending plan. This budget would then be divided between the individual Member States. This process is likely to involve several iterations and negotiations with Member States, but does have precedents in the current EU ETS system and also in the Burden Sharing Agreement in which the Kyoto target for the EU was split differentially between the, then, 15 Member States according to national circumstances.

Further division of the carbon budget could then be the responsibility of individual Member States. One exception to this could be in cases where a type of carbon budget is already agreed by the EU, as for example with the EU ETS. There have been calls for the EU to set one EU ETS cap for the whole EU. In such a case it could be conceived that the EU would subtract the total EU ETS cap from the total EU annual carbon budget and split the remaining budget between Member States for the other sectors of the economy.

In terms of the parallel with the monetary budget, there are different structures in place and different timescales involved in deciding the various sections of the budget and the ways in which they are distributed. Funding at the EU level as a whole does not therefore offer a clear co-ordinated timetable for the carbon budget cycles to adhere to, as was proposed could work in the UK example given in the UK Carbon Budget discussion paper[45]. In this example a UK carbon budget could be defined in parallel to the Treasury's three-year Comprehensive Spending Review cycles. However the EU's overall budget is controlled by co-decision from the European Parliament and the Council of the EU, who make very high level decisions on monetary allocation. A carbon budget could be announced alongside this main budget, with co-decision from the Parliament and Council of the EU.

The connections between climate policy (both mitigation and adaptation) and EU funding streams vary depending on the funding area involved but there are many areas where this co-ordination could be improved and strengthened. An EU carbon budget could be pro-active in strengthening this connection.

The carbon budget could be discussed in parallel with decisions about high level funding allocation, to accord the carbon budget with equally high profile and to ensure that the final agreements are appropriately integrated.

An approach such as this would be in line with Article 6 of the EU Treaty of Amsterdam calling for environmental protection requirements to be integrated into the definition and implementation of other policies. This was already contained in Article 174 (ex Article 130r).

5.3 Steps towards a carbon budget in the EU

It would be possible to work towards the introduction and development of a carbon budget in the EU in steps. In the early stages a carbon budget could simply be introduced as a means to raise the profile of decisions which affect greenhouse gas emission within the EU and the need for significant long term emissions reductions. At a later stage a long-term carbon budget could be formally set for the EU and the concepts of borrowing within periods etc. incorporated. A few likely steps towards the introduction of a carbon budget for the EU are listed here:

Endorsement by the European Union of the carbon budget approach as a tool to monitor and reduce cumulative emissions from the EU

The EU as a whole is already committed to making significant long term emissions reductions, although Member States differ significantly in the extent to which they have individually made long term commitments to reduce their emissions.

Endorsement of the tool at the European level could work in a number of ways, either from the bottom up with individual Member States or the European Commission first proposing the tool; or in a more top down manner with the European Parliament and the relevant Councils of Ministers proposing the tool for further examination by the European Commission.

Work towards raising the profile of carbon emissions to the highest levels within the EU governance structure to ensure they are factored in to key policy decisions

A carbon budget could initially be implemented at the most basic level in Europe, simply to raise the profile of carbon reductions.

This might be achieved most effectively if the country holding the presidency takes leadership and promotes the use of a carbon budget. Each Member State holds Presidency of the Council of the European Union in six-monthly rotations. The Member State who holds the presidency dictates the agenda for the Council.

A Member State trial of the approach to show its effectiveness as a policy tool at the national level to gain acceptance before broadening the scheme to the EU

In particular those Member States who have stated long term commitments to achieve significant greenhouse gas emissions reductions could work together to develop the carbon budget approach.

5.4 Needs for further research

Areas for further research could include:

- Further detailed modelling of carbon budget approaches, or disaggregation at various levels or to Member States;
- Details of appropriate design at the EU level, for example how the concept of borrowing might work at with budgets at the Member State level and the relationship with the EU ETS;
- A thorough analysis of the ability of existing proposals for EU-level renewables and energy efficiency targets to deliver the necessary limits in temperature rise; and
- Suggestions about more appropriate targets or policies in the renewables and energy efficiency fields, and what these might deliver.
- Suggestions for any other policy that might be required.

ECOFYS

Appendix A Description of the EVOC tool

This section describes the Evolution of Commitments tool (EVOC) version 7, developed at Ecofys, that is used to quantify emission allowances under the various approaches in this report. It includes emissions of CO_2, CH_4, N_2O, hydroflourocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF_6) for 192 individual countries. Historical emissions are based on national emission inventories submitted to the UNFCCC and, where not available, other sources such as the International Energy Agency. Future emissions are based on the IPCC Special Report on Emissions Scenarios (Nakicenovic et al. 2000). The greenhouse gas emission data for 1990 to 2003 is derived by an algorithm that combines emission estimates from various sources.

We first collected historical emission estimates by country, by gas and by sector from the following sources and ordered them in the following hierarchy:

1. National submissions to the UNFCCC as collected by the UNFCCC secretariat and published in the GHG emission database available at their web site. For Annex I countries the latest available year is usually 2004. Most non-Annex I countries report only or until 1994 (UNFCCC 2005)
2. CO_2 emissions from fuel combustion as published by the International Energy Agency. The latest available year is 2003 (IEA 2005a)
3. Emissions from Land-use change as published by Houghton in the WRI climate indicator analysis tool (Houghton 2003)
4. Emissions from CH_4 and N_2O as estimated by the US Environmental Protection Agency. Latest available year is 2005 (USEPA 2006a)
5. CO_2, CH_4, N_2O, HFC, PFC and SF_6 emissions from the EDGAR database version 3.2 available for 1990 and 1995 (Olivier and Berdowski 2001)[46]

Future emissions are derived from the MNP/RIVM IMAGE implementation of the SRES scenarios (IMAGE team 2001).

The datasets vary in their completeness and sectoral split. We first defined which of the sectors provided in the datasets correspond to 7 sectors. Note that CO_2 emissions from the IEA do not include process emissions from cement production. Hence, if IEA data is chosen, process emissions from cement production are not included.

[46] For CH_4 and N_2O, the values of EPA are largely based on the EDGAR database (1990 and 1995), but extended to the year 2000.

For each country, gas and sector, the algorithm completes the following steps:

1. For all data sets, missing years in-between available years within a data set are linearly interpolated and the growth rate is calculated for each year step.
2. The data source is selected, which is highest in hierarchy and for which emission data are available. All available data points are chosen as the basis for absolute emissions.
3. Still missing years are filled by applying the growth rates from the highest data set in the hierarchy for which a growth rate is available.

As future emissions are only available on a regional basis and not country by country. The resulting set of emissions in then extended into the future by applying the growth rates of the respective sectors and gas of the region, to which the country belongs.

Appendix B Description of the allocation approaches as applied in the EVOC model

1.1 Contraction and convergence by 2050

Under Contraction and Convergence (C&C) (Meyer 2000; GCI 2005), all countries participate in the regime with quantified emission targets. As a first step, all countries agree on a path of future global emissions that leads to an agreed long-term stabilisation level for greenhouse gas concentrations (‘Contraction’). As a second step, the targets for individual countries are set in such a way that per capita emissions converge from the countries’ current levels to a level equal for all countries within a given period (‘Convergence’).

The convergence level is calculated such that resulting global emissions follow the agreed global emission path. The resulting convergence levels for this report are given in Table 3.

It might be more difficult for some countries to reduce emissions compared to others, e.g. due to climatic conditions or resource availability. Therefore, emission trading could be allowed to level off differences between allowances and actual emissions. However, C&C does not explicitly provide for emission trading.

As current per capita emissions differ greatly between countries some developing countries with very low per capita emissions, (e.g. India, Indonesia or the Philippines) could be allocated more emission allowances than necessary to cover their emissions (“hot air”). This would generate a flow of resources from developed to developing countries if these emission allowances are traded.

For a stabilisation at about 650 ppmv CO_2e a convergence to about 4 to 5 tCO_2e per capita in 2050 is necessary (see Table 3). In this case the average per capita emissions should lie around 6 tCO_2e per capita in 2020. For a stabilisation at about 550 ppmv CO_2e in 2050 a convergence to about 3 tCO_2 per capita with average per capita emissions of about 5 tCO_2e in 2020 is required. To reach a stabilisation at about 450 ppmv CO_2e a convergence to about 2 tCO_2 per capita is necessary. In this case average emissions in 2020 around 4 tCO_2 per capita is needed.

Table 3. Convergence level of per capita emissions in tCO_2e/cap for the considered SRES scenarios in 2050

Scenario	450 ppmv CO_2e	550 ppmv CO_2e	650 ppmv CO_2e
A1, B1	2.1	3.2	5.1
A2	1.6	2.5	4.0
B2	2.0	2.9	4.8

1.2 Common but differentiated convergence

Common but differentiated convergence (CDC) is a new approach presented by Höhne et al. (Höhne et al. 2006a). Annex I countries' per capita emission allowances converge within, for example, 40 years (2010 to 2050) to an equal level for all countries. Individual non-Annex I countries' per capita emissions also converge within the same period to the same level but convergence starts from the date when their per capita emissions reach a certain percentage threshold of the (gradually declining) global average. Non-Annex I countries that do not pass this percentage threshold do not have binding emission reduction requirements. Either they take part in the CDM or they voluntarily take on positively binding emission reduction targets. Under the latter, emission allowances may be sold if the target is overachieved, but no emission allowances have to be bought if the target is not reached. The CDC approach, similarly to C&C, aims to achieve equal per capita allowances in the long run (see Figure 10).

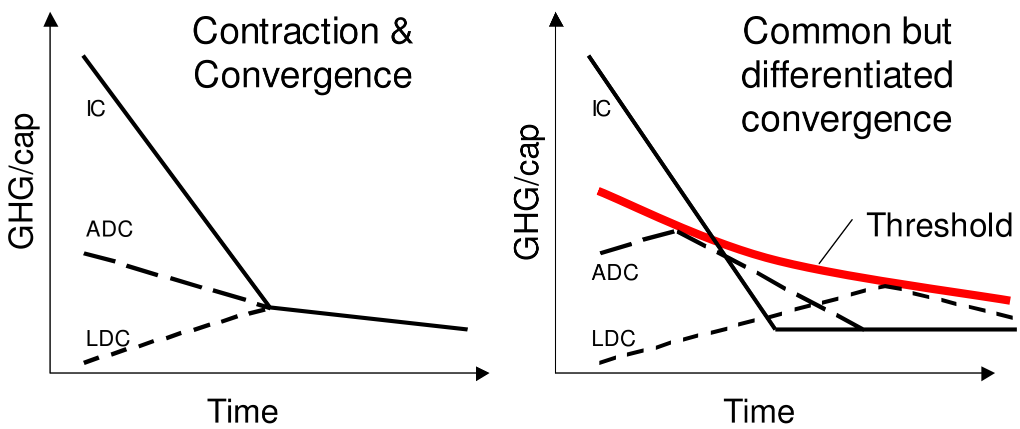

Figure 10. Schematic representation of GHG emissions per capita for three types of countries (an industrialized country (IC), an advanced developing country (ADC) and a least developed country (LDC)) under Contraction & Convergence (left) and under Common but Differentiated Convergence (right)

The parameters of the convergence time, the threshold for participation and the convergence level used in this report are provided in Table 4.

Table 4. Parameters used for the Common but Differentiated Convergence approach[47]

Parameter	Unit	450 ppmv CO_2e		550 ppmv CO_2e		650 ppmv CO_2e	
		2020	2050	2020	2050	2020	2050
Convergence time	Years	30	40	40	40	40	40
Threshold	% above or below world average	-55%	-30%	-10%	-5%	40%	23%
Convergence level	tCO_2eq./cap	1	1.8	2	2.6	8	4.5

1.3 Multistage

In a Multistage approach countries participate in several stages, with differentiated types and levels of commitments[48]. Each stage has stage-specific commitments with countries graduating to higher stages when they exceed certain thresholds (e.g. emissions per capita or GDP per capita). All countries agree to have commitments at a later point in time. For this analysis thresholds based on per capita emissions with four stages were applied as follows (e.g. Höhne et al. 2005a):

- ***Stage 1 – No commitments***: Countries with a low level of development do not have climate commitments. As a minimum all least developed countries (LDCs) would be in this stage. In the model countries in this stage follow their reference scenario as no emission reductions are required.
- ***Stage 2 – Enhanced sustainable development***: At the next stage, countries commit in a clear way to sustainable development: The environmental objectives have to be built into the development policies. Such a first 'soft' stage would make it easier for new countries to join the regime. Requirements for such a sustainable pathway could be defined, e.g. inefficient equipment is phased out and requirements and certain standards are met for any new equipment, or there is a clear deviation from the current policies depending on the countries. This stage is implemented in the model by assuming countries reduce emissions by a percentage below their reference scenario within 10 years and then follow the reduced reference scenario.
- ***Stage 3 – Moderate absolute target***: In this stage, countries commit to a moderate target on absolute emissions. The emission level may be higher than the starting year, but it should be below a reference scenario. The target could be positively

[47] It may not be possible to meet both reference points (for 2020 and 2050) per stabilisation level (450, 550 or 650 ppmv CO_2 e) for one set of parameters. Different parameter configurations are necessary for each reference point. This means that the configurations e.g. for 2020 450 ppmv CO_2 e are valid only until 2020. For long-term calculations (2050) other configurations are necessary which are valid only for 2050.

[48] E.g. Claussen and McNeilly 1998; Gupta 1998; Berk and den Elzen 2001; USEPA 2002; Blanchard et al. 2003; CAN 2003; Criqui et al. 2003; den Elzen et al. 2003; Gupta 2003; Höhne et al. 2003; Ott et al. 2004; Blok et al. 2005; den Elzen 2005; den Elzen et al. 2005b; Höhne et al. 2005a; Höhne and Ullrich 2005; Michaelowa et al. 2005; den Elzen et al. 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

binding, meaning that allowances can be sold if the target is exceeded but no allowances have to be bought if the target is not achieved. An incentive to accept such a target would be the possibility to participate in emissions trading. To model the group of countries in this stage, a percentage reduction below their reference scenario more stringent than in stage 2 is assumed.

- ***Stage 4 – Absolute reduction target***: Countries in stage 4 receive absolute emission reduction targets and have to reduce their absolute emissions substantially until they reach a low per capita level (essentially a fifth stage). The whole group of countries reduces its emissions as a certain percentage compared to 1990. The actual contribution of each country depends on its per capita emissions. Countries with high emissions per capita have to reduce more than countries with low emissions per capita. As time progresses, more and more countries enter stage 4.

The parameters for reductions and stage participation thresholds chosen for the calculations are given in Table 5. The choice of parameter values is subjective but should reflect a reasonable burden sharing of emission reductions among developed and developing countries. Several other possibilities are possible. Lower stage-thresholds, for example, would require higher contributions of developing countries.

Table 5. Parameters used for the Multistage approach [49]

		450 ppmv CO_2e		550 ppmv CO_2e		650 ppmv CO_2e	
Parameter	**Unit**	**2020**	**2050**	**2020**	**2050**	**2020**	**2050**
Threshold to enter stage 2	tCO_2e/cap	3.5	2.5	5.0	3.0	6.0	4.0
Threshold to enter stage 3	tCO_2e/cap	4.5	3.5	6.5	5.0	7.5	5.5
Threshold to enter stage 4 in 2010	tCO_2e/cap	6.0	4.0	7.5	6.0	9.0	6.5
Threshold to enter stage 4 in 2100	tCO_2e/cap	5.0	1.5	6.5	4.0	7.5	5.5
Threshold for no further reduction in stage 4	tCO_2e/cap	1.5	1.0	2.0	1.5	5.0	5.0
Stage 2 (enhanced sustainable development) reduction below reference scenario in 10 years	%	15	25	15	20	5	15
Stage 3 (Moderate absolute target) reduction below reference scenario in 10 years	%	30	30	25	30	10	20
Stage 4 (Absolute reduction) reduction per year*	%	5.0	9.0	3.0	6.0	0.7	3.0

*The reduction percentages per year are applied to the absolute emissions in the previous year and therefore lead to an exponential decline in absolute emissions. Other slopes (e.g. linear) are possible.

[49] It may not be possible to meet both reference points (for 2020 and 2050) per stabilisation level (450, 550 or 650 ppmv CO_2 e) for one set of parameters. Different parameter configurations are necessary for each reference point. This means that the configurations e.g. for 2020 450 ppmv CO_2 e are valid only until 2020. For long-term calculations (2050) other configurations are necessary which are valid only for 2050.

ECOFYS

1.4 Global Triptych

This approach was originally developed at the University of Utrecht[50] to share the emission allowances of the first commitment period within the European Union. It has been updated and revised subsequently[51].

Analogous to the first Triptych approach, the global Triptych approach is a method to allocate emission allowances among a group of countries based on several national indicators.[52] It takes into account main differences in national circumstances between countries that are relevant to emissions and emission reduction potentials. The Triptych approach as such does not define which countries should participate, but we have applied it here to all countries equally.

The Triptych methodology calculates emission allowances for the various sectors which are added to obtain a national target. However, it is not the individual sector targets, but only the national targets which are binding. This provides countries with the flexibility to pursue any emission reduction strategy that they choose.

The emissions of the sectors are treated differently: For ‘electricity production’ and ‘industrial production’, a growth in the physical production is assumed together with an improvement in production efficiency. This takes into account the need for economic development but constant improvement of efficiency. For the ‘domestic’ sectors, convergence of per capita emissions is assumed. This takes into account the converging living standard of the countries. For the remaining sectors, ‘fossil fuel production’, ‘agriculture’ and ‘waste’, similar reduction and convergence rules are applied.

Table 6 provides the parameters chosen for the calculation in this report. Details on the applied methodology can be found in Phylipsen et al. 2004. The choice of parameter values is subjective but should reflect a reasonable burden sharing of emission reductions. Several other possibilities are possible. We intended the chosen parameters to be balanced in stringency over the sectors for the stabilisation levels of 450 and 650 ppmv CO_2e.

The parameters for the 450 ppmv case stretch the methodology to the limit: 70% to 95% renewable and emission-free electricity in 2050, 70% to 95% reduction in electricity generation from coal and oil, convergence to an industrial energy efficiency that is 50% to 70% better than best available technology in 1995.

---

[50] Blok et al. 1997 as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

[51] Phylipsen et al. 1998, Groenenberg 2002, den Elzen and Lucas 2003, Höhne et al. 2003, Phylipsen et al. 2004, Höhne et al. 2005a, Höhne 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

[52] Unlike e.g. the Multistage approach which is more a framework of stages that can be filled with different allocation methods for the several stages or C&C which is based only on per capita emissions.

Table 6. Parameter choices for 2050 for the Triptych cases aiming at 450, 550 and 650 ppmv CO_2e concentration

Sector	Quantity	450 ppmv		550 ppmv	650 ppmv	
		2020	2050	2020 + 2050	2020	2050
Industry	Maximum deviation of total industrial production at country level in 2050	45%	45%	45%	45%	45%
	Maximum deviation of total industrial production at global level in 2050	10%	10%	10%	10%	10%
	Convergence of Energy Efficiency Indicator in 2050	0.3	0.5	0.6	0.95	0.7
	Structural change factor	0.2	0.35	0.45	0.95	0.6
Electricity	Maximum deviation of total power production at country level in 2050	45%	45%	45%	45%	45%
	Maximum deviation of total power production at global level in 2050	10%	10%	10%	10%	10%
	Share of renewables and emission free fossil in 2050	95%	70%	60%	50%	40%
	Share of CHP in 2050	5%	20%	20%	20%	30%
	Reduction of solid fuels in 2050 compared to base year	95%	70%	50%	40%	20%
	Reduction of liquid fuels in 2050 compared to base year	95%	60%	60%	50%	30%
	Total efficiency of CHP	90%	90%	90%	90%	90%
	Convergence of power generation efficiency of solid fuels in 2050	50%	50%	50%	50%	50%
	Convergence of power generation efficiency of liquids fuels in 2050	55%	55%	55%	50%	50%
	Convergence of power generation efficiency of gas in 2050	70%	70%	65%	65%	65%
Domestic Sector	Domestic convergence level – per capita emissions in tCO_2/cap/yr in 2050	0.5	0.7	1	2.6	1.7
Fossil fuel production	Fossil fuel emission level – % total emissions below base year in 2050	90%	90%	90%	90%	90%
Agriculture	Reduction below reference scenario emissions in 2050 – low GDP/cap	70%	70%	50%	20%	20%
	Reduction below reference scenario emissions in 2050 – high GDP/cap	90%	80%	70%	40%	40%
Waste	Waste convergence level – per capita emissions in 2050	0	0	0	0	0

1.5 GHG intensity targets

Targets could be expressed as dynamic variables – including as a function of the GDP ("intensity targets") or variables of physical production (e.g. emissions per tonne of steel produced)[53]. Dynamic targets aim at providing more flexibility to the countries, so that high costs are avoided, if the economic development and therefore emission development is different than expected at the time the target is set. In principle, they do not limit the economic growth of countries, but require that economic development takes place in a carbon-efficient way.

Here, we have assigned intensity targets expressed as improvement of emissions per GDP at the same rate for all countries. This may be a less realistic case, but it may be instructive in understanding the dynamics of such an approach. The parameters used are included in Table 7.

Table 7. Parameters used for the GHG intensity target approach

Parameter	Unit	450 ppmv CO_2e 2020	450 ppmv CO_2e 2050	550 ppmv CO_2e 2020	550 ppmv CO_2e 2050	650 ppmv CO_2e 2020	650 ppmv CO_2e 2050
Equal reduction of GHG/GDP	%/year	5.6	5.3	4.0	4.4	2.6	3.2

[53] E.g. Hargrave et al. 1998; Baumert et al. 1999; Lutter 2000; Müller et al. 2001; Bouille and Girardin 2002; Chan-Woo 2002; Lisowski 2002; OECD/IEA 2002; Ellerman and Wing 2003; Höhne et al. 2003; Müller and Müller-Fürstenberger 2003; Jotzo and Pezzey 2005; Pizer 2005; Kolstad 2006, as presented in Höhne N, D Phylipsen, S Moltmann (2006): Factors underpinning future action, report for DEFRA, UK, prepared by Ecofys [9]

Appendix C Emissions Data

Table 8. Per capita emissions according to C&C for 450 ppmv CO2e from 1990 and 2050 on EU-25 and country basis

	Emissions/ cap. Mt CO2e		Emission allowances per capita under Contraction & Convergence Mt CO_2e														
Year	**1990**	**2000**	**2010**			**2020**			**2030**			**2040**			**2050**		
Country			min	median	max	min	median	max	min	median	max	min	median	max	min	median	max
Austria	10	10	8	8	8	6	6	6	4	5	5	3	4	5	2	2	2
Belgium	16	17	14	14	14	9	10	10	6	6	7	4	6	7	2	2	2
Bulgaria	13	8	9	10	10	7	7	7	5	5	5	3	5	5	2	2	2
Cyprus	8	11	12	13	13	7	8	8	4	5	5	3	4	5	2	2	2
Czech Republic	19	15	15	17	17	11	11	12	7	8	8	4	7	8	2	2	2
Denmark	14	14	10	11	11	7	7	8	5	5	5	3	5	6	2	2	2
Estonia	27	14	15	16	17	10	11	11	7	7	7	4	7	8	2	2	2
Finland	15	14	14	14	14	9	9	10	6	6	7	4	6	7	2	2	2
France	10	10	9	9	9	7	7	7	5	5	5	3	5	5	2	2	2
Germany	16	13	12	12	12	8	8	8	5	6	6	3	5	6	2	2	2
Greece	12	14	14	14	14	9	9	10	6	6	7	4	6	7	2	2	2
Hungary	10	8	9	9	10	7	7	7	5	5	5	3	5	5	2	2	2
Ireland	16	19	16	16	17	11	11	11	7	7	8	4	7	8	2	2	2
Italy	9	10	8	8	8	6	6	6	4	5	5	3	4	5	2	2	2
Latvia	10	4	5	5	6	4	4	4	3	4	4	2	3	4	2	2	2
Lithuania	14	5	6	6	6	5	5	5	3	4	4	2	3	4	2	2	2
Luxembourg	34	24	20	21	21	13	14	14	9	9	9	5	9	9	2	2	2
Malta	9	9	9	10	10	7	7	7	5	5	5	3	5	5	2	2	2
Netherlands	17	17	15	15	15	10	10	10	7	7	7	4	7	7	2	2	2
Poland	12	10	11	11	11	8	8	8	5	6	6	3	5	6	2	2	2
Portugal	6	9	8	8	8	6	6	6	4	4	4	3	4	5	2	2	2
Romania	10	6	7	8	8	6	6	6	4	5	5	3	4	5	2	2	2
Slovakia	14	9	10	11	12	8	8	8	5	6	6	3	5	6	2	2	2
Slovenia	10	10	8	9	9	6	6	7	5	5	5	3	5	5	2	2	2
Spain	8	10	9	9	9	6	6	6	4	5	5	3	4	5	2	2	2
Sweden	9	9	9	9	9	6	6	7	4	5	5	3	4	5	2	2	2
United Kingdom	14	12	11	11	11	8	8	8	5	5	6	3	5	6	2	2	2
F03 EU25	12	11	10	11	11	7	7	8	5	5	5	3	5	6	2	2	2

Table 9. Underlying assumptions on population figures for the EU25 between 1990 and 2050

	Population [million people] Million people																
Year	**1990**	**2000**	**2010**			**2020**			**2030**			**2040**			**2050**		
Country			min	median	max	min	median	max	min	median	max	min	median	max	min	median	max
Austria	8	8	8	8	8	8	9	9	8	9	9	8	9	9	8	9	9
Belgium	10	10	10	11	11	11	11	11	11	11	11	10	11	12	10	11	12
Cyprus	1	1	1	1	1	1	1	1	1	1	2	1	1	2	2	2	2
Czech Republic	10	10	10	10	11	10	10	11	10	10	11	10	10	11	10	10	10
Denmark	5	5	5	6	6	6	6	6	6	6	6	5	6	6	5	6	6
Estonia	2	1	1	1	1	1	1	2	1	1	2	1	1	2	1	1	2
Finland	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
France	59	61	63	63	64	63	65	66	63	66	68	62	66	69	60	67	70
Germany	79	82	84	85	86	84	87	88	84	89	91	83	89	93	81	89	94
Greece	10	11	11	11	11	11	11	11	11	11	12	11	11	12	10	12	12
Hungary	10	10	10	10	10	10	10	10	10	10	10	10	10	10	9	9	10
Ireland	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Italy	57	58	59	59	60	59	61	62	59	62	64	58	62	65	57	62	66
Latvia	3	2	2	2	3	2	3	3	2	3	3	2	3	3	2	3	3
Lithuania	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	4	5
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	15	16	16	17	17	17	17	17	17	17	18	16	17	18	16	17	18
Poland	38	39	38	39	40	38	39	40	38	39	40	37	38	40	36	36	39
Portugal	10	10	10	10	10	10	11	11	10	11	11	10	11	11	10	11	11
Slovakia	5	5	5	5	6	5	5	6	5	5	6	5	5	6	5	5	5
Slovenia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Spain	39	40	41	41	42	41	42	43	41	43	44	40	43	45	39	43	46
Sweden	9	9	9	9	9	9	9	10	9	10	10	9	10	10	9	10	10
United Kingdom	58	59	61	61	62	61	63	64	61	64	66	60	64	67	58	65	68
F03 EU25	442	454	462	467	473	465	478	487	463	486	498	455	486	507	444	484	512

Table 10. Emission allowances for each European country and the EU as a whole to 2050

450 ppmv CO_2e	Emissions Mt CO_2e				Emission allowances 2005-2050 under Contraction & Convergence Mt CO_2e														
Year	**1990**	**1995**	**2000**	**2005**	**2010**			**2020**			**2030**			**2040**			**2050**		
Country				Median	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
Austria	80	82	84	88	70	70	70	52	52	54	39	39	41	26	28	29	15	19	19
Belgium	162	169	169	168	149	149	149	102	104	107	71	71	73	42	44	45	19	24	24
Cyprus	6	7	9	10	12	12	12	9	9	9	6	7	7	5	5	5	3	3	4
Czech Republic	197	155	150	156	161	172	181	112	118	122	74	79	81	42	46	47	17	21	21
Denmark	74	84	76	74	58	58	58	42	42	44	30	30	31	19	20	21	10	12	12
Estonia	43	22	20	22	22	23	24	15	16	16	10	11	11	6	6	6	3	3	3
Finland	74	73	73	84	74	74	74	51	51	53	35	35	36	20	21	22	9	11	11
France	592	588	592	593	592	592	592	430	436	450	316	319	330	208	222	227	116	141	141
Germany	1253	1127	1059	1043	990	990	990	695	704	728	493	496	512	307	325	332	154	189	189
Greece	120	129	148	153	150	150	150	103	105	108	72	72	74	43	45	46	20	24	24
Hungary	104	85	82	88	91	95	98	68	70	71	49	51	51	31	34	34	17	20	20
Ireland	57	61	71	69	64	64	64	43	44	45	29	29	30	17	18	18	7	9	9
Italy	534	549	574	570	496	496	496	368	372	384	276	279	288	186	200	204	108	133	133
Latvia	28	13	10	12	13	13	14	11	11	11	9	9	9	7	7	7	5	5	5
Lithuania	53	26	20	21	22	23	24	18	18	19	14	15	15	11	11	11	7	8	8
Luxembourg	13	10	11	12	9	9	9	6	6	6	4	4	4	2	2	2	1	1	1
Malta	3	3	3	4	4	4	4	3	3	3	2	2	2	1	1	1	1	1	1
Netherlands	260	276	271	265	245	245	245	167	169	175	114	115	119	67	71	73	30	37	37
Poland	466	433	381	395	417	428	434	302	307	313	211	217	220	131	140	141	64	77	77
Portugal	63	75	86	86	80	80	80	60	61	63	46	46	48	31	34	35	19	23	23
Slovakia	74	54	50	54	57	61	64	41	44	45	29	31	32	18	20	20	9	11	11
Slovenia	19	19	19	19	17	17	17	13	13	13	9	9	10	6	6	7	3	4	4
Spain	309	341	419	421	355	355	355	262	265	274	195	197	204	131	140	143	75	92	92
Sweden	76	79	76	79	79	79	79	58	59	61	44	44	45	29	31	32	17	20	20
United Kingdom	789	738	704	695	686	686	686	485	491	507	346	349	360	218	231	236	112	137	137
EU25	5448	5197	5158	5181	4915	4948	4971	3538	3565	3670	2524	2554	2628	1606	1712	1742	844	1026	1026

Table 11. Percentage emissions reduction (compared to 1990) for each European country and the EU as a whole under different burden sharing approaches by 2020

450 ppmv CO_2e	Emissions in Mt CO_2e		C&C 2050 Values as % of 1990			CDC Values as % of 1990			Multistage Values as % of 1990			Triptych Values as % of 1990			Intensity Values as % of 1990			Reference Values as % of 1990		
Year	1990	2010	2020			2020			2020			2020			2020			2020		
Country		Median	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
Austria	80	70	-36%	-35%	-33%	-38%	-37%	-37%	-35%	-34%	-34%	-35%	-34%	-33%	-44%	-39%	-38%	22%	37%	42%
Belgium	162	149	-37%	-36%	-34%	-36%	-35%	-34%	-41%	-41%	-41%	-33%	-32%	-32%	-40%	-35%	-35%	-11%	0%	6%
Cyprus	6	12	56%	59%	65%	75%	86%	94%	46%	67%	70%	69%	81%	86%	75%	100%	107%	167%	200%	207%
Czech Republic	197	172	-43%	-40%	-38%	-44%	-40%	-37%	-50%	-48%	-46%	-37%	-29%	-23%	-43%	-28%	-21%	-6%	11%	27%
Denmark	74	58	-44%	-43%	-41%	-44%	-43%	-43%	-44%	-44%	-44%	-41%	-40%	-39%	-49%	-44%	-44%	0%	12%	17%
Estonia	43	23	-64%	-63%	-62%	-64%	-62%	-61%	-68%	-67%	-66%	-64%	-62%	-60%	-62%	-54%	-50%	-49%	-39%	-32%
Finland	74	74	-31%	-30%	-28%	-30%	-30%	-30%	-36%	-35%	-35%	-25%	-25%	-25%	-35%	-29%	-29%	15%	31%	36%
France	592	592	-27%	-26%	-24%	-29%	-28%	-28%	-27%	-27%	-27%	-26%	-24%	-24%	-35%	-29%	-29%	3%	15%	20%
Germany	1253	990	-45%	-44%	-42%	-45%	-44%	-43%	-46%	-46%	-46%	-42%	-41%	-40%	-49%	-44%	-44%	-15%	-3%	0%
Greece	120	150	-14%	-13%	-10%	-13%	-11%	-11%	-19%	-19%	-19%	-10%	-8%	-8%	-19%	-12%	-11%	29%	45%	51%
Hungary	104	95	-35%	-33%	-32%	-39%	-36%	-34%	-36%	-33%	-32%	-33%	-28%	-24%	-39%	-25%	-19%	3%	18%	35%
Ireland	57	64	-24%	-23%	-20%	-22%	-20%	-20%	-32%	-32%	-31%	-16%	-14%	-14%	-27%	-20%	-20%	26%	40%	45%
Italy	534	496	-31%	-30%	-28%	-34%	-33%	-32%	-30%	-30%	-30%	-31%	-30%	-29%	-40%	-34%	-34%	16%	31%	36%
Latvia	28	13	-62%	-61%	-60%	-67%	-64%	-64%	-62%	-61%	-59%	-64%	-61%	-59%	-67%	-59%	-56%	-48%	-41%	-34%
Lithuania	53	23	-66%	-65%	-64%	-70%	-67%	-67%	-66%	-65%	-63%	-68%	-65%	-61%	-69%	-63%	-59%	-56%	-48%	-42%
Luxembourg	13	9	-52%	-52%	-50%	-50%	-50%	-49%	-61%	-61%	-61%	-47%	-46%	-46%	-53%	-49%	-49%	4%	18%	25%
Malta	3	4	-14%	-11%	-10%	-17%	-13%	-12%	-29%	-19%	-15%	-15%	-12%	-10%	-23%	-16%	-13%	12%	28%	35%
Netherlands	260	245	-36%	-35%	-33%	-35%	-34%	-33%	-41%	-41%	-40%	-31%	-30%	-30%	-39%	-34%	-33%	8%	22%	28%
Poland	466	428	-36%	-34%	-33%	-39%	-36%	-35%	-38%	-36%	-34%	-34%	-29%	-25%	-39%	-25%	-19%	0%	19%	37%
Portugal	63	80	-5%	-3%	0%	-9%	-8%	-7%	-3%	-2%	-2%	-4%	-3%	-2%	-18%	-10%	-10%	43%	61%	67%
Slovakia	74	61	-44%	-41%	-39%	-47%	-42%	-39%	-46%	-43%	-40%	-41%	-32%	-24%	-47%	-32%	-25%	-11%	5%	19%
Slovenia	19	17	-32%	-32%	-29%	-35%	-35%	-35%	-31%	-31%	-31%	-29%	-26%	-24%	-37%	-25%	-21%	40%	63%	86%
Spain	309	355	-15%	-14%	-11%	-18%	-17%	-16%	-14%	-14%	-14%	-14%	-12%	-12%	-25%	-19%	-18%	56%	75%	82%
Sweden	76	79	-23%	-23%	-20%	-26%	-25%	-24%	-23%	-22%	-22%	-23%	-21%	-20%	-33%	-27%	-26%	6%	19%	24%
United Kingdom	789	686	-39%	-38%	-36%	-39%	-38%	-37%	-40%	-40%	-39%	-36%	-35%	-34%	-44%	-39%	-38%	-9%	2%	7%
EU25	5448	4948	-35%	-35%	-33%	-37%	-35%	-35%	-37%	-36%	-36%	-33%	-31%	-30%	-41%	-34%	-33%	2%	15%	22%

Table 12. Percentage emissions reduction (compared to 1990) for each European country and the EU as a whole under different burden sharing approaches by 2050

450 ppmv CO_2e	Emissions in Mt CO_2e		C&C 2050			CDC			Multistage			Triptych			Intensity			Reference		
			Values as % of 1990			Values as % of 1990			Values as % of 1990			Values as % of 1990			Values as % of 1990			Values as % of 1990		
Year	1990	2010	2050			2050			2050			2050			2050			2050		
Country		Median	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max
Austria	80	70	-81%	-77%	-77%	-82%	-80%	-79%	-90%	-89%	-89%	-80%	-75%	-73%	-85%	-80%	-78%	-15%	25%	57%
Belgium	162	149	-88%	-85%	-85%	-89%	-88%	-87%	-94%	-93%	-93%	-90%	-88%	-87%	-84%	-79%	-77%	-39%	-11%	10%
Cyprus	6	12	-45%	-37%	-33%	-50%	-47%	-27%	-72%	-70%	-59%	-22%	7%	19%	-12%	44%	59%	268%	466%	528%
Czech Republic	197	172	-91%	-90%	-90%	-91%	-91%	-90%	-95%	-95%	-95%	-79%	-73%	-68%	-81%	-66%	-59%	-19%	14%	41%
Denmark	74	58	-86%	-83%	-83%	-87%	-86%	-85%	-93%	-92%	-92%	-82%	-80%	-79%	-87%	-82%	-80%	-31%	-1%	23%
Estonia	43	23	-94%	-93%	-93%	-94%	-94%	-92%	-97%	-97%	-96%	-91%	-89%	-87%	-83%	-71%	-65%	-55%	-33%	-18%
Finland	74	74	-88%	-85%	-85%	-87%	-87%	-87%	-93%	-93%	-93%	-78%	-78%	-78%	-83%	-77%	-75%	-23%	13%	43%
France	592	592	-80%	-76%	-76%	-82%	-80%	-79%	-90%	-89%	-88%	-84%	-80%	-79%	-83%	-77%	-75%	-25%	7%	31%
Germany	1253	990	-88%	-85%	-85%	-88%	-87%	-87%	-94%	-93%	-93%	-85%	-82%	-81%	-87%	-82%	-80%	-43%	-17%	6%
Greece	120	150	-83%	-80%	-80%	-84%	-83%	-82%	-91%	-90%	-90%	-79%	-76%	-75%	-79%	-71%	-69%	-12%	26%	57%
Hungary	104	95	-84%	-81%	-81%	-84%	-84%	-83%	-91%	-91%	-90%	-81%	-77%	-73%	-79%	-65%	-58%	-4%	29%	61%
Ireland	57	64	-87%	-85%	-85%	-88%	-87%	-86%	-93%	-93%	-92%	-81%	-77%	-76%	-81%	-74%	-72%	-9%	29%	55%
Italy	534	496	-80%	-75%	-75%	-81%	-79%	-78%	-89%	-88%	-88%	-81%	-78%	-77%	-84%	-79%	-77%	-20%	16%	45%
Latvia	28	13	-83%	-81%	-81%	-84%	-84%	-79%	-91%	-91%	-89%	-88%	-85%	-84%	-85%	-74%	-70%	-40%	-19%	-4%
Lithuania	53	23	-86%	-85%	-84%	-88%	-87%	-83%	-93%	-93%	-91%	-90%	-86%	-84%	-86%	-76%	-72%	-53%	-32%	-19%
Luxembourg	13	9	-94%	-92%	-92%	-94%	-93%	-93%	-97%	-96%	-96%	-94%	-93%	-92%	-88%	-83%	-82%	-27%	9%	38%
Malta	3	4	-77%	-72%	-72%	-78%	-76%	-75%	-88%	-87%	-86%	-75%	-72%	-72%	-80%	-72%	-70%	-27%	7%	34%
Netherlands	260	245	-88%	-86%	-86%	-89%	-88%	-87%	-94%	-93%	-93%	-88%	-86%	-85%	-84%	-78%	-77%	-26%	7%	35%
Poland	466	428	-86%	-83%	-83%	-86%	-86%	-85%	-92%	-92%	-92%	-78%	-74%	-70%	-79%	-64%	-58%	-17%	15%	44%
Portugal	63	80	-70%	-63%	-63%	-72%	-69%	-67%	-84%	-83%	-82%	-71%	-67%	-65%	-78%	-71%	-68%	0%	45%	80%
Slovakia	74	61	-88%	-85%	-85%	-88%	-88%	-87%	-93%	-93%	-93%	-80%	-74%	-67%	-82%	-68%	-61%	-19%	15%	40%
Slovenia	19	17	-82%	-79%	-79%	-82%	-82%	-81%	-90%	-90%	-89%	-74%	-69%	-64%	-79%	-64%	-59%	31%	76%	121%
Spain	309	355	-76%	-70%	-70%	-77%	-75%	-73%	-87%	-86%	-85%	-75%	-71%	-69%	-80%	-74%	-71%	8%	57%	97%
Sweden	76	79	-78%	-73%	-73%	-80%	-77%	-76%	-89%	-87%	-87%	-78%	-72%	-69%	-82%	-76%	-74%	-25%	9%	35%
United Kingdom	789	686	-86%	-83%	-83%	-87%	-85%	-85%	-93%	-92%	-91%	-85%	-83%	-82%	-85%	-80%	-78%	-38%	-10%	12%
EU25	5448	4948	-85%	-81%	-81%	-85%	-84%	-83%	-92%	-91%	-91%	-83%	-79%	-78%	-84%	-76%	-74%	-24%	5%	31%

Table 13. BAU emissions for each European country and the EU as a whole to 2050 (median of 6 IPCC SRES scenarios)

	Emissions Mt CO2e		Emissions 2010-2050 under business as usual														
Year	**1990**	**2000**	**2010**			**2020**			**2030**			**2040**			**2050**		
Country			min	median	max	min	median	max	min	median	max	min	median	max	min	median	max
Austria	80	84	99	102	103	98	110	114	93	112	125	81	108	127	68	100	126
Belgium	162	169	149	154	155	144	162	172	136	163	184	118	155	184	100	144	179
Cyprus	6	9	12	12	12	15	17	17	17	22	23	19	27	30	20	31	35
Czech Republic	197	150	161	174	185	186	219	249	202	249	307	193	245	309	160	224	277
Denmark	74	76	76	79	80	74	83	87	69	84	93	60	79	93	51	73	91
Estonia	43	20	22	23	24	22	26	29	22	29	34	22	30	37	19	28	35
Finland	74	73	87	90	91	85	96	100	79	97	108	68	91	108	57	83	105
France	592	592	622	638	644	610	680	709	580	695	769	514	672	781	443	634	774
Germany	1253	1059	1096	1136	1145	1068	1210	1258	999	1216	1358	857	1142	1366	714	1045	1328
Greece	120	148	160	165	167	155	175	182	145	176	195	126	165	195	106	152	188
Hungary	104	82	91	98	103	107	123	141	119	142	178	116	142	182	100	135	168
Ireland	57	71	74	76	76	72	80	83	68	81	89	60	78	90	52	73	88
Italy	534	574	630	652	658	619	698	726	584	708	785	505	671	791	425	620	774
Latvia	28	10	13	13	14	15	16	18	16	20	23	17	22	26	17	23	27
Lithuania	53	20	22	23	24	23	27	30	25	32	37	26	35	41	25	36	42
Luxembourg	13	11	14	14	14	14	15	16	13	16	18	11	15	18	9	14	18
Malta	3	3	4	4	4	4	4	4	3	4	5	3	4	5	2	3	4
Netherlands	260	271	289	299	301	282	318	333	265	320	358	230	303	359	192	279	350
Poland	466	381	417	449	477	473	556	631	507	618	760	475	596	751	391	535	663
Portugal	63	86	92	95	96	91	102	106	86	104	115	75	99	116	63	92	114
Slovakia	74	50	57	61	64	65	77	87	72	89	109	70	90	113	60	85	103
Slovenia	19	19	22	24	25	26	30	35	29	35	43	28	35	45	24	33	41
Spain	309	419	489	505	510	481	542	563	454	551	612	395	524	620	334	487	610
Sweden	76	76	82	85	86	81	91	95	77	93	103	67	89	104	57	83	103
United Kingdom	789	704	735	759	767	716	806	842	673	815	909	583	771	912	489	709	887
EU25	5448	5158	5524	5727	5825	5564	6261	6626	5416	6460	7340	4848	6189	7404	4158	5722	7130

Table 14. Cumulative BAU emissions ("BAU carbon budget") for each European country and the EU as a whole to 2050 (median of 6 IPCC SRES scenarios)

	Emissions Mt CO2e		Cumulative emissions 2005-2050 under business as usual Mt CO_2e														
Year	1995	2000	2010			2020			2030			2040			2050		
Country			min	median	max	min	median	max	min	median	max	min	median	max	min	median	max
Austria	82	84	581	592	595	1567	1657	1688	2524	2778	2894	3387	3877	4158	4125	4915	5426
Belgium	169	169	881	898	904	2354	2488	2548	3764	4130	4341	5031	5719	6187	6107	7214	8009
Cyprus	7	9	66	67	68	200	213	216	359	405	415	542	653	682	741	953	1005
Czech Republic	155	150	933	973	1009	2694	2949	3209	4647	5332	6029	6639	7801	9143	8402	10140	12066
Denmark	84	76	453	461	464	1205	1275	1298	1924	2116	2205	2569	2930	3141	3118	3691	4064
Estonia	22	20	132	135	138	351	381	405	570	658	725	789	954	1084	994	1248	1444
Finland	73	73	516	527	529	1378	1465	1488	2205	2440	2536	2938	3377	3621	3553	4244	4691
France	588	592	3672	3729	3748	9844	10353	10542	15823	17277	17981	21271	24106	25750	26011	30636	33547
Germany	1127	1059	6484	6619	6650	17374	18415	18733	27762	30641	31918	36986	42404	45580	44740	53321	59082
Greece	129	148	947	964	970	2528	2673	2721	4039	4438	4618	5387	6139	6572	6532	7721	8492
Hungary	85	82	529	550	568	1529	1661	1803	2680	3012	3422	3869	4443	5250	4952	5815	6995
Ireland	61	71	437	443	445	1164	1223	1243	1866	2032	2105	2502	2827	2999	3057	3584	3891
Italy	549	574	3726	3801	3820	10006	10593	10776	16069	17677	18390	21481	24559	26293	26078	31007	34137
Latvia	13	10	74	75	77	211	225	239	365	406	448	532	614	697	702	838	964
Lithuania	26	20	129	132	135	357	385	407	600	684	748	858	1019	1144	1115	1374	1565
Luxembourg	10	11	80	81	82	216	229	235	349	385	406	469	539	586	571	685	767
Malta	3	3	22	23	23	58	62	64	93	103	109	124	142	154	149	178	198
Netherlands	276	271	1714	1748	1755	4594	4851	4942	7348	8067	8424	9810	11173	12019	11894	14082	15576
Poland	433	381	2419	2525	2616	6943	7578	8225	11873	13554	15274	16817	19605	22904	21140	25233	29945
Portugal	75	86	546	556	559	1463	1545	1572	2348	2579	2683	3146	3590	3839	3829	4542	4990
Slovakia	54	50	326	339	351	944	1032	1120	1637	1875	2115	2356	2771	3236	3007	3645	4314
Slovenia	19	19	129	134	138	375	406	441	653	738	837	941	1088	1283	1205	1423	1711
Spain	341	419	2890	2943	2959	7754	8206	8353	12453	13715	14278	16675	19084	20458	20277	24133	26621
Sweden	79	76	486	494	497	1303	1376	1402	2093	2301	2398	2808	3207	3440	3423	4065	4481
United Kingdom	738	704	4340	4421	4447	11634	12291	12532	18614	20455	21351	24857	28367	30480	30148	35756	39496
EU25	5197	5157	32511	33232	33547	88043	93533	96202	142658	157798	166651	192782	220990	240700	235869	280444	313479

Table 15. Average annual emission reductions under Contraction & Convergence (Figure 5)

	Annual reduction under Contraction and Convergence			
	2010-2020		2010-2050	
	min	max	min	max
Austria	-3%	-3%	-3%	-4%
Belgium	-3%	-4%	-5%	-5%
Cyprus	-3%	-4%	-3%	-3%
Czech Republic	-3%	-4%	-5%	-6%
Denmark	-3%	-3%	-4%	-4%
Estonia	-3%	-4%	-5%	-5%
Finland	-3%	-4%	-5%	-5%
France	-3%	-3%	-4%	-4%
Germany	-3%	-3%	-4%	-5%
Greece	-3%	-4%	-4%	-5%
Hungary	-3%	-3%	-4%	-4%
Ireland	-3%	-4%	-5%	-5%
Italy	-3%	-3%	-3%	-4%
Latvia	-2%	-2%	-2%	-3%
Lithuania	-2%	-3%	-3%	-3%
Luxembourg	-4%	-4%	-5%	-6%
Malta	-3%	-3%	-4%	-4%
Netherlands	-3%	-4%	-5%	-5%
Poland	-3%	-4%	-4%	-5%
Portugal	-2%	-3%	-3%	-4%
Slovakia	-3%	-4%	-4%	-5%
Slovenia	-3%	-3%	-4%	-4%
Spain	-3%	-3%	-3%	-4%
Sweden	-3%	-3%	-3%	-4%
United Kingdom	-3%	-3%	-4%	-4%
EU25	-3%	-3%	-4%	-4%

Appendix D Existing EU Processes

The way the EU is governed internally is unique: 27 individual Member States retain national sovereignty whilst working together and being governed on some issues by the EU. The main EU governance structure comprises:

European Council

- Comprises Heads of State of each Member State.
- Led by the Head of State from the country currently holding Presidency of the EU (annual rotation).
- Meets four times per year at the 'European Summit'
- Role is to provide guidance and high level policy to the Council of the European Union (also called Council of Ministers).

Council of the European Union

- Main decision-making body
- Comprises Ministers from Member State governments who meet regularly on their relevant policy areas e.g. Environment Council
- Responsibility for approval of the EU budget (in co-decision with the European Parliament).
- Co-ordinates the broad economic policies of the Member States
- Concludes international agreements on behalf of the EU
- Also has a remit to co-ordinate and take decisions on foreign and security policy and justice.

European Parliament

- Members democratically elected by EU citizens every five years
- Shares legislatory power with the European Council i.e. has the power to adopt European laws (directives, regulations, decisions)
- Shares budgetary authority with the Council and can therefore influence EU spending
- Has democratic and political decision over the EU institutions including the European Commission. Approves the nomination of Commissioners and, where necessary, has the right to censure the activity of the European Commission.

European Commission

- Administrative and executive body
- Led by Commissioners from all Member States, delegated to the Commission by the Member States (after approval by the European Parliament)

- Structured into departments ("Directorate General" – DG), each led by one commissioner and each with responsibility to further a specific area of European policy
- Drafts legislation and presents legislative proposals to the Parliament and the Council
- Also responsible for implementing European legislation, budget and programmes.
- Ensures appropriate implementation and compliance with Community law (together with the European Court of Justice)
- Represents the European Union on the international stage and negotiates international agreements.

Monetary Budget

Like any country the EU has a budget to spend, and policy decisions are made that relate to the way in which these budgets are distributed and the timing of their distribution. The EU budget is divided into separate sections and into different funding streams below this. For example specific funds are allocated to research and development, structural funds, Common Agricultural Policy, international aid etc.