**Paul Watkiss Associates**

# Review of the Methodological Approaches Available for Setting UK Carbon Budgets. RMP/4850

## Draft Final Report to the Shadow Secretariat on Climate Change/ Office of Climate Change


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# Executive Summary

The aim of this study is to provide external advice and recommendations to the Shadow Committee on Climate Change (SCCC) on the methodological approaches that could be used to propose UK interim carbon budgets for the period 2008-2022. These interim budgets are bounded by existing Government commitments, most notably the 26-32% reduction in $CO_2$ emissions by 2020 (on 1990 levels), on the way to 'at least' a 60% $CO_2$ reduction by 2050. As such, the interim carbon budgets will effectively set the UK's 2020 reduction target, and this date has been the primary focus of the study. The findings are summarised below.

- The setting of interim budgets is strongly influenced from the 'top down' by: long-term global stabilisation targets; the global pathways of emissions to these long-term targets; and the UK's relative share in global emissions reductions (e.g. as a developed country). It is also influenced from the 'bottom up' by the UK's decisions on how much of its commitment to meet from overseas through international flexible mechanisms, and the relative share of reductions by sectors within and outside the emissions trading scheme. Finally it is influenced by external political negotiations with respect to the EU's 2020 GHG targets and the burden sharing agreement. Any decision on interim targets therefore sits within a much wider set of policy considerations.
- A review has found a variety of possible methods for setting carbon targets. These reflect different perspectives for framing climate-change policy, and accordingly, different methodological approaches. The entry points range from a strong economic perspective through to a non-economic/precautionary perspective. To date, most proposed long-term targets have used a precautionary approach, but most interim targets (and the UK Government's long-term target) have been set after a check for technical and economic achievability using cost-effectiveness analysis (CEA).
- The challenge for the UK is to set short-term (interim) carbon targets under multiple sources of uncertainty over the future evidence and the course of policy. Many of these uncertainties will be reduced in the future. Therefore, any methodological approach should consider the extent to which interim targets keep options open for the longer term, thereby avoiding irreversible commitments. This problem is one of decision making under uncertainty, or options analysis. In the literature, this has been explored in most depth using cost-benefit analysis (CBA), though such a framework can be applied to other methods.
- Each of the different possible methods for setting targets has been reviewed, with a focus on how they can be used within an options framework. On the basis of this review, the recommended approach is to undertake cost-effectiveness analysis with options analysis as the central pillar of a multi-attribute framework. CEA is the method that has been used in previous assessments by UK Government. It can assess the feasibility and cost of different levels of policy ambition. It is also an input into other methods, and is central to the analysis. However, CEA is a relative measure and cannot provide a justification for the benefits of different targets on its own. For this reason, we believe it needs to be complemented with other approaches.
- The approach proposed examines the 'top down' and 'bottom up' influences, with some consideration of stronger economic and stronger precautionary perspectives. This is consistent with an approach that includes different methodological approaches and decision perspectives as complements, reflecting the diversity of different stakeholder views. The approach is also complemented by consideration of environmental, political and social risks and benefits of different budgets.

As part of the study, some case study work has been undertaken to test this type of options analysis framework. The case study investigates the possible option values in relation to UK 2050 targets and the current 26 to 32% UK 2020 target. A simple curve-fitting analysis suggests that choosing 26% rather than a 32% reduction in 2020 could require a significantly greater rate of decline in annual emissions in the period 2020-2050 in order to achieve cumulative emissions consistent with a 550ppm $CO_2e$ stabilisation level. Given that steeper reduction paths are likely to be more costly, and given the current uncertainty over the level of emission reductions required in 2050, this suggests that there may be significant option value in aiming for a more ambitious 2020 target in order to maintain the feasibility of reaching more stringent long-term targets. Further economic analysis of the costs implied by these different pathways needs to be undertaken to evaluate this option value. This analysis needs to weigh up the expected pre-2020 and post-2020 costs associated with different pathways, the likelihood of different long-term targets, and the economic effect of making irreversible decisions regarding the UK's capital stock. Nonetheless, it highlights that such an approach is very relevant for the CCC.

Following these findings, we recommend that the SCCC's approach comprises four steps:

1. To frame a range of long term UK carbon reduction goals. This range should consider alternative perspectives (stronger economic and stronger precautionary) and associated approaches for setting long-term targets.
2. To recognise the uncertainty over what the UK might want to achieve in the long term. Following from this, to use an options-based approach to keep different long term goals open. The options approach should consider the feasibility and costs of achieving the long term goals contingent on near / medium term action.
3. To set interim budgets based on a cost effectiveness approach (including option value), taking account of international agreements / commitments including EU burden-sharing. This analysis should take account of uncertainty in cost estimates and implementation.
4. However, to complement the steps above with an assessment of the wider ancillary risks and benefits of different interim carbon budgets including environmental, social and economic considerations (e.g. air quality, fuel poverty, energy security, employment, trade, competitiveness, public finances, innovation). The analysis of these non-carbon effects could be undertaken with CBA, though uncertainties may necessitate a broader approach.

The recommended approach therefore uses cost-effectiveness analysis as the central pillar of a wider multi-attribute framework (a non-formalised comparison of costs and benefits). Note that whilst formalised cost-benefit analysis provides a potentially powerful tool for setting carbon budgets, we believe that the current uncertainties in the Social Cost of Carbon (SCC) are too large to rely on it for specifically setting interim UK budgets. Nonetheless, CBA should be used to periodically monitor the economic case for Government policy and targets, especially when new information on the costs and benefits of emission reductions emerge, as part of a stronger economic approach. However, there is a wider issue of consistency here, as the SCC has been used to set the Shadow Price of Carbon (SPC) in the current Government appraisal guidance. It is therefore essential that the SCCC ascertain whether the current SPC is in line with the marginal abatement costs of achieving the interim targets (derived above), to avoid inconsistencies in policy appraisal (and if necessary to seek to address these through the SPC). It is also highlighted that the SCCC may need to investigate the impact on the SCC (and SPC) from any changes in long-term targets, as the Social Cost of Carbon (SCC) is path dependent.

A detailed description of the study findings and recommendations are included in the report, along with a road-map that outlines the practical steps needed to work through these proposals.

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# Chapter 1 Background and Study Objectives

## Introduction

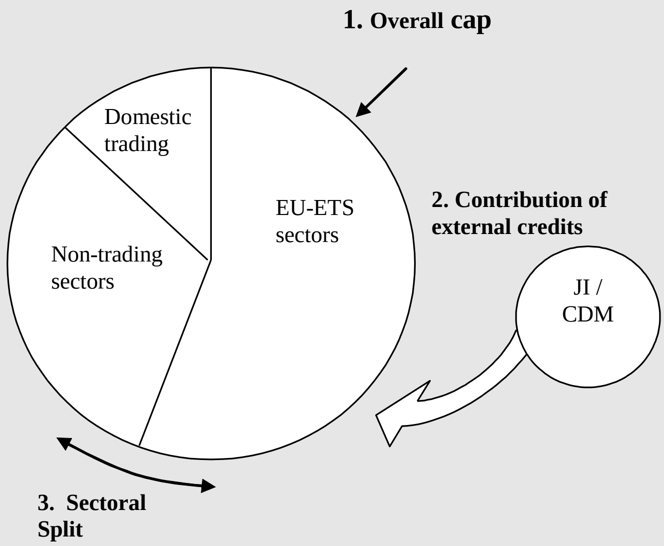
This report sets out the findings of the research contact '*Concerning the provision of consultancy service to review the various methodological approaches available for setting UK carbon budgets, RMP/4850*' for the Shadow Secretariat on Climate Change (Office of Climate Change).

The aim of the work has been to review the different methodological approaches for setting interim carbon budgets. This supports the role of the Committee on Climate Change (CCC) (see box), in their task to provide advice on the level of the first three carbon budgets (2008-12, 2013-17, 2018- 22) by 1 September 2008. The study aims to contribute to this role by providing a review of the current state-of-the-art in terms of understanding of the issues that underpin decisions on setting climate change targets.

**The Committee on Climate Change (CCC)**

The Committee on Climate Change (CCC) is a statutory body, set up in the Climate Change Bill, to provide independent, expert advice on how the UK can best achieve its climate change goals. Its main duty (shown schematically in the figure below) will be to advise Government on:

- The level of the carbon budgets (caps covering five year periods) consistent with the UK's 2020 and 2050 targets and its international obligations;
- The extent to which carbon budgets should be met by domestic emissions reductions versus emissions purchased overseas;
- The respective contributions towards meeting the budgets of those sectors of the economy covered by trading schemes (e.g. EU ETS, Carbon Reduction Commitment); and
- The contribution towards meet the budget of those sectors not covered by trading schemes (e.g. transport, households).




The rationale for entrusting these decisions to the CCC is to de-politicise target setting, and to try to help increase the credibility and predictability of policy decision-making.

As part of their initial task, the CCC will implicitly propose a 2020 emissions reduction target which is within the range specified in the Climate Change Bill and the earlier 2003 Energy White Paper (DTI, 2003), which set out a $CO_2$ emissions reduction of between 26% and 32% on 1990 levels. This sets the main time-frame for the current study. However, these targets are strongly linked to the Government's existing long-term commitments, and so these are also considered in this work. These are:

- The long-term commitment, as set out in the Energy White Paper (DTI, 2003), for a reduction of $CO_2$ emissions of 60% versus 1990 levels by 2050. The interim target of 26 to 32% by 2020 (also DTI, 2003), which was intended to signify real progress towards this long-term target.
- It was thought that such a reduction across developed countries, together with (less) action in developing countries, would be sufficient to limit concentrations of greenhouse gases to 550 ppm and the increase in global mean temperature to 2ºC. This target has recently been updated to '*at least'* a 60% reduction. There has also recently been an announcement by Hilary Benn[1] asking the Committee on Climate Change to report on whether the Government's target (the 60% target) should be strengthened.
- The Stern Review (Stern et al, 2006) concentrated on stabilisation targets of 450 to 550 $CO_2$e ppm and concluded that stabilisation at 500 to 550 $CO_2$e ppm involved significant but manageable costs.

The methodological approaches considered in this study also have to consider a wider range of factors that the CCC must consider (as set out in the Climate Change Bill) when giving its advice. These include:

(a) scientific knowledge about climate change;

(b) technology relevant to climate change;

(c) economic circumstances, and in particular the likely impact of the decision on the economy and the competitiveness of particular sectors of the economy;

(d) fiscal circumstances, and in particular the likely impact of the decision on taxation, public spending and public borrowing;

(e) social circumstances, and in particular the likely impact of the decision on fuel poverty;

(f) energy policy, and in particular the likely impact of the decision on energy supplies and the carbon and energy intensity of the UK; and,

(g) international circumstances.

Equally, the CCC has to have regard to existing and forthcoming EU and global commitments, including

- The commitments agreed by EU heads of state and government at the 2007 EU spring council (Brussels, March 2007), including the "firm independent commitment to achieve at least a 20% reduction of greenhouse-gas emissions by 2020" compared with 1990 levels. It was also agreed to increase this target reduction to 30% "provided that other developed countries" such as the US "commit themselves to comparable emissions reductions". At the same meeting, EU heads of state and government endorsed "a binding target of a 20% share of renewable energies in overall EU energy consumption by 2020". Proposals for specific national targets to achieve the overall figure, taking into account each country's potential and point of departure were produced in January 2008[2].
- At the G8 meeting in Heiligendamm (June 2007), the leading industrialised nations (G8) pointed to the need to at least halve global $CO_2$ emissions by 2050.[3]

Finally, consistent with the study ITT, a number of other factors have been considered:

[1] http://www.defra.gov.uk/news/latest/2007/climate-1029.htm

[2] http://ec.europa.eu/environment/climat/climate_action.htm

[3] The European members of the G8 plus Japan and Canada agreed that they would aim to reduce emissions by half by 2050. USA and Russia only agreed to "seriously consider" such a halving proposal.

- Alternative approaches for identifying an efficient level of climate stabilisation;
- Alternative ways of identifying the various emissions reduction trajectories consistent with given stabilisation levels;
- The various methodologies for determining how given reduction levels globally can / should be split between developed and developing countries;
- How budgets might relate to current international agreements / likely future agreements;
- Basing budgets on a conception of what the UK can do in terms of emissions reduction;
- Budgets based on cost effectiveness analysis;
- Budgets based on UK level cost benefit analysis (e.g. using the Social Cost of Carbon and the Marginal Abatement Cost);
- Methodological approaches for determining the relative contribution of traded vs. non traded sectors to the UK burden, allowing for any issues relating to supplementarity;
- At a high level identifying ancillary impacts, and how information on these can be used to inform budget proposals;
- To identify risks for the UK of not meeting its carbon budgets, and risk mitigating mechanisms;
- To explore the (economic and more general) case for making greater use of international carbon credits (e.g., CDM credits) in achieving the UK 2010 target and to increase the level of effort in subsequent budget periods to 2020.

The overall aim of the assignment is to provide external advice and recommendations to the Shadow Committee on Climate Change (CC) on methodological approaches they might take in proposing carbon budgets.

## The Framework for Setting Policy for the CCC

The study has first outlined the overall framework for setting UK interim targets. This involves a flow of decision-making at different levels and time-scales. It can be seen to start at the top with long-term global stabilisation targets. It then progresses through emissions pathways towards these long-term targets, the allocation between countries (developed vs. developing, and between EU member states), through to national (UK) long-term targets and from these, national (UK) interim targets. Finally, it involves sub-UK targets in relation to the level of domestic action and interim sub-sector targets.

The current project is focused on the area highlighted in yellow in this figure (the CCC's interim targets). However, any decisions on these interim targets are influenced by the long-term international targets and stabilisation pathways (the upper part of the figure), as well as the share of domestic action and UK sectoral allocations (the bottom part of the figure). For the interim targets, a particularly important issue is the process of EU burden sharing and the links with the EU GHG 2020 targets.

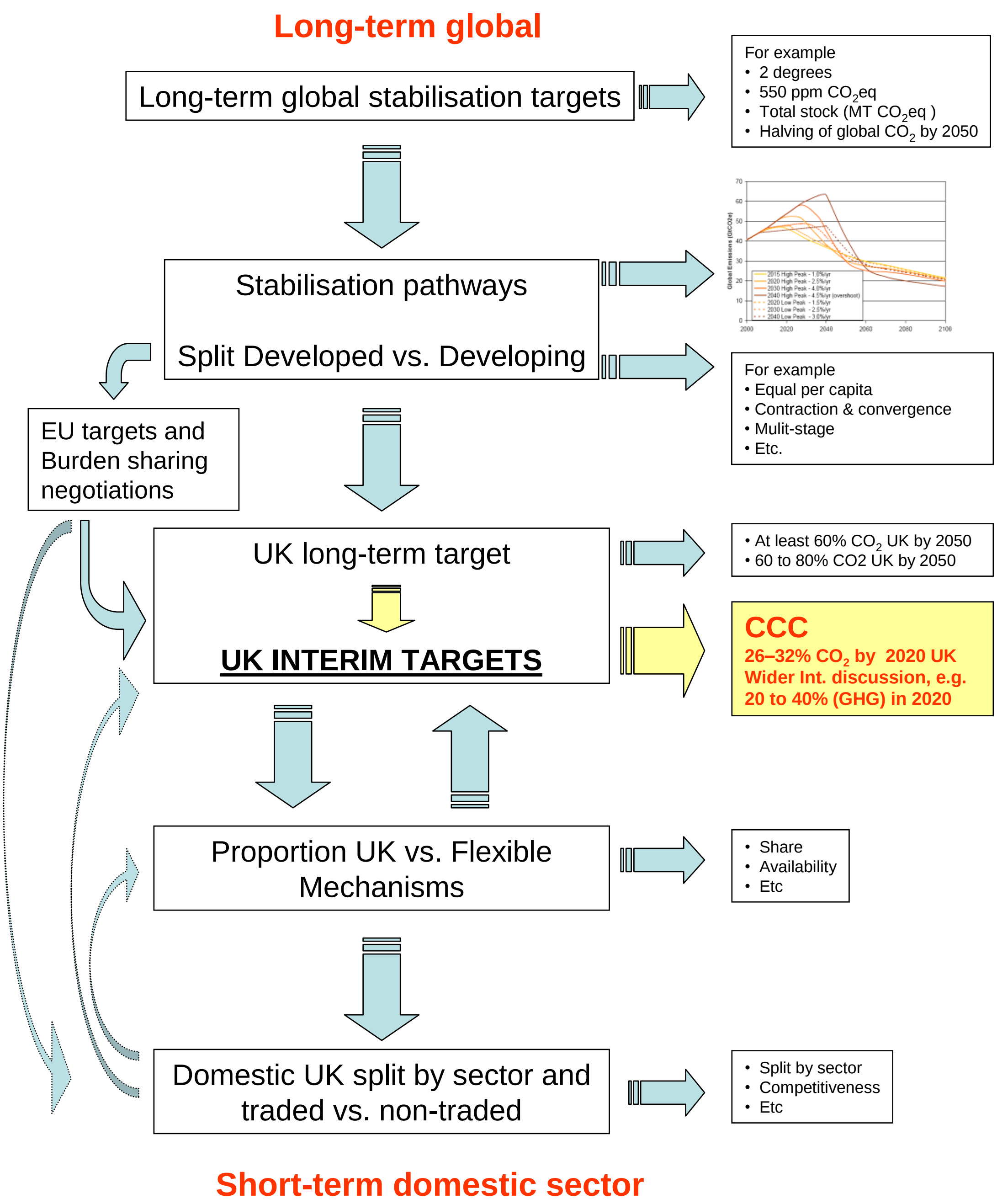



**Figure 1.1 Overall Framework for Target Setting for the CCC**

Some discussion of these steps is presented below:

- The setting of long-term international stabilisation targets (at the top of the figure) can involve different metrics. This can include stabilisation targets in terms of:
  - Temperature change (global average mean temperature change in degrees, either from a pre-industrial baseline, or from current levels), e.g. as in the EU long-term stabilisation target of 2ºC (from pre-industrial);
  - $CO_2$ or $CO_2$ equivalent (all GHG) concentrations in ppm, as in the Stern recommendation of 500 – 550 ppm $CO_2$ equivalent.
  - Some form of global emission stock or global emissions reduction, e.g. the Heiligendamm proposal to at least halve global $CO_2$ emissions by 2050.

- The next step involves the emission paths over time that can achieve these stabilisation targets, and the allocation between developed and developing countries for action. Note these aspects are related and vary over time, i.e. it is the combination of the stabilisation path, and the relative contribution of different countries to such paths at different points in time, that leads to the overall achievement of the long-term stabilisation aim.
- This can lead to the setting of long-term national emission targets, which are consistent with a global long-term stabilisation target, and with the agreed level of action to achieve this for a developed country. As an example, the current UK target of a 60% $CO_2$ reduction by 2050 was set on the basis of achieving 550 ppm $CO_2$ concentration[4], based on an analysis of likely developed and developing country emission paths towards this long-term objective. Such a target requires global participation and action.
- These can lead to interim national targets which are consistent with a pathway towards achievement of a national long-term target (and also the stabilisation paths towards global targets consistent with, e.g. developed country action). It is these interim targets that are the main focus of this current study. In the UK, the existing interim target - a 26-32% $CO_2$ reduction by 2020 - is consistent with the pathway towards the UK's 60% target, itself consistent with the previous analysis of a global emission reduction that would achieve the 550 $CO_2$ ppm level.
- The allocation of these national interim targets between domestic (UK) action and traded allowances from flexible mechanisms (Permit trading schemes, CDM or JI) can then be made prior to;
- The split of domestic action between trading and non-trading sectors.

While this shows a logical sequence by which one could arrive at a UK-level interim target, actual decisions are <u>unlikely</u> to flow smoothly from the global level at the top of the figure through to UK-level sectoral policy decisions at the bottom[5]. In practice there is a two way flow between the decision-making steps outlined above.

Importantly, the decisions which the CCC will be advising on will be subject to various levels of negotiation, either within the EU or more broadly on the international stage, and over which the UK will different levels of control.

Finally, it is highlighted that the existing UK long-term targets (and therefore the interim targets) are based on the presumption of action at a global level, i.e. that any UK action can achieve stabilisation only with global participation, and that the UK global target is predicated on other similar international action in developed countries.

## Definitions and Metrics

There are a number of important issues in relation to the definition of targets, and the use of different metrics. This frequently leads to confusion between different reported targets. Key differences are:

- Whether a temperature stabilisation target refers to the change above pre-industrial levels (and note that 0.7°C of change has already occurred in the 20th century), or to the change relative to average levels in 1980 -1999 (as in the IPCC 4th Assessment Report), or relative to 1961-1990 (the baseline period in many climate models).

[4] The RCEP document states a 550 ppm $CO_2$ concentration. Evidence given by Defra has interpreted this as a 550 ppm $CO_2$ equivalent concentration target (i.e. closer to a 500 ppm CO2 target). See Chapter 2 for details.
[5] note it is also possible to consider what UK targets infer for the global stabilisation levels, i.e. by working in reverse up the diagram.

- Whether a ppm stabilisation target relates to a $CO_2$ concentration in the atmosphere (e.g. 550 $CO_2$ ppmv) or an equivalent $CO_2$ concentration including all greenhouse gases (e.g. 550 $CO_2$ eq. ppmv or $CO_2$e).

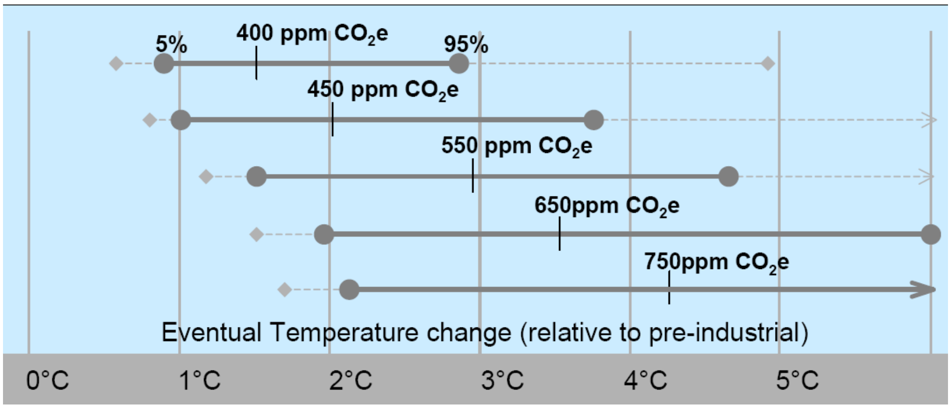
- Whether emissions reductions refer to $CO_2$ only, or all GHG emissions.

There are also complex issues in the inter-comparison between the different types of metrics (above) because of uncertainty.

Ultimately, all long-term stabilisation targets are related to temperature, where temperature is a proxy for global climate change, and the target level is set to avoid dangerous anthropogenic interference.

However, in practice, the different metrics above are used as a short-hand proxy for these long-term targets. Targets are often expressed as $CO_2$ or $CO_2$ equivalent ppm concentrations, which relate to temperature predicated on the relationship between $CO_2$ concentration or GHG concentration, the latter expressed as $CO_2$ equivalent ($CO_2$e or $CO_2$ eq.) and temperature. For such targets, the assumptions about how ppm concentrations relate to temperature are strongly influenced by the equilibrium climate sensitivity. As defined by IPCC AR4 (2007), *this is 'a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is likely to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is very unlikely to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values*.

The relationship between ppm and temperature is shown below, taken from the Stern Review. The uncertainty is presented between ppm change and temperature, given by the distribution across the temperature range from given ppm changes. As an example, achieving 450ppmv $CO_2$e would give around a 50% chance of not exceeding 2°C (from pre-industrial).




*500 to 550 implies 2.5 to 3C, i.e. 2 C from today (50%)*

*Based on climate sensitivity with Ensemble run*
*vertical line indicates the mean of the 50th percentile point and line the 5 – 95% .*
*The dashed lines show the 5 - 95% range based on eleven recent studies.*

Note that the IPCC 4th Assessment Report reports that using the 'best estimate' of climate sensitivity, the AR4 WGIII (Barker et al, 2007) concludes that the most stringent scenarios (stabilizing at 445–490 ppm $CO_2$- eq) could limit global mean temperature increases to 2-2.4°C above pre-industrial, at equilibrium, requiring emissions to peak within 10 years and to be around 50% of current levels by 2050. Scenarios stabilizing at 535-590 ppm $CO_2$-eq could limit the increase to 2.8-3.2°C above pre-industrial and those at 590- 710 $CO_2$-eq to 3.2-4°C, requiring emissions to peak within the next 25 and 55 years respectively.

Similarly, there is uncertainty in the relationship between $CO_2$ or GHG emissions and ppm concentrations, not least due to the influences of carbon sinks. It is highlighted that as one moves further away from a temperature target, the relationships between the planned targets and the ultimate goal of temperature stabilisation becomes more uncertain, as the simplified table below sets out.

**Table 1.1 The uncertainty of relationships between different targets**

| Long-term Target | Attributes | Uncertainty |
|---|---|---|
| Temperature change, e.g. 2ºC | Related to global temperature change, either relative to pre-industrial or current | Highest confidence in terms of achievement of preventing dangerous anthropogenic interference. However, high uncertainty in achieving the target objective. |
| Stabilisation concentration, e.g. 550 ppm $CO_2$ eq. | Atmospheric concentration, expressed either in terms of $CO_2$ only, or all GHG as $CO_2$ eq. | Lower confidence in relation to temperature, because of climate sensitivity, but higher confidence in achieving the given target. |
| $CO_2$ or GHG Emissions (stock MtC eq.) | Total stock of $CO_2$ or GHG. | Still lower confidence in relation to temperature, because of the role of sinks, etc. but higher confidence in being able to achieve stated target. |
| $CO_2$ or GHG % reduction in long-term (e.g. 2050) | Global reduction level (e.g. halving). Requires an emissions pathway to relate to total $CO_2$ (stock) or $CO_2$ (ppm). | Lowest confidence in relation to temperature and ultimate objective of preventing dangerous anthropogenic interference, but higher confidence in achieving stated target. |

In the UK the main Government long-term target is expressed as a $CO_2$ reduction by 2050: from the table above this means there is a high confidence that it is possible to achieve this objective through emission reductions, but a very low confidence that this will achieve the related long-term stabilisation goal of the 550 $CO_2$ ppm or the original assumption that this would prevent in excess of 2 degrees of temperature change from pre-industrial.

In terms of environmental impact, what matters most (particularly for carbon dioxide) is the total cumulative emissions over time, not the achievement of a particular level of annual emissions at some fixed point in time. The political focus on particular emissions paths is only relevant to the extent that it helps to delineate an overall cumulative level of emissions consistent with some concentration level. In practice, managing cumulative emissions in this way is likely to be essential. Setting interim targets over the course of the coming century helps to identify the steps that will be needed to limit cumulative emissions at the target level. Whilst this requires an imperfect estimate of how the costs of abatement will evolve over time, the alternative of setting cumulative emissions limits for the century with no interim milestones is probably unworkable because it is hard to envisage a credible penalty system that would incentivise the necessary timely investments over the course of the next several decades when the cumulative target would not itself be threatened until the end of this period.

## Report Outline

The outline of the report is presented below.

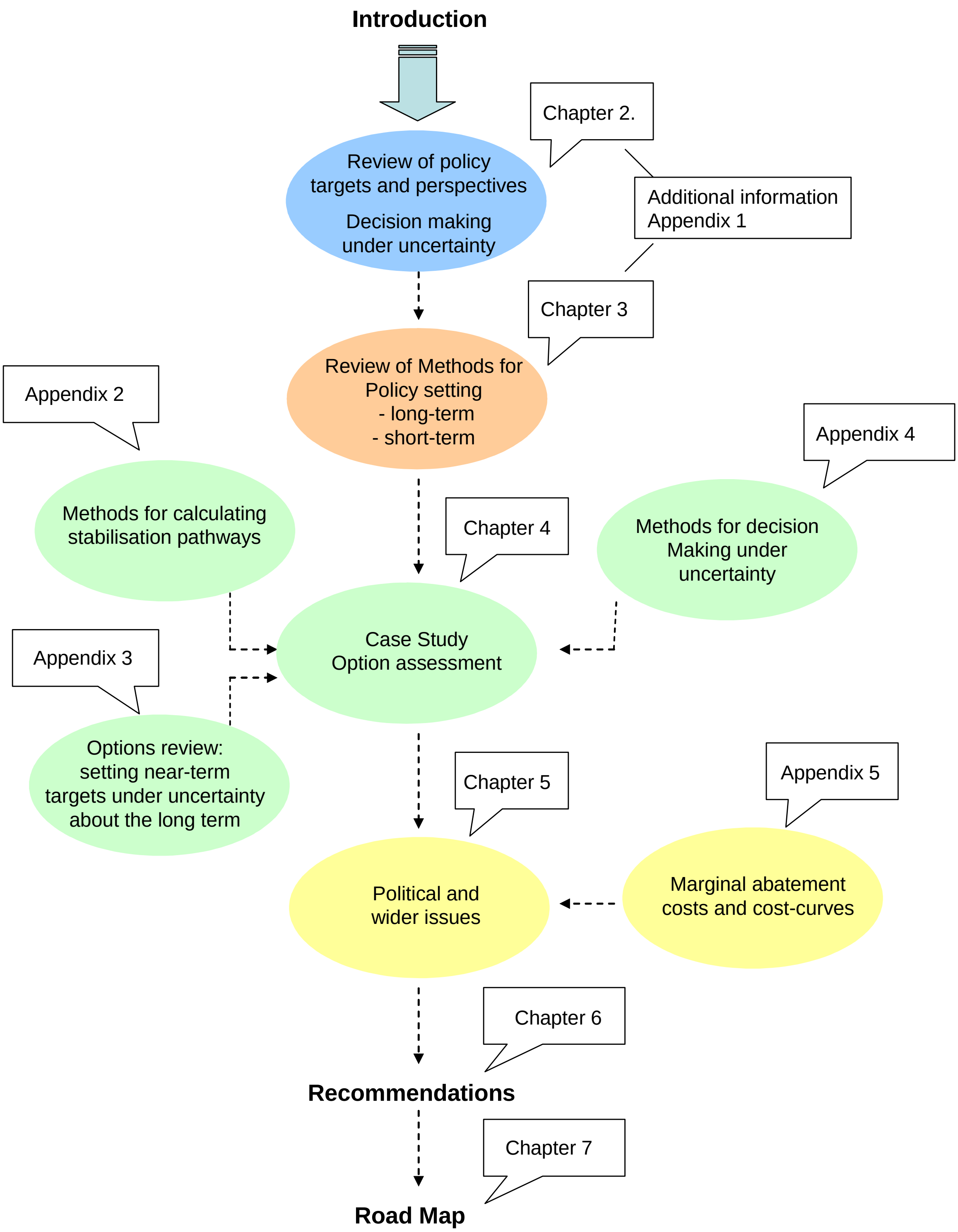



**Figure 1.2 Report outline**

The information in the main chapters is a summary of the overall main analysis (in order to keep the report brief). Additional technical appendices are provided for some areas of work.

Chapter 2 sets out the decision perspectives and frameworks that can be used in climate change policy. It reviews the existing long-term target proposals and identifies which decision frameworks have been utilised to inform them.

Chapter 3 describes the different methodological approaches incorporated in the decision frameworks that can be used for setting long-term and interim targets. It focuses on cost-benefit analysis, multi-criteria and multi-attribute analysis, risk approaches, hedging and option appraisal strategy in the context of climate change policy, and other approaches (e.g. tolerable windows).

Some of the additional background details for chapter 2 and 3 are given in Appendix 1.

Chapter 4 present a case study to work through the approaches that are relevant for decision making under uncertainty, and the linkages with long-term and global targets.  It advances the discussion of option (hedging) strategy and provides an example that raises the analytical approach.  It is supported by three appendices: analysis of methods for assessing stabilisation (emission) pathways; a review of the options literature; analysis; and a review of decision making under uncertainty. More details of each of these areas is set out in Appendices 2, 3 and 4.

Chapter 5 discusses the wider issues that need to be considered in the methodological framework, e.g. with political burden sharing, ancillary effects, and the issues of trading and non-traded sectors.  Appendix 5 presents some of the technical issues associated with cost-curves.

Chapter 6 summarises the study recommendations, and Chapter 7 outlines a road map for the SCCC on how to implement this approach in practice.

# Chapter 2. Existing Climate Change Targets

The obvious starting point for this study is to review how existing long-term and short-term climate change or greenhouse gas reduction targets have been set. This chapter therefore reviews the existing literature on targets - for both Government commitments and other actual or proposed targets - and reports on the supporting analysis and methods that have been used. It then goes on to put the alternative approaches in context, through the consideration of the different perspectives which have been adopted in setting climate change policy and specifically climate change targets specifically.

## Overview of Policy Targets

There are a number of existing long-term stabilisation proposals and interim targets adopted in public policy or developed in other literature. Some of these have been the analysis of previous review, e.g. Jones and Preston, (2006). The study has reviewed a number of the most relevant policy targets, split into long-term and interim targets, listed below. The difference in metrics between $CO_2$ ppm and $CO_2$e ppm, and $CO_2$ and GHG, are highlighted.

**Table 2.1. Summary of Relevant Long-term and Interim Policy Targets**

| Organisation | Target |
|---|---|
| **Long-term** | |
| RCEP (2000) | 550 **$CO_2$** ppm (equivalent to 2ºC from pre-industrial at lower end of range) |
| UK: EWP (DTI, 2003) | Goal of 60% **$CO_2$** reduction by 2050 for UK |
| Stern Review (2007) | 450 to 550 **$CO_2$e** ppm, with statement that costs manageable for 500 to 550 $CO_2$e ppm |
| European Council (1996) | 2ºC from pre-industrial |
| EC (2007) | 60-80% **GHG** by 2050 by developed countries (50% global) |
| France | Reducing **GHG** emissions four- or fivefold by 2050 |
| Sweden | 50% to 60% **GHG** by 2050 |
| Norway | Carbon neutral by 2050 |
| Japan | Proposals of 50% **GHG** by 2050 |
| G8 Heiligendamm | Consider seriously at least a halving of global emissions of **GHG** by 2050 |
| **Interim** | |
| UK EWP (DTI, 2003) | 26 – 32% **$CO_2$** by 2020 ('real progress' on path towards the 60% target) |
| UK Government CCP | Target of 20% **$CO_2$** reduction by 2010, with |
| European Council (2007) | 20% **GHG** by 2020, rising to 30% GHG with international agreement |
| Norway | 30% **GHG** reduction by 2020 |
| Germany | 40% **GHG** by 2020 |
| Czech republic | 25% **CO2 on 2000** by 2020 |

The targets are shown below, with interim targets at the top (either as $CO_2$ or GHG reductions by 2020), followed by different long-term targets of emission reductions (either as $CO_2$ or GHG reductions by 2050), stabilisation targets (either $CO_2$ ppm or $CO_2$e ppm), and temperature. Note that it is difficult to map the UK targets directly against other international targets, because of the use of different metrics. The most relevant of these targets, and the documents that support them, are summarised below.

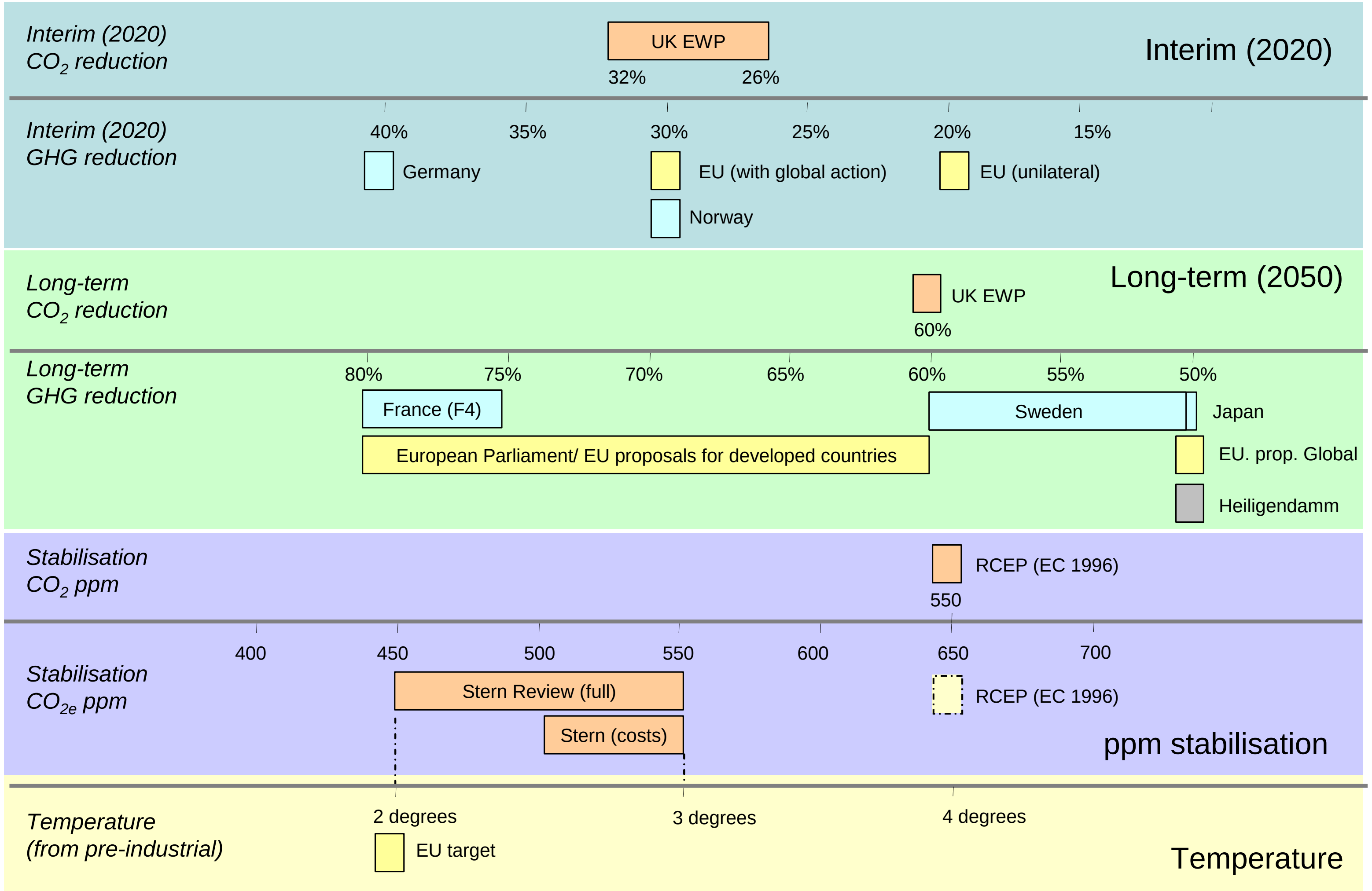



**Figure 2.1. Existing Target Proposals**

The relative level of ambition of the UK's $CO_2$ reduction targets of 26 to 32% (2020) and 60% (2050) depends on a little on exact interpretation. Note that the RCEP target of 550 ppm $CO_2$ is less ambitious than the 550 ppm $CO_2$e in Stern. The Stern Review cites that stabilising at 450 – 550 $CO_2$e ppm could be equivalent to 400– 490 $CO_2$ ppm, and that the RCEP target of 550 ppm $CO_2$ translates into a total atmospheric concentration of all GHGs of around 650ppm. A line is drawn from $CO_2$e to temperature, based on the Stern review figure (shown earlier in the chapter).

# The UK Long-Term and Interim Targets

## The Royal Commission on Environmental Pollution (RCEP) – 550 ppm $CO_2$

The RCEP made recommendations on a long-term goal for the UK of 550 ppm $CO_2$, translated into a UK target as a 60% reduction in carbon dioxide emissions by 2050:

'*on the basis of current scientific knowledge about human impact on climate, an atmospheric concentration of 550ppm of carbon dioxide should be regarded as an upper limit that should not be exceeded.'*

'*A reduction in carbon dioxide emissions of 60% by 2050 is consistent with the level of reduction likely to be needed by developed countries in order to move towards stabilisation of carbon dioxide concentrations in the atmosphere at no more than 550 ppm, taking account of a realistic assessment of emissions growth in developing countries*.'

This justification for this goal was outlined in '*The scientific case for setting a long term emission reduction target*'[6]. The goal was based around a scientific-precautionary stance on preventing dangerous anthropogenic interference with the climate system, using information from the IPCC Second Assessment Report of 1995. However, there is very little discussion on how the value was actually chosen. The justification appears to derive principally from a comparison of different stabilisation levels and their range of associated temperature changes (see table in Appendix 1), together with an assessment of the associated climate change impacts. The RCEP centred on 550 ppm $CO_2$, which was related to 2°C at the low end of the temperature range[7]. This target was therefore consistent with the EC's 2°C target[8] and was benchmarked against this target in the report. Note that subsequent IPCC reports have shown much lower concentration levels are likely to be needed to achieve this temperature limit.

## The Energy White Paper (2003): The 60% $CO_2$ Reduction by 2050 and Interim 2020 Targets (26 to 32%)

The UK was the first country to adopt a long-term carbon goal (announced in the Energy White Paper in 2003), when it adopted the advice of the Royal Commission on Environmental Pollution (RCEP) above. The Energy White Paper (DTI, 2003), published in 2003, set out the longer term framework for the UK's energy policy and accepted that the UK should put itself on a path to reducing carbon dioxide emissions by some 60% (from 1990 levels) by 2050, with real progress by 2020. The Energy White Paper went on to set out the first steps to achieving this goal. Note that this target is presented in the context of similar international emissions reductions in other developed countries, consistent with the RCEP analysis.

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6 http://www.defra.gov.uk/environment/climatechange/pubs/pdf/ewp_targetscience.pdf

7 Note that Defra has interpreted the 60% target in the EWP2003 differently, e.g. in evidence given to the HoL Committee on the Economics of Climate Change paras 12 and 14 (http://www.publications.parliament.uk/pa/ld200506/ldselect/ldeconaf/12/5030104.htm and clarification at http://www.publications.parliament.uk/pa/ld200506/ldselect/ldeconaf/12/5030111.htm ). In this statement, is it implied that the EWP goal is a 550 ppm $CO_2$ equivalent concentration target (or approximately a 500 ppm $CO_2$ target). However, the text of the RCEP paper, and the EWP2003 itself, both cite the target as 550 $CO_2$ concentrations, not $CO_2$e.

8 The text in the report associates global mean temperature rise of 2.0 °C with greater risk to unique and threatened systems (ecosystems and societal), some increase in climatic extreme events, negative impacts for some regions, positive and negative market impacts, the majority of people adversely affected, unknown but probably low risk of large scale high impact events (e.g. major instability of ice sheets/ocean circulation changes).

Prior to the acceptance by Government, extensive analytical work was undertaken to look at the costs and the implications of meeting this long-term goal. In particular, the technological feasibility and the cost implications of reaching such a target were analysed through a major modelling exercise involving the calibration of the MARKAL energy model to the UK. This suggested that *the cost impact of effectively tackling climate change would be very small - equivalent in 2050 to just a small fraction (0.5-2%) of the nation's wealth, as measured by GDP, which by then will have tripled as compared to now*[9]. Therefore the analysis compared the costs of achieving the targets, to check technical feasibility and the associated costs, prior to accepting the predefined level of benefits that the target would deliver. The Energy White Paper also referred to the Government estimates of Social Cost of Carbon (the marginal damage costs, which can be used to undertake a cost-benefit analysis of climate change policy), and observed that until 2020 most of the carbon savings required to put the country on a path towards the 60% reduction could be achieved at a cost that is lower than the estimated range for the SCC.

The long-term goal was also translated into a series of short-term targets in the paper, i.e. to ensure real progress by 2020. The 2003 EWP states that '*on the basis of existing policies, including the full effect of our current Climate Change Programme, we would expect UK carbon dioxide emissions of some 135 million tones of carbon (MtC) in 2020. To be consistent with demonstrating leadership in the international process, we expect to aim for cuts in carbon of 15-25 MtC below that by 2020'*. This equates to the 26 – 32% reduction that is now in place. In relation to the target setting approach, it is largely based around the feasibility of policies (presumably with the supporting analysis of marginal abatement costs).

The 2020 range of emission reductions is cited in the Climate Change Bill and supporting RIA, as providing a firm legislative boundary for the trajectory to 2050. It is also cited in the 2007 EWP, along with an updated economic analysis of the costs of achieving the 2050 target and interim 2020 targets[10]. In respect of the latter, 2007, the EWP concludes that under optimistic assumptions, the set of policies currently proposed are likely to yield sufficient emissions reductions to move towards the lower end of the target range for 2020 (i.e. 26% below 1990).

### The Climate Change Programme Review (2006): The 2010 and 2020 targets

The UK implemented a Climate Change Programme in 2000 which was reviewed in 2006. The 2006 updated Climate Change Programme set out the policies and priorities for action in the UK.[11]. One of the interesting aspects of the review was the analysis of progress against the UK domestic target of reducing carbon dioxide emissions by 20 per cent below 1990 levels by 2010. The review concluded that higher than anticipated levels of economic growth and the rise in global energy prices, which altered the relative prices of coal and gas, had led to increases in carbon dioxide emissions, and as a result, the achievement of this target was more challenging than anticipated in 2000. The review went on to consider the impact of existing policies and the potential contribution of new policy options.

The analysis adopted in the 2006 review followed a similar pattern to the other UK targets, being based primarily around the use of cost-effectiveness analysis. However, it is interesting as it provides an example where the use of this type of approach was influential in a

[9] The analysis suggests that for many of the assumptions tested the cost of reducing $CO_2$ emissions by 60% by 2050 was in the range £200-300 per tonne of carbon. GDP in 2050 was reduced by 0.5-2.0%, equivalent to an average annual reduction of between 0.01 and 0.02 percentage points from a business as usual GDP growth rate of 2.25% per annum.

[10] MARKAL-MACRO modelling analysis was undertaken as part of the context of the 2007 Energy White Paper and updated for the CCC Bill, http://defraweb/environment/climatechange/uk/legislation/pdf/cc-impact-assessment-final.pdf.

[11] http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/ukccp06-all.pdf

reduction in ambition (i.e. a feasibility check). The review concluded that the new measures proposed will take the UK '*close to the* [2010] *domestic target*[12]*'*, rather than achieving the target. This decision was made mostly on the basis of political considerations and the limited time-window to 2010, but because the achievement of the targets required additional measures in sectors with high marginal abatement costs, see NAO report[13].

## The Stern Review

In July 2005, the Chancellor of the Exchequer commissioned the Stern Review, reporting to both the Chancellor and to the Prime Minister, as a contribution to assess the evidence and to build understanding of the economics of climate change. The review reported in Autumn 2006 and provided a report assessing the economics of moving to a low carbon economy, focusing on the medium to long term, and climate change coals.

The review concluded that the scientific evidence was overwhelming: climate change is a serious global threat and demands an urgent global response. From a review of the evidence, the report concluded that the benefits of strong and early action far outweigh the costs of not acting. Based on an extensive review of the literature on cost-effectiveness analysis, the long run costs of global action to stabilise atmospheric GHG concentrations at 550ppm $CO_2$e are expected to be around 1% of GDP by 2050, within a range of +/-3%.

The Review adopted a multi-attribute approach to target setting, which we could classify as non-formalised cost-benefit analysis (CBA). The central pillar of the analysis was a 'scientific' assessment of the benefits of emissions reductions on multiple physical metrics such as food and water availability, compared with an economic assessment of the costs of emissions reductions using cost-effectiveness models. This was complemented by the use of formalised economic models from the literature on CBA. However, in contrast to the academic literature on formalised CBA, the Stern Review did not use one model (or even a suite of models) to calculate the optimal emissions pathway (i.e. setting the marginal costs and benefits of emissions reduction to be equal period by period). This mode of analysis has been extremely influential and arguably occupies the middle ground between previous Government approaches to target setting that have used little economic input (e.g. the RCEP study) and previous economic assessments in the academic literature that have adhered strictly to formalised CBA. The Review recommendations were that the feasibility and costs of stabilisation of greenhouse gas concentrations in the atmosphere implied a range of 450-550ppm $CO_2$e. While this appears similar to the RCEP, advances in the measurement of climate sensitivity suggest that it actually requires a greater emission reduction (for developed countries)[14].

The Stern Review did not assess in detail the potential contributions to global emission reductions from developed and developing countries. Nonetheless some analysis in the review indicates that developed countries may need to take responsibility for emission reductions between 60% and 90% on their 1990 levels by 2050 to achieve the recommended stabilisation range.

[12] *The package of existing and new policy measures in the Programme are projected to reduce carbon dioxide emissions to 15-18 per cent below 1990 levels – the new measures saving 12 million tonnes of carbon by 2010.*

[13] *Working papers of the Project Board show that these indicators [cost-effectiveness] did have an influence on the final policy programme. However, the principal driver of policy choice in the 2006 Review was the early recognition that the UK would fall well short of its 2010 domestic target – achievement of the Kyoto target was never in much doubt. Cost effectiveness data was just part of policymakers' consideration of the right policy mix to achieve the national target.* Cost effectiveness in the 2006 Climate Change Programme Review. http://www.nao.org.uk/publications/nao_reports/06-07/Climate_Change_analysis.pdf

[14] The review was been the subject of significant debate, particularly over the estimates of global costs and benefits presented, and over the choice of input assumptions on issues such as discount rate.

## European Targets: The Long-term Goal and 2020 Targets

Alongside the UK targets, the other major influence for the UK (for long-term and interim targets) is European Commission policy, as the UK is part of a set of wider climate change policy commitments through European agreements.

The European Union has a long-term ambition[15], agreed at the European Council Meeting on 1996 (and reconfirmed in 2004; 2005), which aims to limit global temperature increase to 2°C above pre-industrial levels. This was set on the basis of helping to avoid serious adverse effects to, for example, water resources, ecosystems, biodiversity and human health, and was based on evidence given in the IPCC Second Assessment Report of 1995[16]. It adopted a strong precautionary approach to target setting, based on a strong focus on ecological effects. For a critique of the target see Tol (2006). The target was reconfirmed in the 2005 Communication (Winning the Battle Against Climate Change), which assessed the costs of global emission reductions, and investigated the avoided damages from climate change of such action, and most recently, reasserted in the communication from the European Commission on '*Limiting Global Climate Change to 2 Degrees Celsius'* (EC, 2007), with a proposed move to outline interim targets.

The 2007 communication stated that '*the EU should now take on a firm independent commitment to achieve at least a 20 % reduction of GHG emissions by 2020*' and that '*by 2050 global emissions must be reduced by up to 50 % compared to 1990, implying reductions in developed countries of 60-80 % by 2050'*. These 2020 targets were agreed at the Council summit meeting on the 8-9th March 2007, though there remain important burden sharing discussions to apportion this target between Member States (discussed in a subsequent chapter)[17]. Specifically the targets set by the European Council were:

- A reduction of at least 20% in greenhouse gases (GHG) by 2020 on 1990 levels – rising to 30% if there is an international agreement committing other developed countries to "comparable emission reductions and economically more advanced developing countries to contributing adequately according to their responsibilities and respective capabilities".
- A 20% share of renewable energies in EU energy consumption by 2020.

The Commission proposals and the EU agreement of 8-9 March 2007 state that these decisions were informed by an increased awareness of the economic costs of climate change impacts if the absence of further action - often known as the '*costs of inaction'*[18]*,*

[15] Advocated initially by the Scientific Advisory Council Global Environmental Change of the (German) Federal Government (WBGU), as in 1995.

[16] 'Council believes that global average temperatures should not exceed 2 degrees above pre-industrial level and therefore concentrations lower than 550 ppm $CO_2$ should guide global limitation and reduction effort'. 1996. 'Council…acknowledges that to meet the ultimate objective of the UNFCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2˚C above pre-industrial levels'. Spring Council meeting of 2004. The European Parliament has also stated that "strong emission reductions of – 30% by 2020 and 60-80% by 2050 –are to be undertaken by developed countries"

[17] Consistent with the EU's objective, the Communication highlights that to limit global average temperature increase to less than 2°C compared to pre-industrial levels will require atmospheric concentrations of GHG to remain well below 550 ppmv CO2 eq. By stabilising long-term concentrations at around 450 ppmv CO2 eq. there is a 50 % chance of doing so. This will require global GHG emissions to peak before 2025 and then fall by up to 50 % by 2050 compared to 1990 levels. The Council has agreed that developed countries will have to continue to take the lead to reduce their emissions between 15 to 30 % by 2020.

[18] The European Council (2004, 2005) requested that the Commission investigate the benefits of climate change mitigation policies, recognising that *monetised avoided impact benefits, estimated globally, but with a focus also on the European scale, will enable fully informed policy making*. Note, however that a cost-benefit analysis was not undertaken, only a consideration of costs of inaction, as reported in the earlier EC communication '*Winning the Battle Against Global Climate Change'* (EC, 2005) and supporting information. The 2007 communication assessed the potential impacts of climate change in Europe only in detail, though it stated that 'achieving the 2 degrees target would '*limit the impacts of climate change and the likelihood of massive and irreversible disruptions of the global ecosystem'*.

though this analysis was not part of a formalised or non-formalised cost-benefit analysis. The supporting Impact Assessment reported on the costs and benefits, though benefits related to the costs of inaction in Europe (not the global benefits of achieving the 2 degrees target).

Cost-effectiveness analysis has been a major focus of the EC's analysis[19], especially for the analysis of interim targets. The underlying technical studies on costs (EC, 2007) presents cost estimates up to 2030. It used POLES: a partial equilibrium model that focuses on the energy sector, GEM E3: a general equilibrium model that can project the impact of a climate policy on the entire economy, and DIMA to look at deforestation). For the period up to 2050 the POLES model was used to project technology paths, focussing on the feasibility and costs of the proposals.

## Other Stabilisation Targets (Country Goals or Commitments)

A number of other countries have proposed or adopted long-term or interim targets. These are summarised below.

The **French** Government announced a Climate Plan (2004)[20] as an action plan to respond to the climate change challenge. It contains measures affecting all sectors of the economy with a view to reducing the equivalent of 54 million tonnes of $CO_2$ each year by the year 2010. Beyond 2010, the Climate Plan sets out a strategy for technological research which will enable France to meet a target of reducing greenhouse gas emissions four- or fivefold by 2050 (hence the paper is often referred to as the factor4 plan [facteur4). Within this framework, France's long term objective is to reduce its greenhouse gas emissions by 75 to 80% by 2050. The analysis was supported by an assessment of feasibility and costs.

The **Swedish** Parliament[21] has endorsed the goal of reducing national emissions of greenhouse gases by at least four per cent on average below 1990 levels by 2008 - 2010. Moreover, the environmental quality objective of reduced climate impact implies that Swedish emissions of greenhouse gases should decline by up to 50 per cent from present levels by 2050 or emissions below 4.5 tonnes of carbon dioxide equivalents per person per year. In order to reach its objectives, the former Government has drew up a strategy with guidelines for Swedish climate policy (Government Bill 2001/02:55, Sweden's climate strategy[22]), which was adopted by the Swedish Parliament. Under the Riksdag decision, Sweden is to press for the level of greenhouse gases to be stabilised in the long term at a level below 550 ppm greenhouse gases, i.e. $CO_2$e. It is assumed that stabilisation at this level will restrict the rise in global mean temperature to below 2°C compared with the pre-industrial level (this conclusion is made on the basis of the EC analysis above). As far as Sweden is concerned, emissions under these circumstances may need to decrease by 50–60% GHG by 2050.

[19] The European Commission carried out a cost assessment of a global greenhouse gas emission reduction scenario that would allow reaching in the long-term 450 ppmv CO2 equivalent of atmospheric greenhouse gas concentrations. Greenhouse gas concentrations would first overshoot 450 ppmv CO2 equivalent before reducing again. This scenario is similar to the 500 ppmv CO2 equivalent scenarios in the Stern Review that also overshoot initially before stabilising in the long-term at 450 ppmv CO2 equivalent. The assessment described in this background document complements the earlier analytical work of the European Commission on scenarios that would reach levels of 550 ppmv and 650 ppmv greenhouse gas Concentrations (EC Impact Assessment of the 2007 Communication).

[20] http://www.effet-de-serre.gouv.fr/fr/actions/PLANCLIMATANGLAIS.pdf

[21] http://www.sweden.gov.se/sb/d/5745/a/21787

[22] http://www.energimyndigheten.se/web/biblshop_eng.nsf/FilAtkomst/ET33_04.pdf/$FILE/ET33_04.pdf?OpenElement

In its white paper the **Norwegian** Government is proposing that Norway should have the world's most ambitious climate targets[23]. The country is to be carbon neutral by 2050, which means that all remaining emissions will be set off against emissions in other countries. It also has targets of a 30% reduction by 2020[24].

**Germany** intends to press forward with a goal of achieving a 40 percent reduction in greenhouse gas emissions by 2020. This target sits within the current EU negotiations, such that if an international agreement is reached for a, 30% EU target reduction, Germany would reduce its emissions by no less than 40 percent[25].

In **Japan**, the prime minister, Shinzo Abe, has outlined a plan for a 50% reduction by 2050. There is some supporting information on this objective[26] outlining a strong scientific-precautionary approach, largely benchmarked to the 2 degrees target. This also outlines that to achieve this might require that all GHGs will need to be stabilised at 475ppm from the year 2030, and that all GHG emissions worldwide will have to be reduced about 10% by the year 2020, about 50% by 2050, and about 75% by 2100. Some work has been undertaken by the National Institute for Environmental Studies (NIES), which explores scenarios for a Low Carbon Society 2050, and suggests that a 70% reduction of GHG emissions (as compared to the 1990 level) is both technologically and economically feasible, with a cost no more than 1% of GDP in 2050 (e.g. see Pedersen, 2007[27])

The **Czech Republic** in a National Programme to Mitigate Climate Change Impacts[28] stipulates indicative targets for limitation of GHG emissions, namely a reduction in specific $CO_2$ per capita emissions between 2013 – 2020 by 30%, compared with the year 2000, and a reduction of total aggregate $CO_2$ emissions by 25%, compared with the year 2000 during the same period.

In June 2007, the **G8** leaders[29] met for their annual summit in **Heiligendamm**, under the German presidency. The documents[30] from the summit state that '*we (the G8) will consider seriously the decisions made by the European Union, Canada and Japan which include at least a halving of global emissions by 2050.'* There is no information (at least that is available from the G8 site) on how this proposal was set.

There are also a number of US state level targets[31], and examples of regional government targets (e.g. New South Wales GHG Advisory Panel) presented in Appendix 1.

[23] http://www.regjeringen.no/en/dep/md/Press-Centre/Press-releases/2007/New-measures-to-reach-Norways-ambitious--2.html?id=473402
White Paper, Report no. 34 (2006-2007) to the Storting (Parliament) on Norwegian Climate Policy.
http://www.regjeringen.no/en/dep/fin/campaign/Carbon-Neutral-Norway.html?id=479281

[24] *We will improve on Norway's commitment under the Kyoto Protocol by 10 per cent, and plan to cut global emissions of greenhouse gases by the equivalent of 30 per cent of our 1990 emissions by 2020. These targets will be achieved both by substantially reducing Norway's emissions and by paying for cuts in other countries. The whole of the extra 10 per cent will be accounted for by reductions outside Norway*
http://www.regjeringen.no/en/dep/md/Press-Centre/Press-releases/2007/New-measures-to-reach-Norways-ambitious--2.html?id=473402

[25] http://www.bundesregierung.de/nn_6538/Content/EN/Artikel/2008/01/2008-01-18-regerkl-bali__en.html. There are some additional caveats associated with the target. Firstly, the agreed climate change mitigation activities must be made competition-neutral (e.g. especially in relation to CO2 limits from passenger cars). Second, though the language is ambiguous, that this target is conditional on the world's industrialised nations to agree on a 30 percent cut in their greenhouse gas emissions by 2020.

[26] http://2050.nies.go.jp/material/200505-MOEJ_Long-term-targets.pdf

[27] http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/pedersen_peter_japan.pdf

[28] http://www.un.org/ga/president/61/follow-up/climatechange/statements/statementCzechRepublic.pdf

[29] The G8 members are Germany, France, the United Kingdom, Italy, Japan, the United States of America, Canada and Russia. The European Commission is also represented at all the meetings.

[30] http://www.g-8.de/Content/EN/Artikel/__g8-summit/anlagen/chairs-summary,templateId=raw,property=publicationFile.pdf/chairs-summary

[31] http://www.pewclimate.org/what_s_being_done/targets/

Finally, it is highlighted that there is considerable discussion on the issue of potential ambition levels in the Intergovernmental Panel on Climate Change **IPCC** 4th Assessment Report, though consistent with previous reports, no specific targets are proposed.

In terms of overall temperature and stabilisation targets, the AR4 (WGII, Chapter 20, Yohe et al, 2007) provides a multi-attribute analysis of potential impacts (which updates the key reasons for concern in the TAR), but also considers abatement costs for different stabilisation levels (WGIII, Barker et al, 2007). In this respect it can be considered to be similar to the approach of many governments in combining a strong scientific precautionary approach with a check with cost-effectiveness analysis.

## Review of Academic Literature

The study has also reviewed the target proposals in the academic literature. The emphasis in the academic literature has been predominantly on discussion of appropriate methodologies for deriving stabilisation targets, (see e.g. Schneider, 1997; Yohe, 1999; Mastrandrea and Schneider, 2004). For example, Rijsberman and Swart (1990) were amongst the first generation of authors to propose the setting of long term climate stabilisation targets. They suggested the use of global average temperature increases as the target indicator, in the absence of more sophisticated regionally disaggregated temperature and other climate variables that identified specific impact thresholds. The principal exceptions are Azar and Rodhe (1997), O'Neill and Oppenheimer (2007) and Hansen 2005). All three are written by scientists and all adopt a precautionary approach relative to defined projected physical climate change impacts. In particular:

- Azar and Rodhe (1997) utilises the future projections of atmospheric CO2 concentrations given by the IPCC Second Assessment Report, and their stabilisation levels at a range of ppmv to plot associated temperature increase ranges. They then compare these temperature increases with the range of natural fluctuation in temperature over the past millennium - equal to 1ºC at most. The authors simply argue subsequently that the burden of proof is on those that argue for allowing global concentrations to breach the 350ppmv likely to achieve a 1ºC. They do suggest, however that adaptation may alleviate the impacts to such an extent that an increase of 2°C is likely to be critical and argue that, without evidence to the contrary, the global community should initiate policies to keep within this temperature increase, with stabilisation of concentrations between 350-400ppmv. The decision rule is therefore essentially precautionary-based.
- O'Neill and Oppenheimer (2002) interpret the UNFCC goal of avoiding dangerous anthropogenic interference (DAI) using two of the IPCCs criteria for concern for assessing DAI. The criteria selected are: a) warming involving risk to unique and threatened systems and b) warming engendering a risk of largescale discontinuities in the climate system, and are represented by the bleaching of coral reefs and the disintegration of the West Antarctic Ice Sheet (WAIS), respectively. On the basis of the scientific evidence, the authors suggest that a long-term target of 1°C above 1990 global temperatures would prevent severe damage to some reef systems. They argue that, taking a precautionary approach because of the very large uncertainties, a limit of 2°C above 1990 global average temperature is justified to protect WAIS. In addition, to avert shutdown of the THC, they define a limit at 3°C warming over 100 years,. An equivalent stabilisation level of 450 ppmv by 2100 as a maximum is suggested as a possible target for reducing the probabilities of these events, though not eliminating the possibility of them. Furthermore, the authors argue on the basis of feasibility that required emission reductions cannot be delayed to 2020 without overshooting the target.
- Hansen et al (2005) argue that there is a likelihood that the western dome of the Greenland ice sheet will melt in the next 100-400 years giving rise to an increase in

global sea level of 2 metres. Since the time-scale is relatively close he argues that there is no opportunity for global decision makers to reverse climate forcings by reducing emissions, before the ice sheets respond. Similar to Azar and Rohde, Hansen uses the historical analogue of inter-ice age sea level rise under a 1°C global temperature increase to suggest a concentration of 475 $CO_2$ ppmv.in 2100.

More recently, there has been work undertaken in the UK by the Tyndall Centre (Anderson and Bows, 2007) exploring long-term and interim UK targets. In a recent paper, they express targets in terms of cumulative emissions of carbon, and propose a carbon budget for 2005 – 2050 for the UK of 4.8 billion tonnes of carbon. In order to hit this target, this implies a 9% per annum reduction between 2012 and 2032 (for 450 ppm, based on a similar allocation method to the RCEP) and a 6% p.a. reduction for the same period for a 550ppmv trajectory. The study compares these to the Climate Change Bill, and the 26 to 32% reduction (to 60%) which implies ~5.5 to 6.0GtC (and if aviation and international shipping are included, without action, a cumulative 2000-2050 budget of ~ 7 to 7.5GtC, equivalent to 600 to 750ppmv $CO_2$). The proposed targets equate to around a 70 per cent reduction in carbon within the next 30 years, and 90% by 2050.

While the studies mentioned above followed a precautionary approach in defining climate change policy targets, there are also a number of academic studies that use cost-benefit analysis to implicitly consider long-term and short-term targets. These studies rely on a number of integrated assessment models, including DICE, PAGE and FUND, which are described in more detail in the next chapter. The outputs of DICE (in e.g. Norhaus, 1994) could be argued to have informed the development of US policy in this area whilst PAGE was used directly in the cost-benefit analysis undertaken within the Stern Review on the economics of climate change (Stern, 2006).

## Decision Frameworks and Perspectives in Climate Change Policy

### Previous Consultation on Approaches for Carbon Targets

As part of the review of the Social Cost of Carbon (Watkiss et al, 2006) the current project team investigated the use of the SCC as part of short-term and long-term climate policy. This was followed up with a stakeholder consultation exercise, asking a selection of experts for their views on the role of the SCC, but also (and more relevant here) on how best to set interim and long-term carbon policy in the UK. A number of methodological approaches were discussed with experts including:

- CBA
- Cost-effectiveness analysis
- Risk based approach
- Multi-criteria analysis
- Precautionary approaches

The consultation found a wide range of views on the preferred approach. The responses were found to comprise the following broad categories.

- Those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy and targets, and believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle (some respondents also raised the issue of the duty of care and human rights).

- Those who believed that when policy is not easily based on an objective assessment of the costs and benefits (as with climate change), the process of target setting helps to reveal the weight which society puts on costs and benefits. They implicitly believed that policy makers use the available information to make the most efficient decisions possible with the knowledge available.
- An alternative group started from the position that unless policy makers have a good understanding of the costs and benefits, targets may be set at an inefficient level. They believed that formal cost-benefit analysis leads to better policy making, through its transparency and consistency, and its explicit attempt to assess the optimal policy outcome.
- A final group accepted that cost-benefit analysis is a useful input to policy decision-making, but highlighted concerns over what they see as simplistic application of SCC values for longer-term climate change policy. This group also drew attention to the considerable uncertainty in both MAC estimates and SCC estimates and recommended a pragmatic approach that might consider a wider multi-attribute framework.

The results of this consultation are repeated here, because of their relevance for the current study. These views have been important in framing how different stakeholders frame the problem of climate change, and from this how they move to corresponding decision frameworks. This is discussed in more detail below.

## Decision Frameworks

The review of policies, and the consultation above, shows a broad range of approaches have been used in setting targets, and a diverse set of methods are recommended by different stakeholders. It is found that:

- There is no consensus on the best approach for setting long-term climate policy, and by implication interim carbon targets.
- The approaches adopted range from strong economic perspectives (e.g. with the use of formalised cost-benefit analysis in some of the IAM analysis), through to a strong scientific-precautionary perspective (e.g. in setting long-term stabilisation targets to prevent potential major risks as in the EU's 2 degrees target).
- It is clear that there are very divergent views on the best target setting approach, which are partly determined by discipline (e.g. climate scientist, economist, social scientist) but also according to perceptions of climate change itself. Individuals tend to be firmly rooted in their perspective domain, such that someone who believes in the precautionary principle is unlikely to accept that economics should set the climate policy agenda.
- These views are almost always influenced by key parameters (whether expressed explicitly or not), which are largely subjective, and involve moral and ethical stances.

These differences are also confirmed by stakeholder discussion undertaken as part of the Defra social cost of carbon project (Watkiss et al, 2006), discussed in more detail in the next chapter, but which indicated a broad range of view on how best to set climate change policy.

To understand the differences in the approaches adopted, and to frame the existing policies in the previous sections, some previous work advanced a categorisation of decision entry points (primary concerns) and decision perspectives (Watkiss, 2007), shown in the figure below. These reflect the underlying principles used in framing climate change policy or adaptation policy and accordingly, in the methodological approach used. The entry points range from strong economic perspectives through to strong social or environmental perspectives, the latter often framed around a precautionary approach.

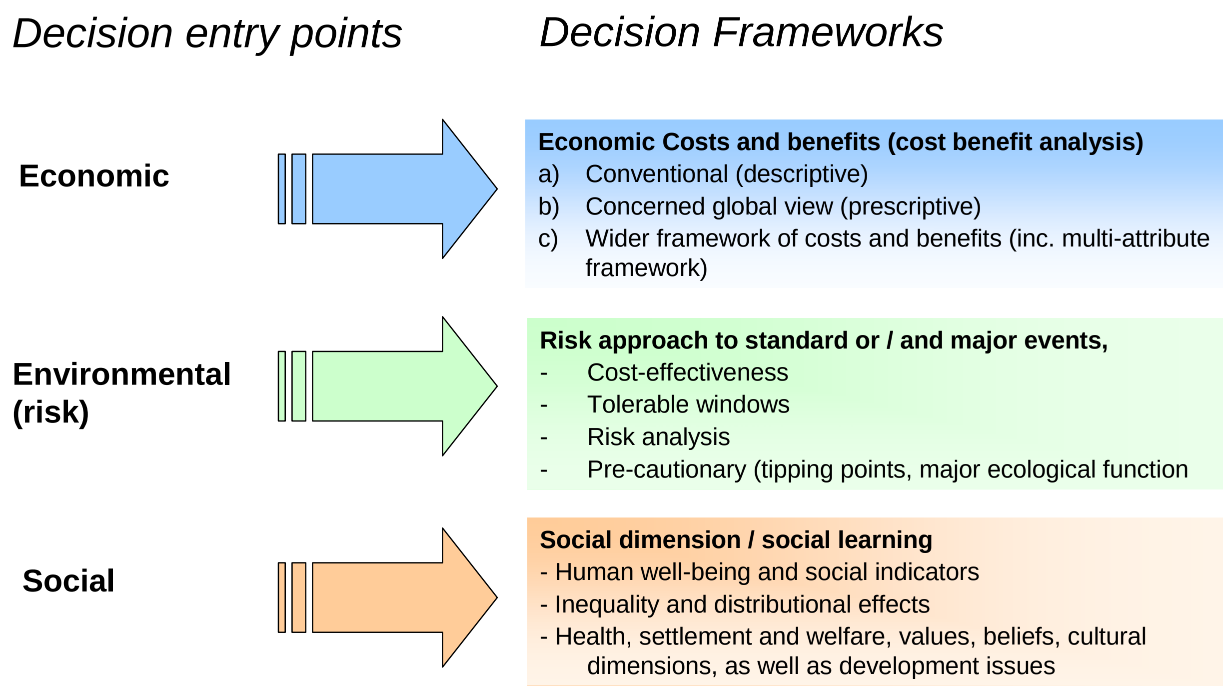


**Figure 2.2 Multiple frameworks for climate change policy**

Source Paul Watkiss[32].

For the study here, where there is a stronger focus on targets for mitigation, and also reflecting the previous UK consultation in the SCC project, this taxonomy has been adjusted, as shown in the figure below. A number of selected examples (from review above) have also been mapped onto the framework.

[32] Submitted to the OECD symposium on Engagement, learning & action on climate change: towards a new research agenda. 1 April 2007.

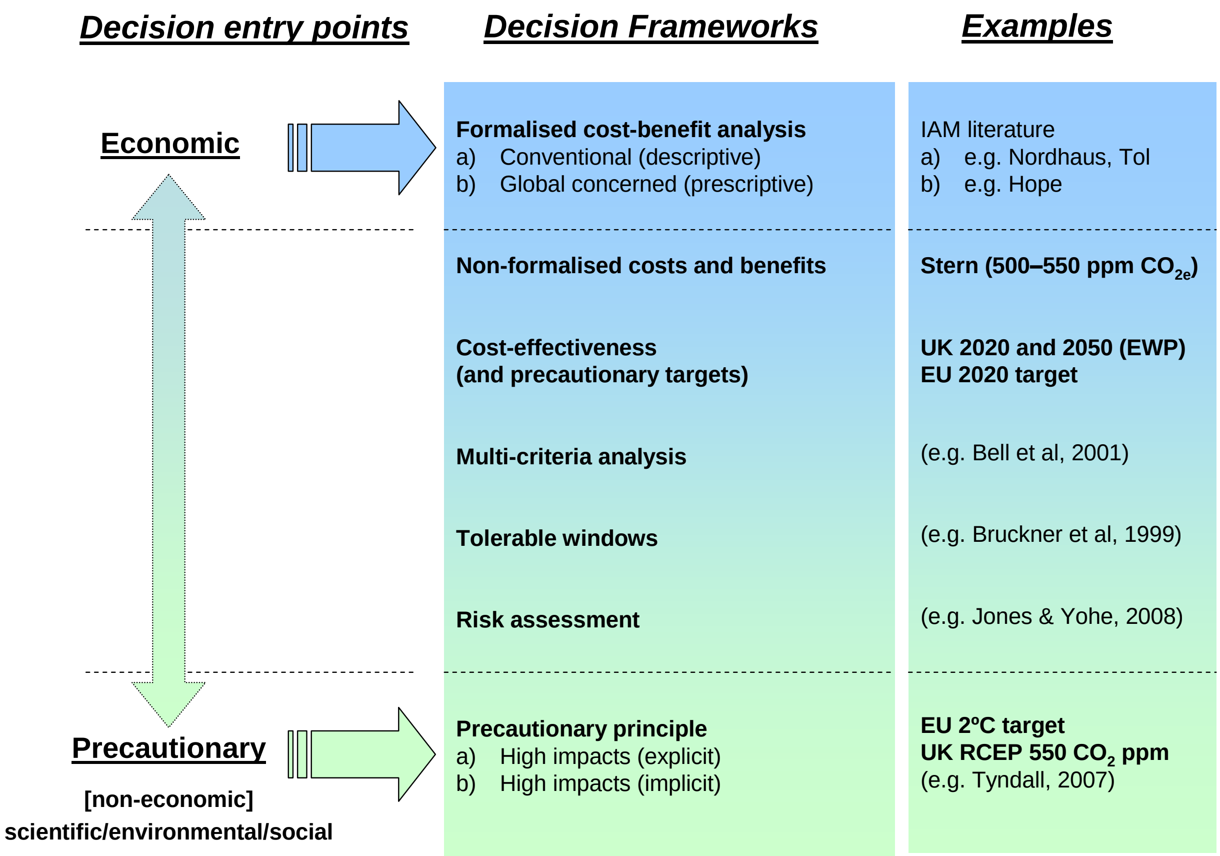


**Figure 2.3. Decision Perspectives and Methods for Setting Climate Change Targets**

To summarise:

- The approaches start at the top with a formalised approach to economic appraisal and cost-benefit analysis (and including the analysis of optimal levels).
- This then moves to consideration of costs and benefits as part of a less formalised framework, where benefits are measured in physical quantities while costs are measured in terms of income/output. A number of alternative approaches can be included in this broad category.
- It then moves through to more precautionary approaches where targets are set largely irrespective of mitigation costs[33]. This can include concerns about major irreversible climate change, ecological function, or social aspects in relation to society and human impacts.

Note that all methods consider costs and benefit, but each reflects a different balance of explicit or implicit consideration (e.g. precautionary approaches implicitly assume that beyond a certain threshold damage costs far outweigh mitigation costs).

They can also be considered to adopt different perspectives on sustainability and substitutability, i.e. whether a weak or strong economic sustainability approach. To illustrate, formalised CBA allows full substitutability, i.e. economic benefits from agricultural yield increases in Finland can be netted against environmental dis-benefits such as irreversible

[33] Generally framed around the ultimate objective of the UNFCCC, which is 'to achieve…… stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.'

coral reef loss), whilst the stronger environmental or social precautionary approaches do not accept this type of substitutability between categories.

## Summary

A summary of the different targets is presented below. When comparing the targets it is extremely important to differentiate between apparently similar targets, e.g.:

- 2 degrees of change from pre-industrial (e.g. EU) vs. 2 degrees of change from current (IPCC)
- $CO_2$ ppm (e.g. RECP) vs. $CO_2$e ppm (e.g. Stern Review).
- $CO_2$ reduction (e.g. UK 2020 targets) vs. GHG reductions (e.g. EU 2020 targets).

**Table 2.2. Summary of Stabilisation and Interim Targets**

| Organisation | Target | Notes | Approach |
|---|---|---|---|
| **UK** | | | |
| RCEP (2000) | **550 $CO_2$ ppm** (considered equivalent to 2ºC from pre-industrial at lower end of range) | Allocated using stabilisation pathways and DC split to 60% by 2050 for developed countries | Precautionary approach. Based on information from IPCC AR2, and also benchmarked against EU 2ºC target. |
| UK Government : EWP (DTI, 2003) | Goal of **60% $CO_2$** reduction by 2050 for UK<br><br>**26 – 32% $CO_2$** by 2020 | Conditional on similar action for developed countries | Long-term benefits from RCEP above (precautionary), with cost-effectiveness (least cost optimisation) to check technical and economic feasibility.<br><br>Feasibility of considered policies (and assumed costs). |
| UK Government CCP 2006 | Target of **20% $CO_2$ reduction** by 2010, with | Lowering of likely ambition from 20% to 15 – 18% (due to changes in growth and energy prices) | Cost-effectiveness was key analytical framework. Policy decisions informed by other considerations but broadly consistent with cost-effectiveness analysis. |
| Stern Review | **450 to 550 $CO_2$e ppm,** with statement that costs manageable for **500 to 550 $CO_2$e ppm** | 5 – 20% BGE economic costs (though residual costs from policy not quantified), vs. 1% of GDP by 2050, within a range of +/-3%. | Comparison of cost and benefits, plus multi-attribute framework for temperature thresholds and impacts |
| **Europe** | | | |
| European Council (1996, 2004, 2005, 2006) | **2ºC from pre-industrial** | Initially 550 ppm. In 2007 updated that 50% chance of achieving by stabilising at around 450 ppmv $CO_2$ eq. | Precautionary approach, mostly around ecological concerns / information from IPCC AR2. Some consideration of costs and benefits in 2005, 2007. |
| EC (2007) / European Parliament | **60-80% GHG by 2050** by developed countries (50% global) | See 2007 update above. | |
| European Council (2007) | **20% GHG by 2020, rising to 30% GHG** with international agreement | Note also part of wider set of 2020 targets for renewables and biofuels. | Cost-effectiveness to check technical and economic feasibility. |
| | | | |

| | | | |
|---|---|---|---|
| **Other Country** | | | |
| France | **Reducing GHG emissions four- or fivefold by 2050** | Probable benchmark to 2ºC from pre-industrial | Some analysis of feasibility and costs. |
| Sweden | **50 to 60% GHG by 2050** | Stabilised below 550 ppm greenhouse gases, and 2ºC | Not known, but benchmarked 550 against other reviews |
| Norway | **Carbon neutral by 2050**<br><br>**30% GHG reduction by 2020** | Includes offsetting of remaining emissions | Not known |
| Germany | **40% GHG by 2020** | 2ºC from pre-industrial. Conditional on international agreement and the EU 30% target plus competitiveness issues. | Not known |
| Japan | **50% GHG by 2050** | Stabilisation less than 550ppm (GHG, 475ppm). Some benchmarks to 2ºC from pre-industrial | Some consideration of costs and technical feasibility. |
| **Other** | | | |
| G8 Summit in Heiligendamm | Consider seriously…..at least a halving of global emissions by 2050 | | |

The conclusions of the review are that:

- For both UK domestic policy, EU policy, and for most Country targets, the first step has been to set a long-term target. This has then been followed by the development of short-term targets on a path towards the long-term target. This is important for this study, as it highlights that it is not possible to separate the long and short-term policy domains: the long-term target sets the parameters for the short-term objectives. Some might also argue that to ensure consistent policy making, the approach used for setting short-term targets should be consistent with that used for setting long-term targets. However, there are many examples where different approaches are used for setting long-term and interim policy, especially where proposals on long-term policy restrict the choices available in the interim, and this is relevant for the issue here.

- For long-term stabilisation goals, the approach that has been used for advising Governments (e.g. the RCEP 550 ppm $CO_2$ and the EU 2ºC target) has been a scientific-precautionary one, based around the available evidence and concerns about high levels of impacts (usually social or ecological) associated with different temperature levels. The justification for choosing a specific threshold level is usually to prevent ‘dangerous anthropogenic interference’, consistent with the UNFCCC objectives. There appears to be little explicit consideration of the costs of stabilisation in these assessments. This reflects the fact that historically, climate-change policy discussion has not favoured the use of economic analysis. Instead, policies have tended to be set on the basis of scientific and political negotiations, and are driven by an underlying focus on scientific evidence and the precautionary principle.

- The use of a precautionary approach is due to the unusual attributes of climate change that make it a particular challenge for conventional marginal economics. Climate change includes issues of inter- and intra-generational equity, potential major irreversibility, and extremely large uncertainty. Indeed, it is the major effects that have driven much of the climate-change debate and international policy in recent years, with the concept of large-scale climatic events, often expressed in the climate literature as major irreversible events or 'tipping points'. It is these concerns that have led many to conclude that the preferred evaluation framework for a very long-term problem such as climate change, with a large inertia in the system (such that mistakes cannot be quickly corrected), and the possibility of extreme and irreversible changes in the climate system, is not cost-benefit analysis, but cost-effectiveness analysis with respect to a given climate target (sometimes looking at other elements such as within a "tolerable climate window").

- When long-term ambitions are translated into firm government commitments, a greater focus on cost-effectiveness can be seen, where the precautionary approach is complemented by analysis of technical costs. This is found in many country-specific long-term targets (e.g. UK EWP (2003); French factor 4 plan (Climate Plan (2004)) and for nearly all interim targets (e.g. UK 26-32% by 2020, EU 20% by 2020). The cost-effectiveness analysis is usually undertaken to demonstrate that the long-term goals are technically achievable and that costs of compliance are not dis-proportionately high (i.e. bounded by acceptable levels of marginal abatement costs consistent with a modest reduction in GDP growth). These approaches consider costs in detail using marginal abatement costs, but take predefined benefits as set by the political process and accepted in the precautionary targets. They do not undertake cost-benefit analysis (CBA), but they do include a non-formalised comparison of costs and benefits.
- The Stern Review is another example of a non-formalised comparison of costs and benefits. Although the Review considered the results of formalised CBA, it did so as part of a wider, multi-attribute framework that placed more emphasis on measuring the environmental and social risks of climate change in their own, 'natural' units. Hence the Review did not recommend an optimal level of greenhouse-gas emissions.
- Other decision tools for setting targets (e.g. formalised CBA, multi-criteria analysis, tolerable windows) are principally to be found in the academic and grey literatures.

Following on from this, it is highlighted to the SCCC that:

- Actual (Government) climate-change policy / target setting does not adopt a strong economic perspective, nor has it favoured the use of formalised CBA. Instead it has used scientific evidence and political negotiations, driven by an underlying focus on the precautionary principle (inferred from the long-term targets). This is balanced by a consideration of cost-effectiveness, particularly when moving from long-term to interim targets.
- There are cases where different approaches are used for setting long-term and interim targets, with the latter generally including a stronger economic perspective at least in terms of the costs of policy action (at least as a check of technical and economic feasibility).
- More generally, across the broad range of stakeholders that are interested in long-term climate change policy, there is no consensus on which approach should be used for setting targets. The views of different stakeholders span the entire range of decision perspectives in the table above. The views of different individuals are set according to their underlying decision perspectives (e.g. economic vs. precautionary) and these perspectives are typically fixed, i.e. individuals rarely switch between perspectives, even as evidence emerges.
- It is already clear from the consultation preceding the Climate Change Bill that there is a wide diversity of views on both long-term and short-term targets, and also that most people see the two as inter-related. There is also a clear range of views that span the decision entry points above, e.g. from strong economic analysis associated with CBA, through to precautionary thinking (as in the Tyndall Centre report, 2007). Any approach that tries to ignore specific views or concerns across different stakeholders is unlikely to

gain widespread support, and the choice of one particular framework over others will also lead to groups who do express strong disagreement.

- The diverse range of views has led some methodological approaches to advance the use of multiple perspectives and frameworks, i.e. using several of the approaches above in the same overall target setting approach in a complementary analysis, rather than trying to only focus on one single (overarching) method or framework. Such an approach has a number of advantages: it can provide additional information that one framework alone cannot generate; it can help to achieve wider stakeholder buy-in to the process of target setting and; interestingly, it can examine how (and why) different decision approaches affect the choice of target level.

## Particular Factors affecting Interim Emissions Targets

One of the key factors affecting the UK's interim emissions target and associated carbon budgets is uncertainty about the future path of policy. We do not currently know what long-term global target will be achieved due to uncertainties about physical, natural and economic processes, uncertainties or disagreements about the values to be attached to these processes, and other uncertainties about policy. Some of these sources of uncertainty have been used to argue that interim climate policy should be weak, until we learn more about what long-term response is judged desirable. This is known as a 'wait-and-see' approach. Conversely others argue that interim climate policy should be aggressive in the face of uncertainty amongst other things. Chapter 4 sets out the issues in more detail, but the factors affecting the choice of 2020 targets in the context of long-term targets can be summarized as follows:

- *Uncertainty, learning and irreversibility*: it is to be expected that present uncertainty about long-term climate policy will be reduced through learning, and therefore an options approach to interim climate targets points to the importance of avoiding making irreversible investments until we know more. This is likely to be an important factor affecting the UK's choice of 2020 target, but it is not clear what the implication is for the size of the UK's carbon budgets, because we face three irreversible decisions pointing in different directions. Firstly, several features of climate change are irreversible and so if we later find out that climate change is damaging, we cannot reverse the process. Secondly, investments in polluting capital such as power stations and transport infrastructure are also irreversible, so if we later find out that climate change is damaging, it will be costly to replace such capital quickly, before the end of its economic life. Thirdly, and in contrast, investments in clean capital like nuclear power stations are also irreversible and if we later find out that climate change is not damaging, some resources will have been committed unnecessarily.
- *Ancillary benefits of greenhouse-gas emissions reductions*: greenhouse gas emissions reductions generate benefits beyond slowing climate change, including concomitant reductions in air pollution. More aggressive interim emissions reductions are likely to produce greater ancillary benefits that must be factored in to the analysis.
- *Technical change*: our understanding of the process of technical change also affects the choice of interim target. It is sometimes argued that interim targets should be weak, because it will be more cost-effective to wait until new technologies become available. On the other hand, others argue that strong emissions reductions in the interim actually stimulate technological innovation, increasing the chances of new technologies becoming available in the future that will make long-term goals cheaper and easier to achieve.
- *Transient temperature change*: Although many emissions pathways are possible that lead to the same long-term target, they do not lead to the same profile of temperature change. The greater are emissions in the near term, the faster is the rate of transient

temperature change. There are two consequences of this. First, more rapid climate change increases the demands on adaptation, including feasibility (especially for natural systems that are particularly sensitive to the required rate of adaptation) and cost. Second, overshoot pathways that cause transient global temperatures to exceed those expected to correspond to the long-term target increase the possibility of crossing certain irreversible thresholds or 'tipping points' in the climate system, such as those triggering melting of the Greenland and West Antarctic Ice Sheets.

- *Other greenhouse gases:* It is generally recognised that control of a wider set of greenhouse gases can lead to the achievement of any given long-term emissions target at lower cost, compared with control of $CO_2$ alone.[34] This also raises the issue of how reductions in the emissions of various greenhouse gases should be sequenced. The flow target for emissions of $CO_2$ in 2020 could rise or fall depending on how much abatement of non-$CO_2$ greenhouse gases takes place in the near term.
- *Attitudes to risk and intergenerational* equity: Binding all of these issues together in any methodological approach are assumptions about the structure of the decision-making problem and, within that structure, key value judgements, especially on the decision-maker's preparedness to take risks and to trade-off the costs and benefits of policy today with those in the future. The various approaches differ in the extent to which these issues are modelled explicitly and formally, and (partly as a result) also place their emphasis on different aspects of the decision problem. Loosely speaking, a risk-taking decision-maker little concerned with intergenerational equity might choose to delay substantial emissions reductions; a risk-averse decision-maker much concerned with intergenerational equity might make more intense and earlier emissions cuts in order to preserve options for future generations.

Whichever methodologies are chosen, it is important to take these factors into consideration in structuring the analysis. In line with our recommendations, chapter 4 contains a worked example of how cost-effectiveness analysis can be used to examine the consequences the choice of interim target has for the cost and feasibility of the UK's 2050 target.

Options analysis has been most completely explored using cost-benefit analysis (CBA), yet the general framework can be applied to other less strongly economic methods. We recommend it forms the key overarching framework for tackling the analysis of interim targets, with potential different methodological approaches nested within this. The individual methods are reviewed in the next section. The discussion below focuses on the 2020 interim targets, but the preceding 5 year budgets are a subset of this overall target, and the same methodological issues apply

[34] See Weyant *et al*. (2006) and various contributions to Special Issue Number 3 of *The Energy Journal.*

# Chapter 3. Methodological Approaches for Setting Long-term and Interim Carbon Targets

This chapter reviews the different methodological approaches that can be used for setting climate change targets, either for long-term stabilisation or interim GHG emissions targets or commitments. It considers their strengths and weaknesses, their practicability, and likely acceptability.

In undertaking this task, a number of key themes will be investigated. These include:

- The key attributes of climate change including the extended time frame, the uncertainties, the global dimension, and irreversibility, and how these are considered in any method.
- How to use the different frameworks in such a way to ensure that costs and economic perspectives are included (even on approaches that typically have a less economic focus),
- How the different approaches can cope with the issue of uncertainty.
- How each of the different approaches could be tuned to be more relevant for the CCC.
- Alternative ways of using the approaches, either as individual stand-alone application or through a combined (consensus based) framework that seeks to engage a wider set of stakeholders.

To date, most of the discussions on global policy have been based, first, on a scientific-precautionary discussion of what level of policy ambition is required to avoid dangerous climate change and, second, on what will be the costs of reducing greenhouse gas emissions consistent with these levels of ambition. Formal comparisons of the economic benefits and costs of policy have been largely confined to the academic and gray literatures, but it is increasingly apparent that information on the economic benefits of policy can contribute. All methods, whether explicitly or implicitly, will consider the costs and benefits of action. However, the techniques that have been used do have important differences. They are discussed in turn below.

## Cost-Benefit Analysis (and the Social Cost of Carbon)

The UK Government, and its economic regulators, extensively use economic appraisal. The Treasury Green Book (HMT, 2004: 2006) provides the guidance on how to do this. It requires that appraisal be based on an assessment of how any proposed policy, programme or project can best promote the public interest, and identifies two key questions:

- Is the rationale for intervention clear?
- it reasonable to assume that intervention will be cost-effective: i.e. that the benefits of intervention will exceed the costs?

The technique recommended to address the latter question is cost-benefit analysis (CBA), whereby all relevant costs and benefits to government and society of all options are valued, and the net benefits or costs calculated (though note it is usually difficult to value all the costs and benefits of a particular project). CBA differs from cost-effectiveness analysis (see later discussion), where a goal is set and the most cost-effective way to meet it is determined, or other approaches such as multi-criteria analysis (also below), where benefits are not (solely) expressed in monetary terms.

In theory, formalised CBA of this kind could also be used to set long-term and interim targets for the CCC. This requires analysis of the marginal abatement costs and marginal social costs of different levels of ambition, and through this the analysis of the optimal policy objective. However, while CBA is the preferred means of policy appraisal in the UK, it has proved particularly controversial for long-term climate change policy[35]. One of the key problems has been over the estimation of the economic costs of climate change, as captured through the marginal social costs, usually referred to in the UK as the Social Cost of Carbon (SCC). This is the net present value of climate change impacts from one additional tonne of carbon emitted to the atmosphere today, over its lifetime in the atmosphere (i.e. 100 years or more), i.e. the marginal global damage cost of carbon emissions. Recent reviews (e.g. Watkiss and Downing, 2008) have guarded against the use of the SCC values in CBA at present, due to the uncertainties in the estimates36, though they do stress that the information on the economic benefits of climate change policy has an important input in long-term climate change policy.

In 2002, the UK Government (GES, 2002) recommended an illustrative marginal global SCC estimate of £70/tonne of carbon (tC), within a range of £35 to £140/tC, for use in policy appraisal across Government (all three estimates rising at £1/tC per year from the year 2000). These values were used in regulatory impact appraisal and in the consideration of environmental taxes and charges. The GES paper also recommended that these values should be subject to periodic review. The GES paper sparked a response, with many commentators questioning the values (e.g. Pearce, 2003; House of Lords, 2005). This debate over the state-of-the-art in estimates of the SCC, and its use in Government policy making, led to two parallel review projects, commissioned in 2004. The first review looked at the underlying SCC values and uncertainty (Downing et al, 2005), whilst the second looked at how best to use these values in policy (Watkiss et al, 2006). These studies form a large part of the evidence base on the SCC, and are discussed in detail in Appendix 1. Most recently, the SCC evidence was assessed in the Stern Review, and new estimates of the SCC were produced, that were used to update the GES appraisal guidance.

The literature on the SCC estimates was reviewed by Tol (2005)[37]. The SCC review studies (Downing et al, 2005: Watkiss et al, 2006; Watkiss and Downing, forthcoming) investigated the evidence on the values and found:

- Key variations occur in the values according to decision parameters in the choice of input or decision perspectives, most importantly discount rate, study time horizon, equity weighting, the reporting of central tendency, and climate sensitivity (see Appendix 1). Each of these five variables can significantly influence the SCC values, leading to

[35] While some commentators have concerns about the use of this approach for climate change policy, this does not constitute rejection of comparing costs and benefits of action in principle. Indeed most policy makers recognise that once decisions are made they reflect an implicit balance of costs and benefits (e.g. an implicit value of carbon). Rather it is linked to the difficulty of providing a complete and robust representation in monetary terms of the benefits of mitigation. In the context of international negotiations, value judgements about certain issues have also proved controversial.

[36] *The economic benefits of climate change policy should be considered when setting long-term targets and goals, but a wider framework is needed (i.e. simple cost-benefit analysis should be avoided). It is recommended that this framework should include a disaggregated analysis of economic winners and losers by region and sector, and a disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems. It should also include a full and explicit consideration of the risk matrix (including consideration of major events including non-marginal events and irreversible effects) and the analysis should include extensive uncertainty and sensitivity analysis (e.g. over key decision variables such as discount rate and equity weighting). Given the status of the knowledge on economic effects, alternative decision frameworks (e.g. risk based approaches) enhance the knowledge available for such decisions (Watkiss and Downing, 2007)*

[37] The study reported 28 studies in the literature, providing 103 estimates. The Tol paper reported that if all studies were combined, the mode was $2/tC, the median $14/tC, the mean $93/tC, and the 95 percentile $350/tC. Excluding the studies that were not peer reviewed, the mean was $50/tC (for any discount rate). The author, Richard Tol, concludes that 'using standard assumptions about discounting and aggregation, the marginal damage costs of carbon dioxide emissions are unlikely to exceed $50/tC, and are probably much smaller'. While studies since the year 2000 have generally shown declining values, recent updates of the review by the same author (e.g. see EEA, 2007) have shown recent values increasing.

differences in values of orders of magnitude. However, there is no consensus on which parameter values to use.

- The values include large assumptions about substitutability. The existing models usually implicitly assume full substitutability, i.e. between very different impact categories, in consumption and production.[38] This means that the aggregated economic cost is the net of the losses from for example damages to natural ecosystems, against the plusses, for example from reduced energy for heating. In this respect they differ from other stronger precautionary approaches discussed later.
- The values also vary according to the coverage of climate impacts and sectors assessed (see Appendix 1). The coverage was mapped against a matrix comparing the potential full economic costs of climate change. It was found (Watkiss et al, 2006) that most studies/models cover only limited climate effects such as temperature change, and generally only value market damages (e.g. agriculture and energy). Very few studies cover any non-market damages, locally-specific precipitation effects, or the risk of extreme weather (floods, storms, etc). Almost none cover socially contingent effects and major/catastrophic events. Therefore, much of the variation in the SCC estimates in the literature arises because different model estimates of the SCC include different coverage. As importantly, this indicates that although we do not know what effect the inclusion of the missing climate-change impacts would have on the SCC, the results of expert interviews suggest that the missing effects are likely to have net damages, which could be potentially very large and might increase the value of the SCC. It is these gaps in the analysis, particularly from major events, that have driven most of the climate change policy discussion, and their importance is now being considered in terms of the implications for CBA (see Weitzman discussion below).
- Analysis of the various IAMs as part of the Stern review (Warren et al, 2006) identified a number of other reasons why the IAMs might underestimate values. The review found that all the models are based on literature from 2000 and earlier, and since this time, some predictions of climate impacts have become more pessimistic, as well as identifying aspects in relation to the calibration of the models based on US literature, the higher possibility of discontinuities at lower temperatures, the treatment of adaptation[39], as well as other aspects. It is also highlighted that many of the IAMs rely on aggregated damage functions with a smooth functional form, and make assumptions about how steeply damages increase as temperatures rise. Importantly, there is little direct evidence on the shape of the damage function.
- A number of other aspects related to indirect costs, price changes from future scarcity, transition and learning costs, etc are also not covered (see EEA, 2007), though studies may also have overlooked some positive impacts of climate change.

It was these types of conclusions that informed the recommendations of the SCC review studies, which concluded that knowledge of the SCC was still low, and the evidence precluded establishing a central estimate of the social cost of carbon with any confidence[40]. The study concluded that a wider framework than CBA alone is needed to take all relevant effects into account (no single method, model or tool adequately captures all of the uncertainties) and that single estimates of the SCC, often portrayed as central estimate or best guess should be avoided for such policy decisions (though many stakeholders now recognize the usefulness of SCC values in providing some input to decision making). The

[38] Although non-linear damage functions can be interpreted as an indirect representation of non-substitutability (see Dietz *et al,* 2007).

[39] Note adaptation is also an input into the economic costs, but is not included here for simplification.

[40] The studies concluded that estimates of the social cost of carbon span at least three orders of magnitude, from zero (or even below) to over £1000/tC, reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables (notably over discount rate, equity weighting and climate sensitivity).

recommendations were for a framework with a disaggregated analysis of economic winners and losers by region and sector, and a disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems. A particular focus was to consider explicitly the risks of major change (shown by the risk matrix to be omitted in many studies)

In relation to this there has been some influential literature more recently. The concept of large-scale climatic events (Schellnhuber et al 2005; Lenton et al, 2006), often expressed in the climate literature as major irreversible events or 'tipping points', is undoubtedly one of the major areas driving international concern over climate change. CBA relies critically on the assumption that marginal costs and benefits, as well as absolute costs and benefits, are finite. This is not necessarily the case (see Tol, 2005) and more recently has been highlighted in work by Weitzman (2008) – see box below, which concludes that including plausible, if unknown, probabilities of catastrophic climate change, leads to radically different conclusions for policy from the conventional advice coming out of a standard economic analysis and formalised CBA, which essentially ignores this kind of potential for disasters.

**Modeling and Interpreting the Economics of Catastrophic Climate Change**. **Weitzman, 2008.**

This paper analyzes the implications of structural uncertainty for the economics of low-probability high-impact catastrophes for climate change. It centres on the strong implications for situations (like climate change) where a catastrophe is theoretically possible, and where uncertain parameters induce a critical tail fattening of distributions (i.e. where the probability density function has a fat (or thick or heavy) tail such that the tail probability approaches zero more slowly than exponentially. The paper concludes that such effects can outweigh all other effects in CBA of climate change (due to fat-tailed structural uncertainty, coupled with great uncertainty about high-temperature damages), and that:

(1) because of deep structural uncertainty over potentially disastrously large temperature changes, there is a strong case that the relevant probability density function (PDF) of climate change catastrophes has an extreme tail that is heavy with probability.

(2) when these heavy tails are combined with very unsure high-temperature damages, this can dominate the discounting aspect in calculations of expected present discounted utility (even at plausible real-world interest rates);

(3) This translates into placing severe limitations on the reliability of policy advice coming from standard cost-benefit analysis (CBA) of climate change;

(4) the conventional climate-change policy ramp is an extreme lower bound on what is reasonable rather than a best estimate of what is reasonable;

(5) removing the artificial limitations on conventional CBAs – which exclude very-high-impact disasters – will lead to a more inclusive economic-welfare analysis away from the gradualism of a climate-change policy ramp.

The paper outlines that greater research effort is needed on deep uncertainty rather than the central tendencies of climate change.

http://www.economics.harvard.edu/faculty/weitzman/files/modeling.pdf

These issues inform our subsequent recommendations here that it is not currently advisable to use the SCC to set global long run policy, or to use for optimal analysis for interim targets. However, an issue of consistency is raised here, because there has recently been an update of the SCC value recommended for Government appraisal by Defra, with the introduction of the Shadow Price for Carbon[41]. The guidance adopts the concept of the SPC as the basis for incorporating carbon emissions in cost-benefit analysis and impact assessments. The

[41] http://www.defra.gov.uk/environment/climatechange/research/carboncost/step1.htm

new guidance brings the value of carbon included in appraisals into line with the Stern Review's assessment of the social cost of carbon, but consistent with the value associated with the current policy trajectory towards stabilisation. For this reason it recommends the use for 550ppm $CO_2$e ($30/t$CO_2$ equivalent to £19/t$CO_2$) rather than the BAU ($85/t$CO_2$). The former value is converted to a current price and emission (£25/t$CO_2$ in 2007) with the recommendation that this should be uprated over time, with a rise of 2 per cent per year because of rising damage costs from higher greenhouse gas concentrations. The area of policy consistency here is also addressed in our recommendations later in this chapter.

## Cost-Effectiveness

Cost-effectiveness analysis has historically been used to compare the costs of alternative ways of producing the same or similar outputs. In this respect it is a relative measure, i.e. it only provides comparative information between choices. The approach has been widely adopted in environmental policy appraisal, particularly at a European level[42] and has typically been used in one of two ways – either to identify the highest level of benefits given available resources, or more usually to assess the least-cost path to reaching a given target (e.g. for a predefined threshold level)[43].

The use of cost-effectiveness analysis usually centres on some form of least cost optimisation, usually through the use of marginal abatement cost curves derived from bottom-up or top-down models (or a combination of both). Cost curves are constructed by identifying all the expected abatement opportunities for a particular time period in order of cost-effectiveness, and representing their cumulative abatement potential along the horizontal axis. The vertical axis then represents the cost of abatement (e.g. in €/t$CO_2$) for each of these opportunities. The cost curve then gives a representation of the total cumulative abatement that would be achieved at a particular carbon cost – this can be 'read off' the curve by drawing a horizontal line across the curve, as indicated in the schematic below. The coverage of the MAC curve needs to be appropriate to the scope of the target being considered – i.e. for UK-wide targets, the MAC curve needs to cover the whole economy, whereas sectoral targets would use sector-specific MAC curves.

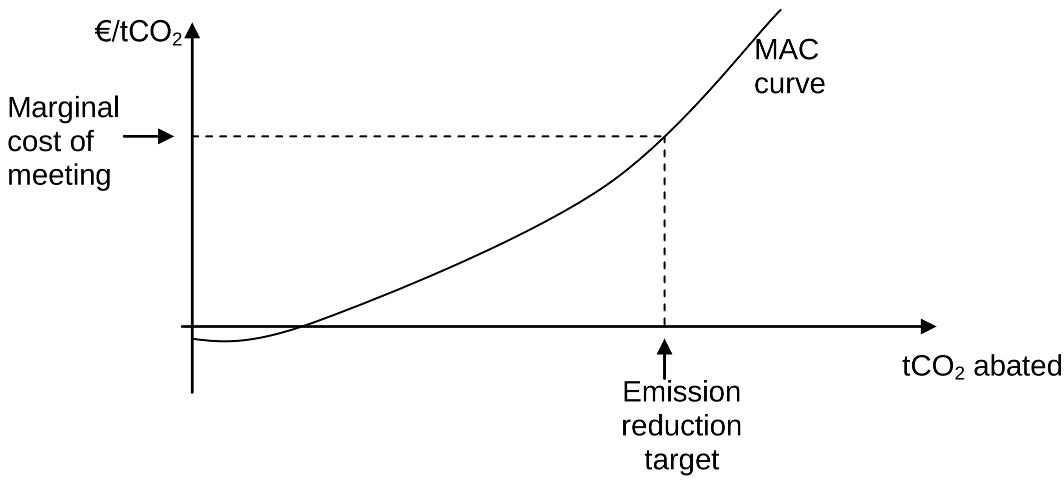


**Figure 3.1 Use of marginal abatement cost curves in cost-effectiveness analysis**

[42] Cost-effectiveness analysis was the central analysis for much of Europe's historic air quality legislation.
[43] Note CBA and cost-effectiveness are not necessarily exclusive: rather cost-effectiveness analysis is nested within CBA and stops short of quantifying the benefits of action on a directly comparable metric. Moreover, there are examples of policy decisions where both approaches are used to complement each other, a good example being the air quality policy analysis undertaken by the European Commission as part of the Clean Air For Europe programme.

In practice, there are a number of technical issues that need to be considered when constructing these curves from technology models. These include: the need to the correctly represent structural changes in the economy; additionality with respect to the climate change policies that are factored into the 'business as usual' scenarios in the models; appropriate choice of discount rates; differentiating between technical potential and realistic estimates of likely delivery at a given price. In addition, cost curves that are populated by technology-rich bottom up models may struggle to identify long-term abatement options, so that analysis of cost-effectiveness of 2050 targets may require different model approaches than analysis of interim targets. These issues are discussed further in Appendix 5.

The previous work in the UK on carbon targets, with the long-term and interim Energy White Paper target, used cost-effectiveness analysis to investigate the feasibility (achievability) of those targets (see chapter 2). It has also been a central theme of the interim analysis of the EU's carbon targets (again see chapter 2) for 2020.

Such a cost-effectiveness analysis can estimate the relative costs of different options up the cost-curve. It can therefore be used to see whether an incremental tightening of targets is associated with rising costs and whether these increases in cost are at some point disproportionate, where of course in this framework what is disproportionate is arbitrary but could be indicated by for example a step change or discontinuity in the cost curve. There are policy examples where such analysis has led to a lowering of ambition.

Cost-effectiveness was used in the previous UK assessments of the long-term 60% target, and the interim 26 to 32% target, as well as in the EC's 2020 target analysis (See chapter 2). In relation to the practical analysis, there are different approaches that can be used for such estimations. As highlighted by Barker et al, 2007 in AR4, WGIII, these include two broad types of approaches:

- Bottom-up studies, which are based on mitigation options, and have detailed considerations of specific technologies and regulations, but do not consider wider macro-economic effects. They are particularly useful for the assessment of options at a sectoral level.
- Top-down studies, which assess the economy-wide effects of mitigation options. These capture macro-economic and market feedbacks, but tend to have less detail on specific technological options. They are particularly useful in informing on cross-sectoral and economy-wide effects.

Note that there is a merging of the two domains, either through integrating models together (e.g. as in the EU studies which combine a suite of models and link the outputs) or through hybrid models, for example where top-down models incorporate technological options, or bottom up models incorporate macroeconomic aspects (e.g. MARKAL-Macro), etc. .

Cost-effectiveness does not, however, provide a justification for policy targets per se (as it does not allow a comparison of costs and benefits) though of course, the information obtained in a cost-effectiveness analysis can be an input into other decision making frameworks, such as CBA, where an explicit comparison of costs and benefits can then be made.

Marginal abatement costs can be used as a proxy for a social cost of carbon in appraisal. This can help to achieve strategic goals with greater confidence, since the marginal abatement costs are generally less uncertain than social costs of carbon.

It is highlighted that whilst the uncertainties are lower than for the marginal social costs, there still remain considerable uncertainties in the MAC of emission reductions, especially beyond very modest emission improvements.

The representation of the MAC curve in Figure 3.1 suggests that costs are known accurately for any given level of emissions reduction. Clearly, in practice this is not the case, and uncertainty in costs is an important issue to consider. Previous studies have highlighted the uncertainties in MAC estimates (notably for longer-term emission reductions). The SCC review (Watkiss et al, 2005) reported that the costs of meeting the UK's 2050 target differed by over an order of magnitude, and some studies even vary in sign. The Stern review also reported a wide range (e.g. reporting that cutting GHG to about three quarters of current levels by 2050, consistent with a 550 $CO_2e$ stabilisation levels were in the range -1 to +3.5% GDP, Stern et al, 2006). There is a wider literature on the estimates of ex post out-turns, which shows wide ranges from anticipated ex ante estimates, though for environmental policies, these often show lower costs than anticipated[44]. It is also important to recognise that there is uncertainty over policy implementation (i.e. whether policy measures are realistic). A discussion of some of these uncertainties is also included in Appendix 5.

In principle, if costs are uncertain, then there may be value in delaying a commitment to a particular level of emission reduction pending further information on these costs. On the other hand, delaying such abatement commitments could lead to additional climate damages. Chapter 4 considers in more detail the issue of decision-making under uncertainty and the question about the balance between uncertain costs and uncertain benefits of action. Generally speaking however, uncertainty can be an important issue, and warrants further investigation and should be considered by the CCC. MAC curves should ideally include ranges of costs rather than point estimates in order to inform a risk-based approach to decision making, and should take account of realistic policy outcomes (i.e. to prevent potential risks to credibility and confidence from setting targets that cannot subsequently be achieved)..

## Multi-Criteria Analysis

Whilst the UK adopts a strong economic dimension to project and policy appraisal, consideration of multi-criteria analysis (MCA) is referred to in the Green Book: '*where full valuation of costs and benefits is thought not to be possible or worthwhile, they should still be recorded. Multi-criteria analysis can then be used to bring directly into the appraisal process data expressed in different units. These can be weighted according to their importance and the results used to rank options*.'

There is a widespread use of multi-criteria analysis in environmental policy analysis across Europe, and a limited, but established, tradition of MCA use in policy analysis in the UK[45].

A multi-criteria framework could be used for short-term carbon budgets (as well as long-term climate change policy). Indeed, many have advocated such an approach and Multi-Criteria Analysis has been recommended in the development of National Adaptation Programmes of Action (NAPA). Some have argued (e.g. see Downing et al, 2005) that this approach would serve to formalise a process that has been informally followed to date in climate policy making in any case. It could also complement an assessment where evidence has been

[44] For infrastructure projects, there is often optimism bias, as reported in the Green book. However, for environmental policy, many studies report that ex post out-turns are lower than anticipated (e.g. as in the Defra Air Quality Evaluation, Watkiss et al, 2004; and the Ex-post estimates of costs of EU environmental policies, IVM, 2006). There has been work evaluating the effectiveness of the earlier Defra 2000 Climate Change Impacts programme (http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/synthesisccpolicy-evaluations.pdf) but whilst this assessed the cost-effectiveness ex post that measures had achieved, it did not compare to the ex ante estimates to check the accuracy of appraisal forecasts.

[45] For example a consideration of different attributes is included as the final stage in DfT's Appraisal Summary Table in transport appraisal, to compare certain environment categories (such as greenhouse gas emissions) alongside the existing cost-benefit framework, though this is not a formalised application of MCA.

gathered in a common metric, (e.g. monetary CBA), to expand the framework to cover other attributes, or to expand the focus of CBA from efficiency only.

The great advantage of MCA frameworks is that they allow consideration of quantitative and qualitative data together (i.e. monetised and non-monetised effects), particularly useful in a case such as climate change where full valuation of all aspects is currently impossible. In cases where monetary data exists (e.g. with costs), direct quantitative values can be used to score different options. In cases where only qualitative data exist (e.g. expert judgement of risk), different options can be assigned a score. Relative weightings are then given to different categories, usually through stakeholder workshops or expert opinion.

There are no direct applications of MCA in setting long-term government policy, but there is some literature on its potential use. Bell et. al. (2001) compare the use of alternative multi-criteria decision methods, (MCDMs), in using the outputs of climate change integrated assessment models to determine climate policy at a national level; the study serves as the most rigorous application of these methods to the climate change context to date. The authors report on the outcomes of a workshop held in the US, involving 20 participants expert in aspects of climate change analysis, and drawn from governmental, academic, national laboratory and corporate organisations. The primary purposes of the workshop were to compare the results and predictive ability of alternative methods, and to evaluate their usefulness – including ease of use - in climate policy-making. The disadvantage of having a relatively small sample size was countered by the fact that the participants included those involved in making the real-life decisions.

Six different GHG emission regulation policies were considered: global $CO_2$ taxes of \$75, \$150 and \$300; relaxed $SO_2$ emission standards; nuclear fuel subsidy; and promotion of biomass, all relative to a base case. The policies were compared using six attributes: temperature increase by 2050; sea level rise to 2050; annualised SO2 emissions; annualised nuclear waste generation and annualised control costs, the estimates (mean, min and max) being derived from an IA model. The MCDM methods were grouped into a) weighting methods; b) deterministic ranking methods and c) uncertainty ranking methods. Weighting methods e.g. using point allocation (say 100 points allocated across attributes) help to define which attributes are most important, and by how much, whilst the deterministic and uncertainty ranking methods, using e.g. utility or value functions, combine these preferences to rank alternatives. Amongst the principal findings from the study were:

- MCDMs were found to be useful in structuring the problem so that large amounts of information become manageable in exploring trade-offs. However, participants did not believe that the methods improved consistency or confidence (probably because their views did not correspond to the trade-off and weighting approaches adopted).
- The use of multiple methods was found to be useful as participants' preferred methods varied widely. It also recognises the differing ways of framing alternative approaches to the climate change problem. However, this increases the resources needed. The MCDMs did not have high predictive ability (i.e. to predict the final user preferences) but, were useful in the decision making process since multiple methods serve to help get people to think about the problem in a number of different ways.
- The weights applied to attributes differ significantly depending on who assesses the weights as well as which method is used to derive the weights. Similarly, policy ranking differs depending on who does the ranking and with what method. The uncertainty in climate change makes the use of point estimates problematic. Incorporating uncertainty by e.g. defining probability distributions for each attribute can help address the issue but makes analysis more complex. The trade-off techniques can force the user into making more definitive preferences than she is able or willing to make.

- Attribute values – in this case the policy impacts – have to be believed and accepted otherwise ranking of alternatives becomes impossible. This could be reduced if a variety of IA models and expert judgements were utilised in multiple MCA exercises, but this increases the resource needed. Moreover, it is clear that the range of attributes has to be comprehensive and expressed explicitly. In actual policy making much effort would go into determining what criteria are important to each decision-maker.

Bell et al. therefore show that MCA exercises in the climate change policy context are possible, but they also show clearly that are a number of difficulties – in particular, the treatment of uncertainties and the associated need for comprehensive attribute definition, the need to represent the complexities of the climate impact linkages to allow valid trade-offs to be made, and the requirement to somehow identify and aggregate the preferences of multi-various decision-makers – that may limit its value as an aid to decision-making.

While MCA can be a useful tool, especially for comparing options, it is also has a number of limitations, particularly in the context of climate change. Like CBA, it is a formal, quantitative comparison of costs and benefits, albeit the metric is no longer money. While this reduces some problems and can allow a wider range of evidence to be compared, it falls victim to (and indeed introduces new problems of) subjectivity in weighting and ranking. There is a particular issue of representation in this context, because weights and ranks in MCA are usually derived from the views of a small number of experts, rather than from a wider constituency. Finally, MCA is also a complex and time-consuming process as it requires extensive consultation and expert input.

## Multi-Attribute Frameworks (including Non-formalised Costs and Benefits)

An alternative to a formalised CBA, or a formalised MCA, is to use a non-formalised multi-attribute framework, which combines element of the stronger economic approaches with scientific-precautionary concerns.

In many ways, this is the approach that has been adopted by the IPCC, with analysis of the Reasons for Concern in the Third Assessment Report (known widely as the 'burning embers' analysis) alongside analysis of mitigation costs of stabilisation, and more recently in the AR4, with the examples of global impacts against temperature (Table 20.8, Chapter 20, WGII, Yohe et al, 2007) as well as the detailed analysis of costs of stabilisation (Barker et al, 2007, WGIII). The key figures from these are presented in Appendix 1.

It is also the approach that was adopted in the Stern Review, again with the projected impacts of climate change (over temperature) combined with a comparison of the economic costs of inaction, and the costs of a 500 to 550 $CO_2$e ppm stabilisation scenario. The Review also quantified the economic benefits of stabilisation and can therefore be considered a non-formalised analysis of costs and benefits.

The advantage of these approaches is that they allow a wider set of non-monetised effects to be included in the decision framework alongside economic costs and economic benefits. The disadvantage is that it is more difficult to use the information to make a decision (i.e. unlike CBA or MCA, it does not lead to a formalised output that provides an answer). There are also some issues with implementing a conceptual framework of multi-attribute analysis for interim targets in 2020, not least as multiple interim pathways will achieve the same long-term objective.

### Tolerable Windows

The Tolerable Windows Approach (TWA) (Bruckner et al, 1999) is based on specifying tolerable sets of climate impacts as well as proposed emission quotas and policy instruments for implementation. In a subsequent step, the set of allowable climate protection strategies which are compatible with these inputs is determined by scientific analysis. In doing so, minimum requirements concerning global and national greenhouse gas emission paths can be determined. The approach is based on an inverse-modeling concept that derives climate-stabilisation objectives (usually from perceived unacceptable impacts, but potentially from other approaches) and produces sets of permitted emission paths satisfying the corresponding climate change constraints. These can be used to set interim targets.

## Risk Assessment and the Precautionary Principle

A precautionary approach has been widely recommended for use in climate change policy. This reflects some of the key attributes of climate change make it particularly relevant to this approach.

- First, climate change has elements of irrreversibility - If an effect is irreversible (e.g., species extinction), we may want to prevent it regardless of how uncertain it is and regardless of what future research will show (according to the “precautionary principle”). In contrast, events that may or may not occur in some distant future, but whose consequences can be alleviated once apparent, are unlikely to worry us as much (EEA, 2007).
- Second, climate change potentially involves large-scale climatic events (Schellnhuber et al 2005; Lenton et al, 2006), often expressed in the climate literature as major irreversible events or ‘tipping points or tipping events’. As highlighted above, this is undoubtedly one of the main areas driving international concern over climate change. It is these concerns that have led many (e.g. Chichilnisky, 2000; Azar and Lindgren, 2003, Tóth 2000) to conclude that the preferred evaluation framework for a very long-term problem such as climate change, with a large inertia in the biogeophysical system (such that mistakes cannot be swiftly corrected), and the possibility of extreme and irreversible changes in the climate system, might not be cost-benefit analysis, but cost-effectiveness analysis with respect to a given climate target .

A precautionary approach is recognised in Government appraisal, e.g.[46] ‘*Where there are significant uncertainties surrounding the scientific case, policy decisions should take account of the precautionary principle. The Rio declaration defines the precautionary principle as: ‘where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation’* and where the ‘*Level of scientific uncertainty about the consequences or likelihood of the risk is such that the best available scientific advice cannot assess the risk with sufficient confidence to inform decision making’*.

Indeed, the Treasury document recognizes there are some policy areas where target setting is not easily based on an objective assessment of the costs and benefits’ and highlights the case of climate change[47]. Similar the HMT Green book recognises the concept of ‘Irreversibility, which occurs where implementation of a proposal might rule out later investment opportunities or alternative uses of resources, and cites relevant examples of

[46] Tax and the Environment: Using Economic Instruments. HM Treasury. Nov, 2002.

[47] ‘Some instances targets will be set through a process of negotiation, such as for the climate change targets agreed under the Kyoto Protocol’….. ‘In these cases the process of target setting will help to reveal the weight which society puts on the costs and benefits, but unless all those involved have a good understanding of these there remains a danger that targets will be set at an inefficient level’

irreversibility are the destruction of natural environments from climate change or, on a larger scale, permanent shifts in the climate system. The Green book states that '*it is particularly important to make a full assessment of the costs of any irreversible damage that may arise from a proposal.' Appraisal of different proposals should not ignore the 'option' value of avoiding or delaying irreversible actions, and the benefits of ensuring flexibility to respond to future changed conditions.*

In summary, a precautionary approach encompasses the concept that precautionary action may be justified to mitigate a perceived risk or uncertainty, even if the probability of environmental damage is low, but where if it did happen the outcome would be very adverse.

It is largely the approach that has been adopted in the original EU 2 degrees target, and thus the RCEP 550 ppm target. In this respect, it is also linked to the ultimate objective of the United Nations Framework Convention on Climate Change (the 1992 established UNFCCC) (1) (Article 2)) is to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

It is highlighted that there are different approaches within the broad category of a precautionary approach, particularly with greater focus on risk based approaches. At one extreme, the strict application of the precautionary approach to the impacts of climate change is an extreme version of risk-management, and is particularly sensitive to longer-term impact risks. However, there are other risk-based approaches that apply a more numerical or quantitative approach. These include approaches with risk weighting (i.e., multiplying likelihood times consequence) for major events as well as to other categories such as economic costs. As an example, there is some work which uses risk perspectives to prioritise environmental outcomes for different metrics using distributional or risk analysis, combining bio-physical risk numeraires with economic and social numeraires (see Jones and Yohe, forthcoming)[48]

These precautionary or risk based approaches have a number of advantages. They explicitly consider the most serious risks of climate change, which are a key factor in driving policy. They can also work together with other approaches. Moreover, use of these methods gives additional rigour to the treatment of uncertainty.

However, there are also downsides in such approaches. Given the uncertainty over climate change, and especially the thresholds for major events, it is very difficult to set precautionary levels (and get a consensus on these). In most cases, therefore, the choice of a particularly target level is arbitrary (or at least based on a very broad consideration of an acceptable/unacceptable level of impacts or risk). The approach generally does not consider the economic costs of targets, nor the technical feasibility, thus the costs of any targets are only consider implicitly – in that the decision maker has made an implicit trade-off that the benefits (or the reduction in risk) far outweighs any costs.

Finally, it is particularly difficult to see how such an approach can be applied to interim targets, other than advocating the maximum target level possible. Within the bounds of the existing targets, this would be a 32% target in 2020, though as recent reports (e.g. Tyndall, 2007) which apply precautionary thinking, show, the level of ambition for a precautionary approach would be much higher than this (see chapter 2).

[48] It is possible to multiply the probability density function of warming and damage curves towards cumulative distributions. The results are estimated risk-weighted average damages whose sensitivity to alternative emissions scenarios can be tracked. As an example, in the long-term setting this could consider economic damages, expressed in percentage decrease in GDP with biophysical impacts as expressed either as percentage lost (for coral reefs, species extinctions, and Greenland ice sheet) or chance of loss (THC collapse). Risk-weighting shows the benefits of reducing emissions on climate-related risks can be significant where they reduce strongly reduce non-linear components of that risk.

# Key Conclusions

Following the initial policy review, the project has undertaken a detailed analysis of each of the possible methodological approaches for setting UK interim targets for the first three periods, consistent with the CCC objectives.

This review works within the boundary conditions of the study, in relation to the existing UK targets – most importantly the 26 to 32% $CO_2$ emission reduction target by 2020 (but related to this the 60% $CO_2$ target by 2050), but also tests the implications of stricter targets, e.g. consistent with the recommendations of Stern, and recent policy announcements from Defra outlining the need for the CCC to investigate whether the current long-term target should be strengthened (with an example here of an 80% $CO_2$ reduction in the UK by 2050).

Each of methodological approaches has been reviewed in detail. Their relevance for the CCC, their advantages and disadvantages, and the practical issues (and application) have been considered.

The review is summarised below.

**Table 3.1 Comparison of Methodological Approaches for Setting Interim UK targets.**

| Approach | Advantages | Disadvantages | How CCC could use for interim targets |
|---|---|---|---|
| Formalised cost-benefit analysis (CBA) | Recommended approach for appraisal in the HMT Green book. Only method which can estimate the theoretical optimal target level.<br><br>Note can be used in a CBA framework which includes irreversibility and option analysis through risk aversion and learning premiums. | SCC (marginal social costs) are too uncertain to apply in a narrow CBA framework with confidence.<br><br>SCC values largely exclude major and socially contingent events. CBA does not adequately capture major irreversible catastrophic risks, and related to this a major question mark over whether marginal CBA is an appropriate tool for CC (see Weitzman). | In order of decreasing 'ambition'.<br><br>1. Set carbon budgets based on the optimal path of emissions as estimated by CBA. Note that the existing Defra SPC value (derived from Stern 550 ppm) is pathway specific, so additional work would be needed to do this.<br><br>2. Set carbon budgets by another less formalised method, but ensure that DEFRA's SPC is consistent with the budget by estimating MACs and SCCs along the implied path of emissions.<br><br>3. Use CBA as an periodic, ancillary test of the economic case for budgets and policies, i.e. by estimating the SCC necessary for a cost-benefit test to be passed.<br><br>4. Use CBA to test the ancillary benefits of climate policy, i.e. by estimating the ratio of costs to non-carbon benefits.<br><br>5. Undertake research to improve knowledge about MACs and SCCs. |
| Non-formalised costs and benefits, i.e. multi-attribute framework (economic) | Consistency with Stern Review. Allows wider set of non-monetised effects to be included in the decision framework alongside economic costs and economic benefits. | More difficult to implement a conceptual framework of multi-attribute analysis for 2020, not least as multiple interim pathways will achieve the same long-term objective. | Possible to use non-formalised analysis of costs and benefits of 500 to 550 ppm $CO_2e$ trajectories, and examine UK interim targets of 26 to 32%. Wider multi-attribute framework would consider issues of costs using formalised MAC analysis, but could also take into account the possible benefits not monetised in SCC values, or other UK specific 2020 issues (e.g. economic and employment effects, fuel poverty, ancillary benefits and impacts). |

| | | | |
|---|---|---|---|
| Cost-effectiveness analysis<br><br>(note usually nested within other approaches, e.g. with scientific-precautionary targets) | Consistency with EWP (2003: 2007) and existing targets. Consistent with most international studies (UK and other countries) on interim targets. Can inform on achievability of targets, relative attractiveness of options, and identify thresholds for costs. Allows consideration of options through pathway analysis and is an input into other frameworks (e.g. CBA). | Does not provide absolute information, only relative cost (achievability) information. Does not provide an assessment of benefits (benefits are implicit and predefined through political process), and so cannot inform of the benefits across the range from 26 to 32%. | Consideration of achievability and proportionality of costs of alternative interim targets. Analysis of MAC curves to see if disproportionate increase in cost curves between 26 and 32% with consideration of any step changes in the MAC curves across the target range.<br><br>Could be extended as part of option analysis. Also provides input for other frameworks (e.g. CBA). |
| Tolerable Windows | Acceptable corridors (guardrails) are set on the basis of indicators. Provides a richer context to bounding the stabilisation pathways, bringing in major events. Could be compared against cost-effectiveness. | Relevant metrics and acceptable levels have to be defined and agreed. | Would be worth exploring. Investigation of a UK specific set of criteria (indicators) would be extremely useful in prioritising key concerns of CCC anyway. They could also be used to help bound the range of interim targets.<br><br>These guard rails could be set on rate of technical change, or in relation to wider social or economic issues, e.g. level of fuel poverty, macro-economic effects. |
| Multi-criteria analysis | Provides framework for monetised and non-monetised attributes, so allows wider range of impacts than CBA or CEA. Can offer transparent way of developing / recording decision-makers preferences. Useful in exploring trade-offs and structuring / thinking about problem. Formalises a process that has been informally used to date in CC policy | Resource intensive and difficult issues on how to set values for weighting and normalisation. Participants often do not find methods improve consistency or confidence. The weights that are applied to attributes differs according to participants (and similar issues with ranking). Difficult to factor in uncertainty. | Some possible merit in using the technique as a counter-balance to the alternative frameworks. Variety of IA models and expert judgments could be used in multiple MCA exercises. Could be used with multiple MCA methods to reflect participants' preferred methods. Would be possible to use with probability distribution functions. |
| Precautionary | Focus on major risks. Is consistent with existing policy, e.g. Green book recognises the precautionary principle. Provides an approach that explicitly recognises the level of uncertainty, and potential non-marginal changes of CC. | No economic consideration. Does not assess the costs of alternative options. Provides almost no input to interim target setting other than a strong pressure to select maximum interim target, or at least not preclude the achievement of stronger long-term targets (e.g. >60%). | Difficult to conceptualise how apply to interim targets, other than ensuring that that a strict long-term option remains open. In this regard, very relevant in relation to option assessment, i.e. to link long-term precautionary approach and investigate whether any 2020 range of targets are inconsistent with a stronger longer term target, consistent if emerging evidence indicates the need for lower stabilisation levels. |

The findings of the review of methodological approaches are summarised below.

- There are large differences between the methodological approaches, primarily relating to the decision entry point and perspective (as discussed earlier). The methods therefore range from a formalised cost-benefit analysis (CBA) at one end (strong economic) to a strong scientific-precautionary approach at the other (strong sustainability), though intermediate methods engage in explicit economic and precautionary considerations to some degree. Ultimately all approaches trade off benefits against costs, whether explicitly (e.g. as in the case of CBA) or implicitly (e.g. the adoption of a strong precautionary target implicitly assumes that the benefits outweigh potential costs). As different stakeholders have different entry points and preferences, they are likely to recommend approaches across the range of methods. We consider that it will be difficult to achieve a consensus- based approach through selecting one individual approach.

- While formalised CBA is the main recommended approach in the Green Book, the same document also recognises the precautionary principle, and therefore existing guidance can be used to justify any of the approaches. The different approaches all have some individual merit. They each reflect a different balance of explicit or implicit consideration of costs and benefits.
- Existing UK policy for previous long-term and interim carbon targets has been set on the basis of a cost-effectiveness analysis of scientific-precautionary based targets. There are potential issues of consistency in target setting (including precedents). It could be argued that the approach for setting long-term and interim term targets should be consistent, as well as previous and current approaches. This would argue towards cost-effectiveness analysis, as this was the main methodological approach used in the EWP 2050 and 2020 targets, and in the CCP review[49].
- However, there are examples in Government where long-term and short-term policy use different methodological approaches. CBA studies can be used to inform government policies that have been set largely using other methods, but here special care must be taken to ensure that the value judgements and decision-making structures chosen in the CBA are consistent with existing policy[50].
- The Government has recently set guidance for the use of a shadow price for carbon (SPC) in appraisal across all departments, for all policy decisions. This SPC is set on the basis of the Stern Review estimate of the social cost of carbon on an emissions pathway to stabilisation at 550ppm $CO_2$e. For consistency and to reduce uncertainty, it should be ascertained whether the SPC used across Government is in line with the marginal abatement costs of achieving the 2020 interim targets. Note that the current SPC (based on global marginal social costs consistent with a 500 - 550 ppm trajectory) is itself conditional on international action.
- It is likely that the choice of interim targets in 2020 influences the achievability of long-term targets in 2050. This is particularly relevant for a precautionary approach, as well as in relation to the emergence of better information appearing later. It leads to the conclusion that any methodological approach should consider the option value of interim targets, i.e. what they imply for subsequent (particularly stricter) long-term targets.
- It is highlighted that the recommendations on methodology and targets depend on the objectives of the carbon budgets and the target setting approach as set-out in the Climate Change Bill, and agreed upon by the CCC. These could vary, for example between a strong objective towards global leadership, or towards providing certainty for business in investment and other decisions (these might lead to higher or lower levels of ambition respectively). From considering the Climate Change Bill and the recent supplementary

[49] Note, however, that if the target is now considered to be the Stern Review's 500 – 550 $CO_{2e}$ ppm stabilisation objective, then short-term targets should arguably be set on the basis of a non-formalised consideration of costs and benefits to ensure consistency.

[50] This is most easily understood in relation to the controversial choice of discount rate. Frequently, policy recommendations from CBA studies have been compared with government policy, even though the former tend to follow from a high discount rate, whereas it can be argued that the UK's near-term and long-term targets are consistent only with a low discount rate. The team recognise that there are many other issues involved in setting interim target which could justify a different approach, but highlight these consistency issues as being likely to be raised by external stakeholders.

statements and the proposals on strengthening the existing long-term targets[51], and 2007 Treasury PSA Delivery Agreement 27: *Lead the global effort to avoid dangerous climate change*, our interpretation here is towards a global leadership role, and this informs our recommendations below.

The key question is what methodological approach should be used to set a target between 26 and 32% for 2020 (as well as the interim targets in earlier periods), i.e. to move from a bounded range to a discrete policy choice. Taking the findings into account, the team considers that:

- Cost-effectiveness analysis should be the central methodological approach adopted by the SCCC. It can be used to estimate the increase in costs associated with stronger levels of ambition (i.e. moving from a 26% $CO_2$ emissions reduction in 2020 to 32%). It can also be used to estimate the impact that tougher interim targets will have on the feasibility and cost of long-term targets. This options analysis (see below) is likely to be a key element of the CCC's decision.
- In relation to marginal abatement costs and cost curves, it is highlighted that uncertainty can be an important issue. It is also important to recognise that there is uncertainty over policy implementation (i.e. whether policy measures are realistic). The CCC should consider uncertainty in its analysis and MAC curves should ideally include ranges of costs rather than point estimates in order to inform a risk-based approach to decision making, and consider realistic policy outcomes.
- However, cost-effectiveness is a relative measure. It does not estimate the benefits of different targets. For this reason, while we believe it forms the core of the overall analysis, we also believe that it needs to be complemented with other approaches. These include a scientific assessment of the environmental risks and benefits of different interim targets in their 'natural units'. This would follow the methodology of the Stern Review and of IPCC in linking emissions targets with possible temperature increases and these in turn with impacts on the environment on various dimensions such as food security, water availability and natural ecosystem health. For interim targets, rates of temperature increase should be afforded more emphasis than is usual in analyses of long-term targets, which focus on levels of temperature increase. Analysis should be carried out of political and social considerations such as EU burden-sharing and fuel poverty respectively.
- These other approaches provide important additional information that can help inform the CCC's decision, and they also are important in relation to the wide diversity of stakeholders. We believe this approach is likely to have a much wider acceptability to the broad group of potential stakeholders, as well as generating useful information that a single approach could not capture. A tiered approach to target setting is therefore recommended to implement this, and this is set out in more detail in the later section.
- In principle, information on the costs and benefits of different interim targets could be brought together within a formalised CBA, which could be used to recommend an 'optimal' emissions pathway. Formalised CBA has also been used to systematically explore the role of uncertainty, irreversibility and learning on interim targets. It is the only framework really capable of bringing the full range of information together quantitatively to estimate option values. However it is our assessment that the uncertainties around estimating the social cost of carbon (SCC, the marginal global damage costs of climate change) are currently too high to rely on this method to determine the CCC's decision. Rather, formalised CBA could play several important ancillary roles.
    - There is a need to investigate the consistency of current recommendations on the shadow price of carbon (SPC) used in Government appraisal in relation to

[51] http://www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/climate-change-bill-summary.pdf and http://www.defra.gov.uk/environment/climatechange/uk/legislation/pdf/govt-amendment-package.pdf

the interim carbon budgets (and estimates of the marginal abatement costs of these budgets). In practical terms this would involve modelling, or meta-analysis of the literature, to calculate the SCC and MAC of the emissions pathway implied by the carbon budgets (noting that the SPC is path dependent i.e. according to a 500 or 550 ppm stabilisation path, there is a need to potentially expand the existing SPC analysis).

- Formalised CBA can be used to understand in general terms the implications of various scientific, economic and social issues and can be periodically undertaken when new information comes to light on any of these issues as a means to 'check' the economic case for Government policy, comparing estimates of the marginal costs and benefits of recommended carbon budgets. A practical example would be to periodically calculate, for carbon budgets or for policies more generally, what SPC would be required as a minimum for the budget/policy to pass a cost-benefit test. However it must again be stressed that the resulting information is unlikely on its own to be decisive.
- Other ancillary monetary benefits (air quality improvements) could be assessed within a CBA framework. Note that these other benefits are important (see chapter 5), particularly as they accrue immediately to the current generation (unlike the benefits of climate policy).

<u>The team recommends cost-effectiveness analysis as the central approach for the CCC, complemented by separate assessments of environmental, social and political factors as part of a multi-attribute framework (i.e. as part of a non-formalised analysis of costs and benefits). Formalised CBA can play a role here but cannot substitute for a multi-attribute approach, due to the uncertainties.</u>

Note that formalised CBA could be used in assessing the non-carbon benefits, and we recommend such a framework be considered for many of the ancillary and economic effects of policies (e.g. air quality). This would allow the presentation of all non carbon costs and benefits of targets alongside their carbon effects. However, many of these 'other elements' may be difficult to monetise formally (see Chapter 5) and thus such an analysis may require a non-formalised (i.e. Stern-like) consideration of costs and benefits. .

# Chapter 4. Methodologies for decision-making under uncertainty and Case Study on Options Analysis

## Stabilisation Pathways: Linking Long-term and Interim Targets

This section summarises the issues on stabilisation pathways. An extended version is presented in Appendix 2.

As the overall framework for target setting shows, there are a number of steps relating long-term international stabilisation goals to interim UK targets: (i) the examination of alternative emissions paths over time towards long-term targets, (ii) the consideration of the relative reductions in developed and developing countries, and (iii) the consideration of burden sharing within the EU.

In undertaking the first of these steps, it is necessary to take account of the relationship between global emissions and atmospheric concentration levels. This relationship is complex and uncertain, due to the role of sinks in the climate system and possible feedbacks between the effectiveness of these sinks and climate impacts. Nevertheless, simplified estimates can be made[52]. Most analysis shows a relative insensitivity of final concentrations to the shape of the emissions path: therefore many different paths (with the same cumulative emissions) will lead to the same concentration. Much of the work related to calculation of emissions paths is therefore dedicated to identifying paths (or emissions corridors) that are realistic given constraints. These constraints include one or more of the following:

1. That the curve is smooth, in order to avoid very rapid changes in emissions trends
2. That the rate of change of emissions from one year to the next is limited (e.g. to below 3% per year) in order to reject emissions paths that would require a decarbonisation rate that is deemed technically unfeasible
3. That a more explicit treatment of abatement technology is introduced, allowing for projections of availability and cost of abatement which could vary over time to account for new technology development (e.g. cost supply curves)
4. That $CO_2$ emission profiles are optimised to achieve least-cost deployment of $CO_2$ abatement technologies, taking account of the expected evolution of technology costs over time (e.g. including learning and R&D effects, etc.).
5. That multi-gas emission profiles are optimised to achieve least-cost deployment of multi-gas abatement technologies over time.

The further one goes down this list of constraints, the more feedbacks are incorporated into the emissions path, and the more complex the model required. Typically, integrated models can provide the optimized profiles described in the final two bullets (as used in a wide range of literature, including the IPCC scenarios), whereas the constraints described in the first two bullets can be achieved through simple curve fitting calculations (also with an established literature including the Contraction and Convergence model, and the recent Ecofys study for Defra). Structurally simpler technology models described in the third bullet tend to be used at the policy analysis level, for example to look at the costs of achieving emission reductions in different sectors, and these can sometimes contain a richer and more detailed description of abatement technologies than integrated assessment models.

[52] IPCC AR4 Working Group 3 chapter 3 p198

Regarding developed/developing country burden sharing, a number of approaches have been advanced for calculating emissions paths at the individual country level. These include:

- **Contraction and Convergence (C&C).** In this approach, emissions rights are allocated on the basis that emissions per capita will converge to a common value for all countries by some agreed convergence year (e.g. 2050).
- **Common but differentiated convergence (CDC)** is a variation in which developed countries immediately begin to contract emissions towards a common convergent emissions per capita level, but developing countries only start to reduce emissions (towards the convergence level) once their emissions per capita have exceeded a threshold based on the world average per capita emissions.
- **Multistage**. In this system, countries take on gradually more stringent levels of commitments depending on their stage of economic development or depending on their emissions per capita.
- **Global Triptych**. The method applies a convergence of per capita emissions only for domestic related emissions, and for other sectors of the economy, analyses the emissions levels and abatement potentials for key sectors. This approach gives more emphasis on cost-effectiveness criteria, whilst also retaining some elements of the equity considerations around convergence.
- **Sectoral approach**. In this approach, instead of dividing the global emission path between countries, certain sectors that are either globalised or produce a homogenous product (e.g. electricity generation) would be required to follow a given emissions profile, irrespective of the country in which they operate.

The order in which these two steps are carried out depends on the architecture of the international system. In some of the above proposed schemes, one would start by defining a global emissions pathway consistent with some pre-defined environmental target, and then proceed to divide these global emissions rights between countries / sectors etc (as is the case for example with the contraction and convergence approach). Other schemes (such as CDC and multistage) start at the other end by defining a set of actions and commitments appropriate to different countries, which then build up to an overall global emissions profile. This second approach is less environmentally determinate, the achievement of environmental goals becoming scenario dependent.

The project has reviewed the approaches, and the models used, to undertake the analysis of emissions paths and the allocation rules. A number of key messages emerge from this review.

- There are a number of approaches that can be used for pathway analysis. Very broadly these tend either to use complex models (e.g. Integrated Assessment Models) or simplistic pathways with constraints (e.g. Contraction and Convergence). There are some hybrid approaches, as in the models of Meinshausen.
- Integrated models provide a sound conceptual approach, integrating technology cost assumptions into the calculation of optimal pathways. However, their complexity can be a disadvantage for policy analysis applications. Although many of the assumptions on technology costs may be quite simplistic, they are often embedded in the model, making them rather opaque.
- In contrast, simple curve fitting approaches aim to use simple constraints on the rate of change of emissions. However, there tends not to be very much analysis of how the values chosen for these constraints relate to technical constraints in the real world. The values chosen for the constraints make a very significant difference to the choice (and availability) of different pathways.

- Therefore, for the setting of carbon targets and the policy frameworks being considered here, we recommend a central approach, based around hybrid approaches, which allows detail and transparency, and that can capture important issues such as technical potential, structural change to the economy, hedging and R&D etc. This involves some elements that link with the cost supply data.

Note, whichever approach is used, significant expert judgement is still required.

As well as the information about the cost-effectiveness of different interim targets, a consideration of this part of the review has been to highlight the need for a detailed pathway analysis for the SCCC, as part of the overall target setting approach for interim targets. This is defined here as options analysis. Given the uncertainty over a number of key elements of the costs, benefits and risks of different mitigation paths, and the potential for gaining better information in the future, interim targets should be considered in terms of their option value, to see whether they influence the achievability of later, long-term targets.

In very simple terms, it would seem sensible that any process that considers targets for 2020 should consider whether these close off options for 2050 (e.g. does a 26% target in 2020 make an 80% reduction in 2050 unachievable). This type of option analysis provides a useful framework within which more detailed economic analysis can be positioned in order to aid decision-making. However its application to climate change is complex, and so the project has advanced the approach through some additional review and some preliminary analysis.

With respect to long term stabilisation targets, the issue of overshoot scenarios is also relevant here[53].

## Decision Making Under Uncertainty

The task facing the Climate Change Committee (CCC) is to set short-term (interim) carbon emissions targets under multiple sources of uncertainty about the costs and benefits of emissions reductions and the future course of policy. Many of these uncertainties will be reduced in the future as we learn more about the costs and benefits of emissions reductions and the course of policy is decided, even though the process of learning may not be uniform.[54]

Yet the CCC faces a decision on interim targets now that can lead to a number of irreversible commitments in relation to capital (e.g. in the electricity-generation sector) and in relation to climate change itself. Such a problem suggests the existence of option values, i.e. the value of avoiding irreversible commitments until uncertainty is reduced. These option values are the focus of this section, together with other factors affecting the choice of interim targets such as technical change.

[53] In relation to the stabilisation pathway, and the range of interim objectives, pathways are often bounded for strict targets by the assumption of whether overshoot scenarios are allowed (i.e. scenarios that lead to an exceedance of say a 550 ppm level, before stabilisation back down to this level, and/or by implication, similar issues in relation to temperature). Overshoot scenarios allow almost any target to be achieved, but they also infer a change in risk associated with overshooting. Overshoot pathways that cause transient global temperatures to exceed those expected to correspond to the long-term target increase the possibility of crossing certain irreversible thresholds or 'tipping points' in the climate system, such as those triggering melting of the Greenland and West Antarctic Ice Sheet.

[54] So-called 'negative' learning is possible. An example is stratospheric ozone depletion. From the late 1970s through to the mid 1980s, uncertainty in predictions of total future ozone depletion decreased, but it turned out that these predictions were narrowing in on the wrong answer, because the models underlying the predictions were all omitting important processes.

# Factors affecting the choice of 2020 targets

## Uncertainty, learning and irreversibility

Uncertainty is central to making climate-change policy. Uncertainties can be found at all links in the chain between greenhouse gas emissions (and their control) and the impacts of climate change on human development and the environment. They include positive uncertainties about physical, natural and economic processes, normative uncertainties or disagreements about the values to be attached to these processes, and uncertainties about policy. Importantly, some of these uncertainties can be affected by the choice of emissions pathway. These issues will be picked up below, and are discussed more fully in Appendix 3.

The first issue to address is how such uncertainty should affect decisions on emissions abatement, compared with decisions that do not take these uncertainties into account. It generally follows from all methodological approaches that global emissions reductions under uncertainty should be greater than those assuming perfect certainty. This is due to common assumptions about the structure of the various uncertainties, as well as society's attitudes to taking risks and to precaution (see Appendix 3), and is evident in formalised economic studies as well as in scientific/precautionary studies. Here is also an appropriate point to emphasise that there is currently much debate about how uncertainty should be modelled. Economic approaches, especially CBA, tend to impose a rather restrictive structure on uncertainty about climate-change policy that probably assumes we are better informed than we actually are.[55]

But the implications of uncertainty are more complicated if we consider the prospect of learning more about climate change and associated policy, thereby reducing the uncertainties in the future, e.g. through the process of research marshalled by the IPCC. Indeed, great strides have been made in our understanding of the climate system since the first IPCC report, e.g. in refining and enhancing General Circulation Models (GCMs). At the same time, it should be acknowledged that in some cases the process of research has in fact increased uncertainty at least for the time being. This is for example true of uncertainty about the important climate-sensitivity parameter, i.e. the equilibrium increase in global mean temperature accompanying a doubling in the atmospheric concentration of $CO_2$ (Stainforth *et al*., 2007). However, in general the prospect of learning is an important one, since we do not face a once-and-for-all decision on an emissions pathway. The CCC, for example, can set the first three carbon budgets and thereby determine the UK's 2020 target for $CO_2$ emissions, but revisions can be made to the pathway of emissions thereafter.

One argument is that the prospect of learning should lead us to 'learn then act' or 'wait and see'. It holds that if we learn over time that climate change is *less* damaging than originally anticipated (e.g. because the climate is changing less or because the impacts of these changes are lower etc.), early action will turn out to have been excessive. But if we learn over time that climate change is *more* damaging than originally anticipated, we can always increase the rate of emissions abatement later. The alternative argument is, however, that the accumulation of greenhouse gases in the atmosphere is irreversible, so if we later learn that climate change is *more* damaging than originally anticipated, it will be too late to reverse the process. Thus we should 'act then learn', taking precautionary measures to avoid irreversible accumulation.

Indeed, the accumulation of greenhouse gases in the atmosphere is effectively irreversible on any reasonable policy timescale, even though it may not be literally irreversible. If emissions stopped tomorrow, atmospheric concentrations of carbon dioxide will remain at

[55] See especially Chichilnisky (2000), Heal (2007), Henry and Henry (2002), and Weitzman (2007).

elevated levels for centuries, if not longer. Furthermore, the climate system is complex, non-linear and dynamical, meaning that it is thought to have several sets of initial conditions from which it moves to a different equilibrium. If emissions of greenhouse gases perturb it sufficiently to push it out of one 'basin of attraction' and into another (Heal and Kriström), then the change can be physically irreversible on any time frame. Examples might include a shut down of the North Atlantic Thermohaline Circulation, a melting of the West Antarctic Ice Sheet, and a 'dieback' of the Amazon rainforest.

But, crucially, we need to consider several possible irreversible commitments with different effects on interim carbon-emissions policy. The atmospheric accumulation of greenhouse gases is irreversible in a technical sense, but so, in an economic sense, are (ii) investments in 'dirty' capital that emits greenhouse gases (e.g. coal-fired power plants) and (iii) investments in abatement capital (e.g. nuclear power plants). There will in theory be a value derived from avoiding making each of these irreversible commitments, which is often loosely called an 'option value'.[56]

## Ancillary benefits

A simplifying assumption in the literature on learning and its effect on the timing of emissions reductions is that there is no benefit to early action to reduce emissions, if we later discover that climate change is not damaging. However there will in fact be a number of so-called ancillary benefits to reductions in greenhouse gas emissions, including in some instances for energy security and air quality.

## Technical change

Another important issue to the timing of emissions reductions is innovation of new technologies that produce fewer greenhouse gas emissions than incumbent technologies. Here, it is possible to distinguish between two quite different views of how technical change affects the recommended timing of cuts.

On the one hand there is the view, expressed in Wigley *et al*. (1996), that the possibility of innovation should cause us to delay more stringent emissions reductions, because in the future we will be able to exploit new technologies to reduce emissions more cheaply. Early expressions of this view in the literature tended to assume that technical change is unaffected by decisions on climate policy (i.e. is exogenous). Subsequently, attention has focused on the ways in which policy can stimulate endogenous technical change or 'induce' it. Nevertheless, economic approaches to endogenous technical change that emphasise basic R&D as the driver of cost reductions also support the view that stringent emissions reductions should be delayed (Goulder and Mathai, 2000). This is rather obviously because it is more efficient to channel efforts into R&D in the short term and undertake more rapid abatement once the fruits of the R&D, cheaper low-carbon technologies, have emerged.

On the other hand there is the view that endogenous technical change occurs through learning-by-doing, which implies that the costs of low-carbon technologies only fall with actual deployment or experience/learning. Goulder and Mathai (2000) also included learning effects in their study and found that such effects could support a high carbon tax rate (i.e. more stringent emissions reductions) in the near term (see also Grübler and Messner, 1998; Rosendahl, 2004; van der Zwaan *et al*., 2004).

[56] Technically in environmental and resource economics a distinction is drawn between an 'option value', which is essentially a risk premium on the benefits of avoiding an irreversible investment where the value of that resource is *ex ante* uncertain and the decision-maker is risk averse, and a 'quasi-option value', which is essentially a learning premium – the expected value of information – on avoiding making an irreversible investment where better information about its future value is anticipated. However, there are different uses of the terminology in the literature (for example the real options literature does not use the term quasi-option value).

At present, the economic literature on technical change and climate policy is split between R&D and learning perspectives. IPCC Working Group III emphasises in the recent *Fourth Assessment Report* that the processes and pace of technical change remain uncertain and generally will not be drawn on which of the two approaches is best supported:

> "all…the sources of induced technical change…play important roles in technological advance." (Fisher *et al*., 2007, p223)

A recent paper by Gerlagh *et al*. (2008) points out that the debate also depends on what policy instruments are available. If policy-makers can correct market failures in environmental R&D with specially tailored instruments, then it is possible that the argument for delaying emissions reductions holds. If, on the other hand, policy-makers are limited to simultaneously trying to correct market failures in the whole of the R&D sector (environmental technologies, pharmaceuticals, defence etc.), it may be necessary to use stringent emissions reductions in the near-term to induce technical change in the longer term.

### Transient temperature change and overshooting

Although many emissions pathways are possible that lead to the same long-term target, they do not lead to the same profile of temperature change. The greater are emissions in the near term, the faster is the rate of transient temperature change. There are two consequences of this. First, more rapid climate change increases the demands on adaptation, including feasibility (especially for natural systems that are particularly sensitive to the required rate of adaptation) and cost. Second, overshoot pathways that cause transient global temperatures to exceed those expected to correspond to the long-term target increase the possibility of crossing certain irreversible thresholds or 'tipping points' in the climate system, such as those triggering melting of the Greenland and West Antarctic Ice Sheets.

### Other greenhouse gases

It is generally recognised that control of a wider set of greenhouse gases can lead to the achievement of any given long-term emissions target at lower cost, compared with control of $CO_2$ alone.[57] This also raises the issue of how reductions in the emissions of various greenhouse gases should be sequenced. The flow target for emissions of $CO_2$ in 2020 could rise or fall depending on how much abatement of non-$CO_2$ greenhouse gases takes place in the near term.

### Attitudes to risk and intergenerational equity

Binding all of these issues together in any methodological approach are assumptions about the structure of the decision-making problem and, within that structure, key value judgements, especially on the decision-maker's preparedness to take risks and to trade-off the costs and benefits of policy today with those in the future. The various approaches differ in the extent to which these issues are modelled explicitly and formally, and (partly as a result) also place their emphasis on different aspects of the decision problem.

Loosely speaking, a risk-taking decision-maker little concerned with intergenerational equity might choose to delay substantial emissions reductions; a risk-averse decision-maker much concerned with intergenerational equity might make more intense and earlier emissions cuts in order to preserve options for future generations.

[57] See Weyant *et al*. (2006) and various contributions to Special Issue Number 3 of *The Energy Journal.*

## Investigating option values in detail

An option value can arise when the future outcomes from a decision are uncertain, when there are irreversibilities and asymmetries arising from the decision and where there is the possibility of learning (i.e. gaining information that could change the decision so as to improve the likely outcomes).

This means that it may be worth keeping open options for the future, even if today's best guess suggests that doing so is not 'optimal' on the basis of expected costs and benefits. In general, option values increase the greater the level of uncertainty over future pay-offs. This is because the greater the level of uncertainty, the more likely it is that a currently unattractive course of action may later turn out to have a positive pay-off. Under complete certainty, it would never make sense to choose a course of action that was expected on the basis of today's knowledge to have a negative pay-off.

Appendix 3 identifies three technical and economic sources of option value relevant to climate change decision-making arising from i) the atmospheric stock of greenhouse gases, ii) the stock of 'dirty' capital that emits greenhouse gases, and iii) the stock of abatement technologies. Another less tangible source of option value could be uncertainty over the target to be set for the UK under the EU burden-sharing agreement, since the UK will be setting its own domestic target prior to learning its EU-level obligations.

Two such potential sources of option value are presented here for illustration. Figure 4.1 illustrates that if the ability to respond to new information regarding the optimal level of abatement is asymmetric (i.e. if it is harder to accelerate abatement than to slacken off), then this can lead to a different choice prior to learning. In part A of the diagram, the abatement level is chosen to be 'optimal' in the sense that it that balances the expected costs and benefits of abatement. These expectations are based on current knowledge, but are uncertain. It is assumed that at some point in the future, there is a 'learning event' at which improved information about the optimal level of abatement is revealed. This learning event reveals either that the abatement level should be more stringent (red line) or less stringent (green line) than previously expected. Given inertia in the economy, the actual abatement path that could be achieved in response to this learning event is shown by the dashed blue lines. These abatement responses lag behind the 'ideal' red or green line, and the shaded areas give a measure of the losses incurred as a result of these lags.

In the diagram, it is assumed that the response rate for increasing abatement effort (i.e. moving up to the red line) is slower than the response rate for reducing abatement (i.e. moving down to the green line). Such an asymmetric response to learning would mean that the path which looks 'optimal' given *a priori* expectations will actually lead on average to under-abatement (i.e. higher than optimal emissions), indicated by the fact that the pink shaded area is greater than the green shaded area.

In part B of the diagram, an alternative 'hedging' strategy is illustrated which starts out with a more ambitious level of abatement. Given the same asymmetric response to learning, the hedging strategy equalises the chances of either over- or under- abatement resulting from the lags.

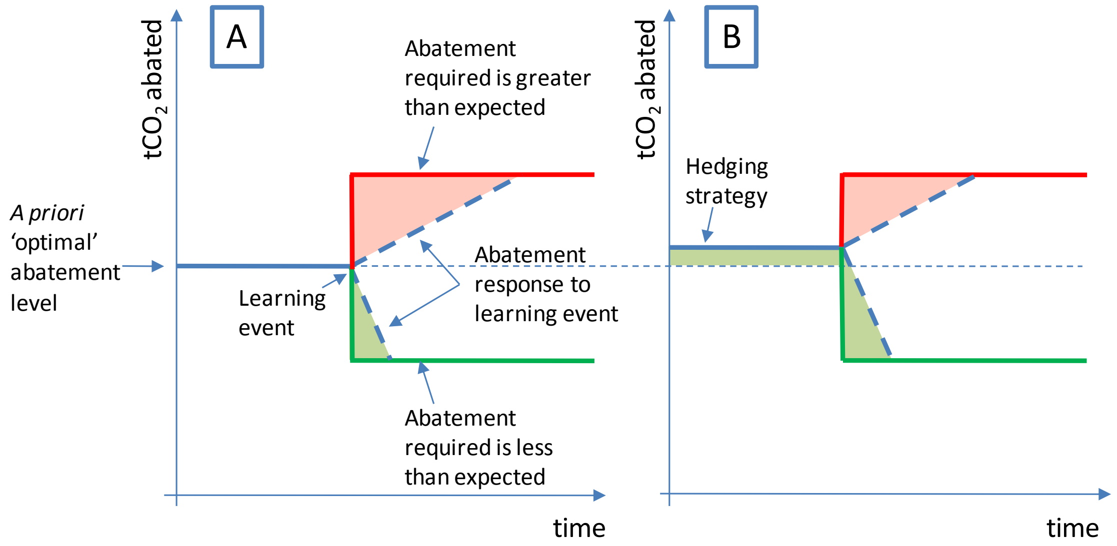


**Figure 4.1 Schematic illustrating option value of a hedging strategy. A] indicates a strategy that follows an *a priori* optimal level of abatement. B] indicates a hedging strategy that takes into account asymmetry in the feasible response to a learning event in the future.**

Figure 4.1 is a simplification, but serves to illustrate some general points about option value under uncertainty. Firstly, the greater the range of uncertainty, and the greater the extent of the asymmetry / non-linearity associated with this uncertainty, the greater the option value is likely to be. Secondly, the timing and 'quality' of the learning event is important. The more distant in time the learning event, the more costly it is to keep the option open. In this case, an earlier learning date would result in a higher option value (i.e. more incentive to take the hedging strategy).

A more detailed analysis of hedging strategies would also need to take into account the impact on cumulative emissions. For example, the cumulative emissions in the hedging strategy in Figure 4.1B are lower than the cumulative emissions in Figure 4.1A. A fair comparison of the costs of two different strategies should be made on the basis of equal cumulative emissions over some period. In other words, the under-abatement 'losses' associated with the pink triangles could be made up for by overshooting the red lines at later times. The degree of overshoot above the red line would need to be higher in case A than in case B (and *vice versa* for undershooting the green line). Given a non-linear increase in marginal abatement costs, the reduced overshoot of the red line in case B relative to case A could lead to an additional component in the value of this hedging strategy.

Appendix 4 outlines further methodological approaches to option valuation, and considers the government's decision problem under three different levels of complexity:

1. Assuming the decision is essentially a 'static' decision process. In this case, government makes a single irreversible decision now in setting a target for 2020 emissions. It then learns what will be required of it for future emissions (in say 2050), and has to meet these 2050 targets whilst living with the consequences of its earlier decision for 2020. The 'option value' in this case simply reflects the balance of emission reduction efforts (and costs) before and after 2020. Greater effort pre-2020 may be more expensive, but could be justified if there is a sufficiently high probability that the 2050 target will turn out more stringent than expected.
2. In a more dynamic decision process, government is able to tailor its decisions according to expected flows of information. In this situation, there may be a value in keeping options open on the basis that better decisions can be taken in the future because there

will be more information available (e.g. through developments in climate science and understanding of technology costs) on which to base the decisions. As discussed above, this would require an analysis of whether decisions taken now might foreclose various future options. A dynamic options analysis could also inform the value of policy flexibility; for example, targets may be set in such a way that they can be altered subject to announcements regarding emissions reduction targets at the EU-level.

3. An additional level of complexity that could be considered is that the decisions taken by the UK government are not taken in isolation, and may affect the choices of other decision-makers. For example, government is simultaneously aiming to send long-term signals to domestic investors, whilst also responding to EU-level and other international negotiation processes. It cannot respond to one set of players without sending signals to the other set. The role of flexibility, leadership (e.g. the impact of UK targets on international ambition levels) and the way in which companies and governments both learn from each other's behaviour in the market are other issues that could be included in the analysis.

### Illustrative assessment of Option Value in the choice of emissions pathway

For any given long-term emissions target (e.g. stabilisation at 550 parts per million of carbon dioxide equivalent – ppm $CO_2e$), it can be relatively straightforward to calculate a path of $CO_2$ emissions to the target using a simple model of the carbon cycle, which links the annual flow of emissions with the accumulation of a stock in the atmosphere. For other greenhouse gases, the approach is similar. This is all that is necessary to identify feasible emissions trajectories, feasible only in the sense of achieving the long-term target according to the global physical and chemical cycling set out in the model. However, economic and technical factors that restrict the set of feasible emissions pathways are likely to be more important.

From this, two observations can already be made, illustrated in Figure 4.2 for a particular model. First, the rate of emissions reductions required to meet a given long-term target is very sensitive to the timing of the peak in global emissions. For example, if those emissions peak at 48 gigatonnes (Gt) of $CO_2e$ (the 'low' peak) in 2020 rather than in 2040, the maximum rate of emissions cuts required thereafter is only 1.5% per year rather than 3% (comparing a 'high' peak of $52GtCO_2e$ in 2020 with the same in 2040, the corresponding rates are 2.5% and 4.5%). So, all else equal, the consequence of delayed effort now is greater effort later. Second, it is equally very sensitive to the height of the peak. For example, if emissions peak at 48Gt $CO_2e$ in 2020, rather than 52Gt $CO_2e$, the maximum rate of emissions cuts required after 2020 is reduced from 2.5% per year to 1.5%.[58]

This rate of emissions decline is important because a key factor affecting the technical feasibility and cost of emissions reductions is inertia in the economy. Capital linked to emissions of greenhouse gases such as energy-generation and transport infrastructure can last for many decades. The faster it is replaced, the more of the capital stock will be replaced prematurely, the greater is likely to be the cost of emissions reductions. Conversely, decisions not to replace 'dirty' capital can lead to many years of further 'lock-in' to that particular capital.[59]

[58] Example from the Stern Review, chapter 8.
[59] See for example Foxon (2007).

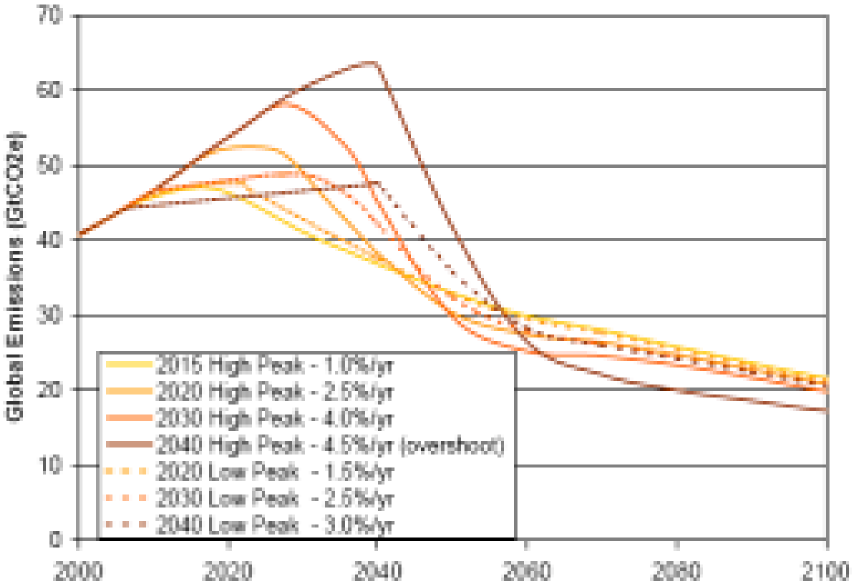


**Figure 4.2 Different global emissions pathways to stabilisation at 550ppm $CO_2$e (source: Meinshausen *et al*., 2006). The rates of emissions reduction are maximum ten-year average rates, which are typically made in the ten years after emissions peak, as the figure indicates.**

Following on from this, such analyses can also be used to identify emissions trajectories that are infeasible (primarily due to economic/technological constraints). For example, in the model behind Figure 4.2 it is judged impossible to stabilise atmospheric concentrations of greenhouse gases at 450ppm $CO_2$e if global emissions peak as late as 2020. This is due to an economic/technical constraint on the maximum annual rate of emissions reductions. Similarly, 500ppm $CO_2$e is unachievable if emissions peak as late as 2040. This analysis largely underpinned the Stern Review's conclusions regarding the necessary timing and magnitude of emissions cuts to stabilise atmospheric concentrations within the range it identified as desirable: 450-550ppm $CO_2$e. Such models can also inform 'hedging' approaches to setting near-term targets under uncertainty as discussed above.

This type of optionality is explored further in Appendix 2. This work does not include a full economic analysis of option value, but attempts to identify the extent to which option value could be important by looking at how different the rates of change in emissions would have to be along different paths. The rate of change of emissions is likely to be linked to the cost (higher rates of emission reductions being more expensive due to capital stock inertia, and constraints on the rate of learning in technology cost reduction), so identifying differences in these rates acts as a proxy for a full cost analysis. Appendix 2 therefore aims to identify the likely extent of differences between pathways with respect to two types of uncertainty:

- **Uncertainty over the UK's 2050 targets**. The analysis looked at whether the choice of 26% vs. 32% for 2020 could affect the achievability of 60% or 80% in 2050, this being the proposed range of reductions for 2050 that the CCC is considering.
- **Uncertainty over global $CO_2$ concentration (stabilisation) targets**. The consistency of different UK-level 2020 and 2050 targets with global emission paths to see whether some choices might be incompatible with global stabilisation targets.

Regarding the first of these, illustrative UK pathways were constructed using various assumptions similar to those found in the literature regarding constraints on the annual rate of emissions decline, and constraints on the ability to accelerate this rate. It was found that if no constraint is placed on the ability to accelerate the emission reduction rate, then emissions pathways in the period 2020-2050 are not significantly different. The emission reduction rate required to achieve an 80% reduction in 2050 given a reduction of 26% in 2020 is 4.27% per year, compared to a rate of 4.00% per year between 2020-2050 given a reduction of 32% in 2020. However, if (as is done in the literature) a constraint is put on the ability to accelerate emission reduction rates (equivalent to a slow-response scenario representing inertia in the economy, financial markets and technology development), then a slightly more significant differentiation begins to emerge between the initial choice of 26% vs. 32%. In this case, the emission reduction rate between 2020-2050 has to be 4.5% per year given a reduction of 26% in 2020, compared to 4.0% given a reduction of 32% in 2020.

If a further constraint is applied which requires the cumulative emissions to 2050 to be equalised between different pathways, then a much more significant differentiation between the initial choices emerges. In this case, if an emission reduction of 26% is achieved in 2020, then emissions reductions in 2050 must be 88% in order to equalise cumulative emissions with the pathway which passes through 32% in 2020 and 80% in 2050. In this case, the emission reduction rate would need to be up to 6.8% per year in order to reach the 88% reduction.

Clearly the costs of this acceleration of effort would need to be assessed in order to evaluate the option value properly. Nevertheless, this initial analysis indicates that option value may be an important consideration, particularly if countries are bound by considerations of cumulative emissions rather than just meeting ‘spot value’ targets. Indeed, there is a strong environmental case for taking account of cumulative emissions, since this is a primary driver of final atmospheric concentrations. The CCC should therefore expect option values to be quite significant. In addition, when analysing UK-specific emissions paths (as opposed to stabilisation paths) account should be taken of cumulative emissions over several decades, not just a flow target in a specified year.

The second type of optionality concerns uncertainty over global atmospheric concentration targets, and the implications for UK-level emissions. For this analysis, illustrative emissions pathways using the Contraction and Convergence model of the Global Commons Institute[60] were constructed which suggest that the choice of UK targets for 2020 and 2050 could have quite strong option value since different domestic emissions-flow targets are compatible with different global atmospheric targets. In the contraction and convergence model, the relationship between UK emissions and global emissions depends strongly on the year of convergence of per capita emissions rights. To illustrate this, 3 different convergence dates were tested, 2040, 2050 and 2060. The following ranges for emission reductions reflect values for convergence in 2040 (more stringent UK reductions) and 2060 (less stringent UK reductions) respectively.

To be consistent with 425ppm $CO_2$ (approx 475-500 ppm $CO_2$e), this model suggests emission reductions relative to 1990 would have to be in the range 33%-42% by 2020, and 85%-88% by 2050. For a less stringent target of 475 ppm $CO_2$ (approx 550-575 ppm $CO_2$e), 2 emissions paths were investigated. For a path which peaks early but minimises the emission reduction rates later on, consistent UK targets could be 25%-35% in 2020 and 76%-81% in 2050. For a different path which peaks slightly later and has a more rapid decline rate after 2020, consistent emission targets for the UK would be 18%-29% in 2020 and 71%-78% in 2050.

These ranges are illustrated in Figure 4.3. The left-most end of each range (i.e. least stringent reductions for the UK) relates to convergence in 2060, whereas the right-most end of each range (i.e. most stringent for the UK) relates to convergence in 2040. The case with convergence in 2050 is shown by the solid bar.

[60] http://www.gci.org.uk/

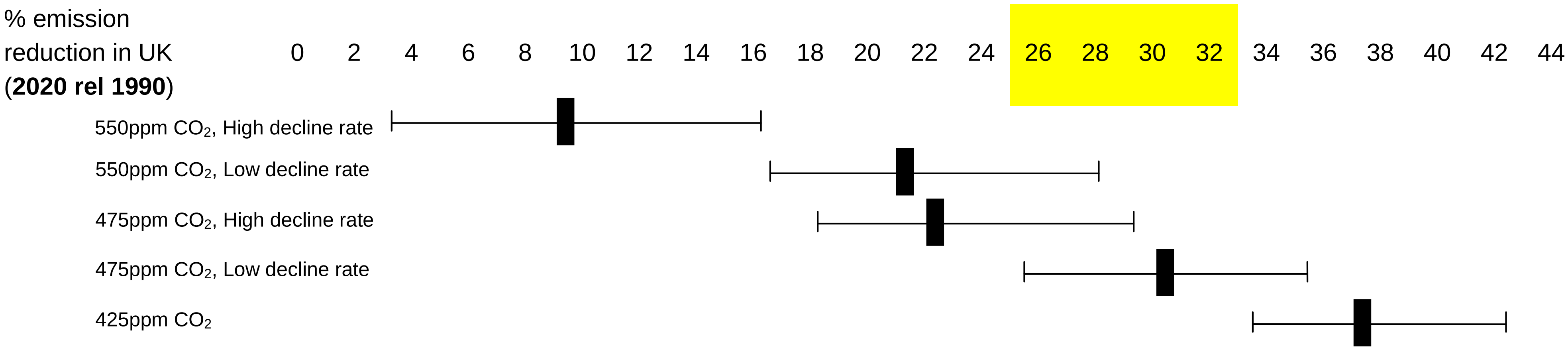


**Figure 4.3a Summary of relationship between UK 2020 targets and stabilisation concentrations (based on C&C model)**

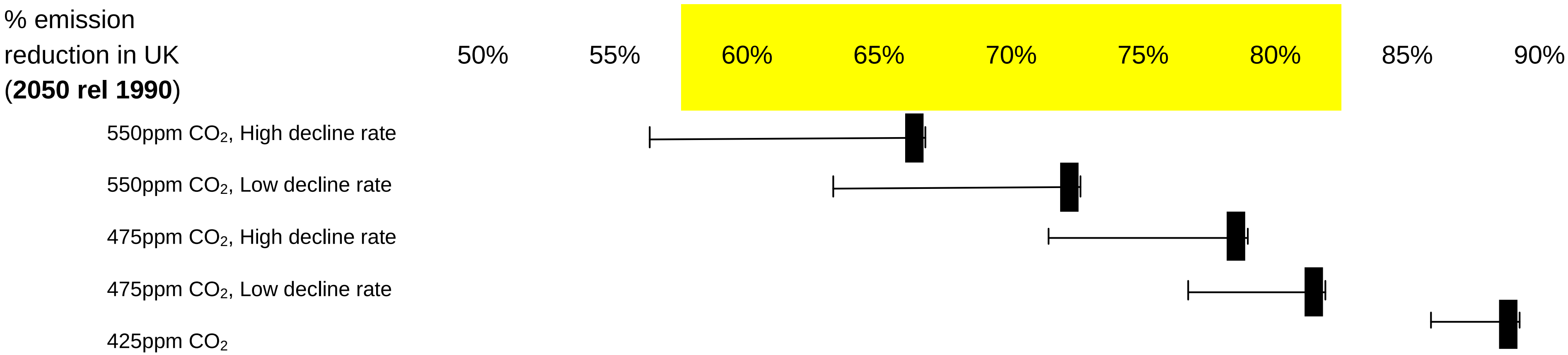


**Figure 4.3b Summary of relationship between UK 2050 targets and stabilisation concentrations (based on C&C model)**

**Note to Figure 4.3.** The purpose of these ranges is to illustrate sensitivity to a single variable. The lower, mid and upper end of these ranges refer to an assumption of convergence in 2040, 2050 and 2060 respectively in the Contraction and Convergence model. The ranges do not incorporate any other sources of uncertainty. Actual uncertainty over these ranges is therefore considerably greater due to several other important sources of uncertainty (notably climate uncertainty).

This analysis of consistent pathways suggests that there could be value in keeping open options to meet more stringent targets, based on the fact that different 2020 targets are consistent with different overall global concentration targets. Evaluation of this option value would require much more significant analysis of the costs and benefits of different stabilisation targets as discussed elsewhere in this report. In addition, this conclusion needs to be tempered with some important caveats:

- The actual values for the consistent UK targets illustrated here are derived from one form of architecture for allocating emissions rights. Other architectures would give different results.
- The UK emission reduction values depend on the assumptions. In the case of contraction and convergence, the convergence year is one sensitive variable. Other architectures will have their own sensitive variable that affect the result. Given the large range of possibilities, this type of analysis could give a wide range of compatible targets for the UK, although the range will tend to be tighter for the more stringent targets as there is less room for manoeuvre since all countries would be required to make very steep reductions.
- Option value only applies if there is a causal relationship between the decision being taken and the outcome being measured. In this case, the causal relationship between UK emissions and global emissions is weak. In other words, meeting a stringent UK-level target in 2020 does not necessarily buy the option of achieving a stringent global concentration stabilisation level. It is more accurate to say that it buys the UK a consistent bargaining position in the negotiation of future stabilisation levels, a lesser prize with consequently lesser (though not necessarily insignificant) option value.

## Implications of Emissions Trading for Setting 2020 Targets

Chapter 5 discusses the role of emissions trading in deciding how the 2020 target should be split between different sectors. In that Chapter, it is argued that for sectors within the emissions trading scheme, the number of allowances actually purchased from outside the UK to cover emissions (as opposed to making emission reductions within the UK) is outside the control of the government. The Chapter then looks at factors that affect the government's decision on how much they should engage in emissions trading on behalf of the remaining (non-trading) sectors.

In this section, we consider whether the existence of emissions trading affects the choice of the 2020 target itself. Although the total use of emissions trading is not something that the UK government can control, the existence of emissions trading could affect the 2020 choice for a number of reasons.

A first-order effect is that emissions credits from international emissions trading (e.g. AAUs, CERs, ERUs) are expected to be cheaper than the marginal cost of reducing emissions domestically within the UK. The reduction in costs associated with trading should enable governments to be more ambitious than would otherwise be the case, since the availability of cheap credits reduces the marginal cost of meeting more stringent targets. Indeed, a simple least-cost approach would suggest only committing to domestic emission reductions whose marginal cost does not exceed the expected price of international carbon credits, and to purchase the remainder required to meet the target. The question is, what should this target be? From a methodological point of view, the existence of an unlimited supply of credits at a particular price poses problems when it comes to setting targets. If the price of these credits is below what is deemed to be an acceptable price to pay (i.e. if they are deemed cost-effective), there is no rational way to decide what quantity should be purchased.

In addition to this methodological problem, governments tend to engage in policies that lead to emission reductions at costs well above the price of international credits. There are several reasons why governments might want to support domestic reductions over international purchases:

- Uncertainty over future credit prices. There are many factors influencing the price of credits, and there will also be a feedback between demand for credits and the price. This effect may not be strong if only one country were to set a high demand for credits, but if all countries set targets in this way, prices would surely increase. Uncertainty over price is one reason for reducing dependency on external credits.
- Policies supporting domestic emission reductions could have a beneficial feedback in terms of increasing investor confidence within the UK, and reducing the costs of delivering emission reductions compared to expectations. This type of positive feedback could be important if learning effects are expected to be significant.
- Encouraging abatement options domestically (instead of buying international credits) may be justified in terms of buying options for the future. Again, if learning effects are expected to be important, then early reductions could lead to cheaper long-term abatement options than would have been the case if targets had been met purely through trading. This may be countered to some extent by arguments in favour of engaging in emissions trading now in order to build institutional capacity and experience if use of credits is expected to be a feature of meeting UK targets over the long term.

Independent of the fact that emissions credits are expected to be cheaper, there is also an important second-order effect of emissions trading which could encourage governments to set more stringent targets. The cost of reducing emissions is likely to be strongly tied to the timing of major infrastructure decisions such as turnover of capital stock in the power generation, transport and buildings sectors. To the extent that these opportunities for abatement are ‘lumpy’, the costs of meeting an emissions reduction target at a fixed date will be very sensitive to the timing of these opportunities with respect to the target date. Emissions trading can help to smooth out these costs over time, by allowing banking and borrowing between what are essentially arbitrary time periods. This smoothing effect will reduce the cost of meeting a particular target at a fixed point in time when abatement costs are uncertain. How useful this option turns out to be will clearly depend on whether each five-year budget is binding, or whether banking and borrowing is allowed between budget periods.

In practice, the most useful way of thinking about the role of emissions trading is likely to be in terms of the flexibility it brings in responding to uncertain external factors. These might include for example unexpected changes in the economy, changes in technical costs of abatement options or shifts in the target imposed from outside the UK (an important example being the possible shift from a 20% GHG target to a 30% GHG target at the EU level). In other words, a pragmatic approach would be to set 2020 targets based primarily on an assessment of what could be achieved domestically at some cost that is deemed reasonable, and to use trading as a flexibility mechanism around that, taking account of the value of this flexibility to consider raising the stringency of targets[61].

[61] Also noting that in practice the level of emissions trading engaged in by companies in the trading sectors is outside of government control.

# Chapter 5 Political and Other Factors

The methods discussed above provide a firm analytical basis for making decisions. However, there are always a number of wider issues that need to be incorporated in any policy decision, i.e. frameworks such as cost-effectiveness and cost-benefit analysis are inputs to the decision making process, not a substitute for it. There is therefore a need to consider the additional issues that will be relevant for the CCC decisions, and how they can best be incorporated within a formal or non-formal decision making process. The most important of these other issues are:

- The political negotiations, especially with EU burden sharing. These are complicated by the nature of the EU proposals, with a lower starting level (20%) and a possible higher level (30%) dependent on the trigger of a stronger global position. The UK interim targets set by the CCC therefore dictate the negotiating position of the UK in these EU burden sharing agreements.
- Wider international negotiations, and also the stated aim of the UK to be influential in the arena of climate change (to *lead the global effort to avoid dangerous climate change*).
- The underlying scientific knowledge about climate change.
- The impact of any targets on the UK economy, on taxation, public spending or public borrowing, or on UK competitiveness (particularly in specific sectors).
- The social impacts of the targets, especially the potential impact on fuel poverty.
- The likely level of domestic action, and the availability of traded allowances.
- The contribution of traded vs. non traded sectors to the UK burden, allowing for any issues relating to supplementarity.
- Energy policy and the relationship with energy supplies and energy intensity, as well as other potential commitments (e.g. the EU renewables target).
- Other ancillary impacts or benefits.

A number of these, and how they could be included in the CCC decision, are discussed below.

## Burden Sharing

One of the most important of these additional factors is the EU targets and burden sharing negotiations. Even if the CCC decides on a higher 2020 target (towards 32% for example), e.g. on the basis of the methods advanced here, then there is still an issue on how to present the UK position at any European negotiations. This arises because of the two tier agreement, first in relation to a 20% unilateral EU target, and second, conditional on international action, the increase to a 30% target. Of course there are many additional complications if the latter occurs, as this would be associated with effectively a global deal of some type, and would change all of the considerations in relation to competitiveness issues, availability of CDM, etc. In very simple terms therefore, from a negotiating position, the UK might want to select a lower 2020 target initially (at or near 26%), consistent with the EU 20% target, to allow some headroom to increase this should the trigger for an EU 30% target come into force (i.e. to allow movement towards or up to 32%). Building in this type of contingency into the UK target may call into question UK government ambitions regarding global leadership on climate change (compared for example to going for 32% irrespective of EU targets). However, the credibility of setting UK targets that are entirely insulated from EU decisions also has to be questioned. It is probably better to explicitly incorporate this type of contingency into the targets than to make the option of such changes tacit, which would leave investors guessing whether or not targets would be revised according to international action.

Moreover, the EC itself has a methodology to allocate potential GHG reduction targets to individual Member States such as the UK. The proposed EC legally binding targets for non-EU ETS sectors and renewables are set out below. Alternative options have been proposed to share the overall level of effort from EU ETS sectors and are available from the EC[62]. Based on the EC proposals the UK would be required to achieve a 16% reduction on 2005 levels for non-ETS sectors by 2020 and a level of effort from EU ETS sector equivalent to a 28% reduction (based on the EC's preferred option). Note that the emission reduction targets are relative to 2005, not 1990.

***Table I Legally-binding targets for Member States***

| (1) | (2) | (3) |
|---|---|---|
| Targets 2020 | Reduction target in sectors not covered by the EU ETS compared to 2005 | Share Renewables in the final energy demand by 2020 |
| AT | -16.0% | 34% |
| BE | -15.0% | 13% |
| BG | 20.0% | 16% |
| CY | -5.0% | 13% |
| CZ | 9.0% | 13% |
| DK | -20.0% | 30% |
| EE | 11.0% | 25% |
| FI | -16.0% | 38% |
| FR | -14.0% | 23% |
| DE | -14.0% | 18% |
| EL | -4.0% | 18% |
| HU | 10.0% | 13% |
| IE | -20.0% | 16% |
| IT | -13.0% | 17% |
| LV | 17.0% | 42% |
| LT | 15.0% | 23% |
| LU | -20.0% | 11% |
| MT | 5.0% | 10% |
| NL | -16.0% | 14% |
| PL | 14.0% | 15% |
| PT | 1.0% | 31% |
| RO | 19.0% | 24% |
| SK | 13.0% | 14% |
| SI | 4.0% | 25% |
| ES | -10.0% | 20% |
| SE | -17.0% | 49% |
| UK | -16.0% | 15% |

Source: Impact Assessment: Document accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020.
http://ec.europa.eu/energy/climate_actions/doc/2008_res_ia_en.pdf

[62] EC (2008) Provisional Annex to the Impact Assessment of the Package of implementation relating to the EU's objectives on climate change and renewable energy for 2020,
http://ec.europa.eu/environment/climat/pdf/climate_package_ia_draft_annex.pdf page 60 - 61

**The "Climate action and renewable energy package": the European Commission's legislative proposal to achieve agreed EU objectives**

On 23 January 2008 the European Commission put forward a package of proposals to deliver on the European Union's commitments on climate change and renewable energy up to 2020.

Central to the strategy is a strengthening and expansion of the Emissions Trading System (EU ETS). Emissions from the sectors covered by the system will be cut by 21% by 2020 compared with levels in 2005. A single EU-wide cap on ETS emissions will be set, and free allocation of emission allowances will be progressively replaced by auctioning of allowances by 2020. The scope of the ETS would be extended with the inclusion of greenhouse gases other than CO2 and all major industrial emitters. National allocation plans would be replaced by auctioning or free allocation through single EU-wide rules. The allocations put on the market would be reduced year-on-year to allow for emissions covered by the ETS to be reduced by 21% from 2005 levels by 2020. Under the new ETS, companies will still have access to CDMs, but the use of credits generated by such mechanisms will be limited to the levels used in the current ETS period. This would leave room for access to this mechanism to be increased once an international agreement is signed.

Emissions from sectors not included in the EU ETS – such as transport, housing, agriculture and waste – will be cut by 10% of 2005 levels by 2020. Some of this would be driven by EU measures – like tougher standards on CO2 emissions from cars and fuel, and EU-wide rules to promote energy efficiency – but otherwise Member States would be free to determine where to concentrate their efforts, and what measures to bring into play to leverage change. Member States would also have access to CDM credits covering almost one third of their reduction effort. Each Member State will contribute to this effort according to its relative wealth, with national emission targets ranging from -20% for richer Member States to +20% for poorer ones.

National renewable energy targets are proposed for each Member State which will contribute to achieving the emissions reductions as well as to increasing the EU's energy independence. The targets should be fair, and take account of different national starting points and potentials, including the existing level of renewable energies and the energy mix, notably low-carbon technologies. The Commission's proposal is based on a methodology according to which half of the additional effort is shared equally between Member States. The other half is modulated according to GDP per capita. As long as the EU's overall target is met, Member States should be allowed to make their contribution by supporting Europe's overall renewables effort, and not necessarily inside their own borders: The targets include a minimum 10% share for biofuels in petrol and diesel by 2020. The package also sets out sustainability criteria that biofuels must meet to ensure they deliver real environmental benefits.

The EU goal of saving 20% of energy consumption by 2020 through energy efficiency is a crucial part of the policy.

The package also seeks to promote the development and safe use of carbon capture and storage (CCS), a suite of technologies that allows the carbon dioxide emitted by industrial processes to be captured and stored underground where it cannot contribute to global warming. Revised guidelines on state aid for environmental protection will enable governments to support CCS demonstration plants.

The Commission considers that with the right design, the costs can be kept to under 0.5% of GDP a year by 2020.

http://ec.europa.eu/environment/climat/climate_action.htm

It is highlighted that within this framework, the discussion of burden sharing and EU targets is an important one. Indeed, it could be considered central to the decision over interim targets. It will therefore be extremely important for the CCC to work through the EU methodology to derive the implied starting point of the negotiations for the UK. This will need to involve a direct comparison between the EU burden sharing assumptions and the UK 26-32% range in equivalent terms, as these involve different metrics and time periods, i.e. the EU GHG reductions on 2005 levels vs. the UK $CO_2$ reductions on 1990.

## The Split between Trading and Non-trading Sectors

In principle, a least cost division of the overall UK-level carbon budget between different sectors can be achieved quite straightforwardly by looking at the expected marginal abatement costs for the different sectors, and dividing the burden of effort between the sectors on the basis of equal marginal cost. Appendix 5 (Part B) provides a detailed discussion of MAC curves, how they are derived from models and how they should be interpreted. A summary of this approach is illustrated schematically in Figure 5.1 for two sectors. The figure also indicates how access to trading might influence the extent to which emission reductions are delivered domestically vs. through purchase of external emissions allowances.

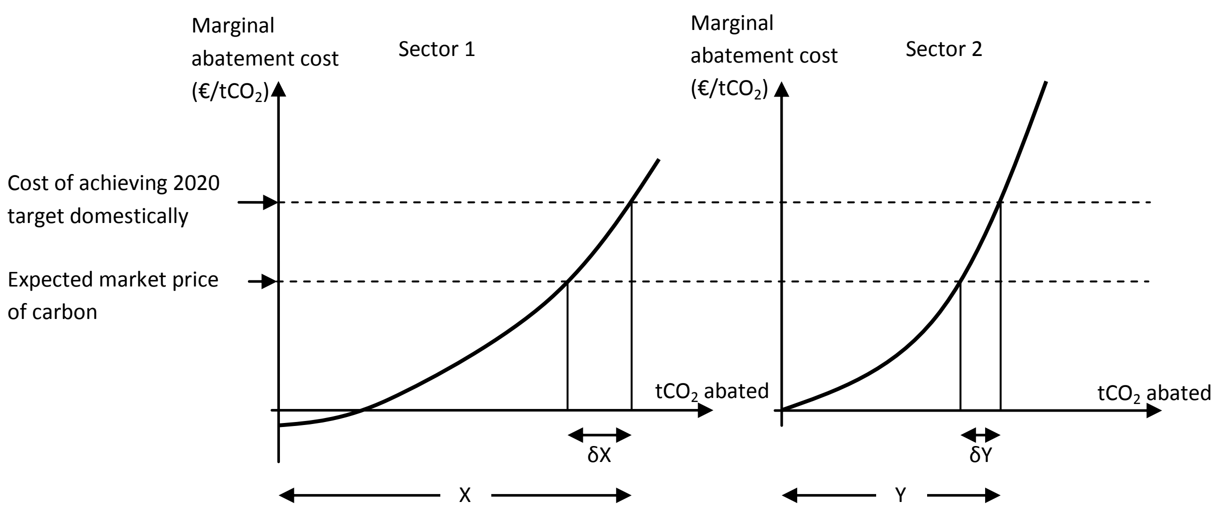


**Figure 5.1 Division of target on an equal marginal cost basis**

The combined delivery of emission reductions from Sector 1 and Sector 2 is (X+Y) which can be set to equal the overall UK emissions budget by adjusting the upper cost line. However, supposing the cost of achieving this overall target is greater than the prevailing or expected $CO_2$ price for the period. In this case, the actual delivery within the UK would be reduced to (X+Y–δX–δY), since Sector 1 would be incentivised to buy allowances to cover δX, and Sector 2 would be incentivised to buy allowances to cover δY. This approach therefore indicates both an appropriate sectoral split and level of trading.

In principle, this approach works for any number of sectors, so long as there is a MAC available for each sector. However, in practice, this relatively simple approach is complicated by a number of factors.

Closely related to the issue of trading is that of "leakage". This is a subject of considerable debate at present, particularly in relation to the relocation of energy intensive industry, and the carbon emissions from international supply chains. This is also an emerging issue at the European level in relation to the future ETS, and issues such as border tax adjustments. These are potentially important, and it is recommended that the CCC investigate these issues and consider the implications for the UK targets.

### Renewable Energy Support

The EU Commission has recently announced a package of renewable energy and climate proposals that would require a major expansion of renewable electricity generation across the EU, to an extent that is likely have a considerable effect on overall emissions levels in the trading sector. These investments in renewable energy are likely to be underpinned by specific policy support measures, in the form of feed-in tariffs, supplier obligations or other forms of subsidy. Most of the renewable energy projects brought forward by these policies would be located above the expected market price of carbon in the MAC curve. Since these projects will be mandated by policies other than the carbon price, they will effectively enter the MAC curve on the left-hand side, shifting the rest of the curve to the right. This is equivalent to subsidising emission reductions. At the EU level, shifting the MAC curve to the right means that any particular EU target will be met with a lower carbon price than would have been the case without the renewables (although the overall policy cost including the cost of the renewable energy will be higher overall). This has the effect of reducing the carbon price in the EU-ETS.

Emission reductions within the UK will also be affected in a similar way. By achieving more through renewable energy projects, less will be required from other measures, such that the additional cost of achieving the UK targets (over and above the costs of meeting the renewable targets) will be reduced. This reduced cost would be used to read across the relative contributions from different sectors as shown previously.

Whether or not this affects the number of allowances purchased depends on the relative drop in the EU carbon price compared to the drop in the cost of delivering the UK target (over and above the UK renewables policy costs). This will depend on the shapes of the MAC curves and the amounts of renewable energy entering the system in the UK and EU.

### Equity and Competitiveness

The assumption that domestic costs for meeting the 2020 targets will be higher than the expected market price of carbon is essentially an assumption that the UK ambition levels are higher than the EU-average. Under the method described above, the burden of achieving this greater-than-average ambition level depends on the shape of the MAC curves in the different sectors. For example, in Figure 5.1, Sector 1 has to purchase more than Sector 2 ($\delta X$ is greater than $\delta Y$) because the slope at that point in the MAC curve is steeper. However, this division of the burden of purchasing additional allowances does not in fact affect whether the solution is least-cost. As long as the total purchases are equal to $\delta X + \delta Y$, then there will be a least cost solution.

The burden of purchasing allowances could therefore be shared using different criteria, for example, according to the exposure of the different sectors to international competition, or other measures of the relative ability of the sectors to absorb the additional costs of achieving the greater-than-average ambition levels.

Access to emissions trading is itself a valuable asset to companies. The ability to buy or sell allowances allows companies to optimise the timing of their investments according to the specific business opportunities in their sectors rather than being driven by the timing of environmental legislation. This flexibility reduces compliance costs irrespective of the absolute cost differences between market prices and the technical costs of domestic delivery. The value of trading could therefore also be factored into the sectoral split, with trading sectors taking more of the burden and non-trading sectors (i.e. sectors without access to international credits) taking less. This may be particularly important if the abatement costs are very uncertain, since the value of flexibility will increase if the uncertainty is higher. These uncertainties may apply to the technical costs of abatement, or they could relate to uncertain growth rates or uncertainty about structural effects that could influence the emissions profile.

## EU-level target setting

The Commission's proposed package "20-20-20 by 2020" include a substantial degree of central control over sector allocation. Under phase III of the EU-ETS, a harmonised approach to allocation is proposed, whereby the Commission would determine the number of allowances that countries were able to auction (with power generation sector required to purchase all their allowances), and the number of free allowances allocated to the remaining sectors also determined centrally. The proposals would lead to a 21% reduction in emissions from the covered sectors by 2020 relative to 2005.

The package also includes proposed legally-binding targets for emissions reductions in the non-trading sectors (averaging 10% for the EU-27, and 16% for the UK relative to 2005). These reductions together with the reductions in the EU-ETS sectors lead to approximately a 20% reduction in GHG emissions by 2020 relative to 1990. The package assumes that if the EU target has to be increased to 30% relative to 1990 following agreement of an international agreement (as agreed by the 2007 Spring Council), then the difference would largely be made up with increased purchases of CDM credits.

Target setting for the UK trading sector (representing approximately half of UK emissions) may therefore lie in the hands of the Commission rather than the UK government, and will not necessarily follow the above approach of equalising marginal costs. To the extent that the CCC knows in advance of its decision in September 2008 what the UK's likely allocation of allowances will be, it can factor this into its recommendations about the likely split between sectors. Nevertheless, this process creates a potential risk for the UK, since unilateral decisions made now within the UK may be overtaken by events in the negotiation of these EU-level targets.

## Use of Emissions Trading by the UK Government

In terms of the trading sectors[63], the UK government is not in control of the extent to which emissions abatement is delivered within UK national boundaries and how much is purchased from the EU-ETS. This balance will depend on commercial decisions being taken by companies in the choice of investments they make and the way they operate their plant. Nevertheless, the target set for the trading sector should be considered as contributing to the UK target whether or not it is delivered domestically.

[63] This includes sectors that are within the scope of the EU-ETS, and may or may not include companies that are in the UK-ETS depending on the rules for use of CDM / JI credits in that scheme

For the sectors that do not have access to external allowances to meet their targets, the government needs to decide how to deal with a potential difference between the cost of achieving the 2020 target and the expected price of carbon in the trading sectors. Supposing 'Sector 2' in Figure 5.1 represents the 'non-trading' sectors (i.e. sectors without access to international emissions credits[64]). In setting a target for the non trading sectors equivalent to Y in figure 5.1, the delivery cost of these emission reductions would be higher than the effective delivery cost in Sector 1. There are various solutions to this problem:

i. Depending on what this cost differential is, and given the level of uncertainty over what the actual costs of abatement are in different sectors, the government might decide to tolerate possible cost differentials between sectors, and simply not allow any use of international credits in the non-trading sectors.

ii. The government can construct UK-level emissions trading schemes in which the "non-trading" sectors have access to international credits to meet their emissions targets (the proposed Carbon Reduction Commitment and a new phase of the Climate Change Agreements with the flexibility to buy CRC or EU ETS allowances are consistent with this approach).

iii. The government could decide to set the overall target for Sector 2 as (Y-δY), and purchase credits itself on international emissions trading markets to cover the difference δY on behalf of the sector.

iv. The government could decide to set the overall target for Sector 2 as (Y- δY), and require Sector 1 to purchase the additional amount δY. This would still equalise marginal costs, but would lead to greater overall costs in Sector 1 than the other two solutions. This could be justified to some extent by the fact that companies in an emissions trading scheme can effectively bank and borrow, smoothing out costs over time. This solution would depend on equity and competitiveness issues raised above.

In addition to these basic economic considerations, there are a number of other factors that could be taken into account when considering the extent to which the government should rely on external credits to meet the UK target on behalf of the 'non-trading' sectors that do not have access to international emissions allowances to meet their targets. These relate to the consideration of uncertainty in the price of international credits, the value that use of credits provide in terms of increased flexibility, and the political / strategic importance of engaging in international emissions trading.

- The choice of whether to purchase allowances or make domestic emission reductions should involve not just a single scenario of expected costs at a given time, but should be a dynamic decision that takes into account cost and price uncertainties and recognises the potential for governments to adapt to new information regarding these uncertainties. For example, a decision to support domestic measures with a higher cost than the expected market price could act as a hedge against possible market price rises and/or greater than expected stringency of future targets. On the other hand, purchasing credits could be a robust strategy if there is the possibility of significant new information on costs of abatement, or if the costs of domestic emission reductions are particularly sensitive to their timing, in which case the use of trading could provide valuable flexibility. These types of dynamic decision-making criteria are discussed in more detail in Chapter 4 and Appendices 4 and 5.

[64]. The largest sectors in this category will be domestic (i.e. housing) and transport.

- If target setting is to be carried out largely at the EU level, then the UK government may wish to engage in trading as a tool to manage delivery of UK targets in two main respects. Firstly, if the UK has information about the balance of pre-2020 and post-2020 costs which are not factored into the targets set by the Commission, then trading could be an appropriate way to smooth out these costs. This could include buying credits, but could also in principle include selling credits (through the JI route) if UK the balance of pre- and post-2020 costs suggests that it would be sensible to overshoot the targets set by the EU. Secondly, given that the EU is quite likely to change from a 20% GHG target to 30% GHG target (contingent on signing an international climate agreement), then the UK government may well want to keep open the option of trading as a way of maintaining the flexibility to accommodate this shift in the target.
- The decision on trading sends contrasting political messages to different audiences. Purchasing international credits indicates faith in the general principle of emissions trading as well as in the integrity of the particular markets. On the other hand, investing in emission reductions domestically indicates that the government is committed to getting the economy onto a more sustainable footing, and perhaps strengthens the credibility of any attempt to take a leadership role in international negotiations. If it is considered important that the government is seen to be supporting both types of action (i.e. international credits and domestic action) then the CCC might consider recommending an explicit target for UK participation in carbon markets separately from the domestic target. Such a target would be based primarily on considerations of an appropriate UK contribution rather than on domestic cost effectiveness considerations. It should be noted however that having two separate targets would reduce the flexibility benefits associated with trading described in the previous bullet point.

## Air Quality (Ancillary) Benefits

Many studies have shown that air quality ancillary benefits of GHG mitigation may be a significant benefit, offsetting a substantial proportion of mitigation costs (OECD, 2000, Defra, 2002).

Whilst the full benefit of GHG reductions resulting from further climate action may only be experienced by future generations, the ancillary benefits of climate policy accrue to the current generation. These ancillary benefits are larger for more ambitious interim targets, i.e. a 32% target will achieve greater ancillary air quality benefits in the short-term than a 26% target.

A summary of ancillary benefits was previously undertaken by Defra (Pittini, 2002). The estimates range from £ 2 per tonne of carbon reduced to £334 per tonne of carbon reduced. The average ancillary benefit, calculated from all studies presented in the table is approximately ~£70/tC per tonne of carbon reduced[65]. Another recent study concludes that about 50% of the costs of the Kyoto target can be re-gained in terms of reduced costs of air pollution control.

The Defra study recommended against using any of the above figures in terms of ancillary benefit per tonne of carbon, as ancillary effects are policy-specific and location specific. It is also

[65] Studies differ because of differences in methodology, analysis techniques and damages included. Thirteen out of twenty estimates of ancillary benefits from the literature are below £50 per tonne of carbon reduced and studies concentrating purely on health impacts from a limited selection of pollutants tend to report the lowest estimates. Studies considering a wider range of pollutants and additional impacts such as materials damage, visibility and vegetation damage generally report higher ancillary benefits.

necessary to keep ancillary effects separate, as these should be covered in existing appraisal (for example, ancillary benefits from air pollution will be picked up separately as part of existing transport appraisal).

Recent work in the DG Environment Clean Air For Europe project (Amann et al, 2006) showed that reducing $CO_2$ emissions in the EU by 10 % by 2020 would generate large health benefits (estimated at € 8 to 27 billion).

More recent work by the CAFE CBA team (Pye et al, 2007) has looked at the benefits of Air Quality Strategy of the new EU 20% GHG reduction and renewable target, at EU and MS level. Under the PRIMES energy projections CLE baseline, the total annual damage associated with quantified health impacts in 2020 in the EU27 is approximately €162 to 516 billion: the value for the UK is €17 to 47 billion. Under the proposed European air quality policy (Thematic Strategy on Air Pollution), the values in 2020 fall to €144 to 457 billion, and for the UK €15 to 41 billion . Therefore, the annual benefits of air quality policy are €18 to 58 billion per year over the baseline in the EU, and €1.9 to 5.2 billion in the UK. The analysis has also been able to investigate the impact of climate and renewable policy, as the EU 20% GHG reduction target also has an implementation date for 2020, and there are strong interactions between the two. The CAFE CBA analysis looked at the co-benefits of climate policy (which is included in the PRIMES coherent baseline). These are estimated at €29 to 94 billion per year for the EU and €2.3 to 6.4 billion per year for the UK.

**Table 5.1. Annual health benefits in 2020 of meeting environmental objectives – TSAP (modified and European parliament proposals (relative to CLE baseline).**

Top Lower estimate with mortality valued using the median VOLY (€million)
Bottom Higher estimate with mortality valued using the mean VOSL (€million)

| | National projection | | PRIMES coherent projection | | Co-benefits of PRIMES coherent projection* | |
|---|---|---|---|---|---|---|
| **Country** | **TSAP-OPT** | **EP-OPT** | **TSAP-OPT** | **EP-OPT** | **TSAP-OPT** | **EP-OPT** |
| United Kingdom | 4,241 | 4,853 | 1,910 | 2,606 | 2,331 | 2,247 |
| **Total (EU27)** | **47,243** | **53,533** | **18,222** | **25,517** | **29,021** | **28,016** |

| | National projection | | PRIMES coherent projection | | Co-benefits of PRIMES coherent projection* | |
|---|---|---|---|---|---|---|
| **Country** | **TSAP-OPT** | **EP-OPT** | **TSAP-OPT** | **EP-OPT** | **TSAP-OPT** | **EP-OPT** |
| United Kingdom | 11,771 | 13,461 | 5,299 | 7,222 | 6,472 | 6,238 |
| **Total (EU27)** | **151,974** | **172,070** | **58,305** | **81,662** | **93,668** | **90,408** |

In addition to these health benefits, there may also benefits to man-made and natural environment, including crops, building materials, and very importantly, ecosystems.

## Assessing UK Air Quality Benefits

The estimation of air quality externalities is well advanced in the UK, and existing values are in place in UK Government for appraisal. The most recent published UK Government (Defra) analysis has been for the Air Quality Strategy Review (AQSR), published by the IGCB (the Inter-Department Group on Costs and Benefits) in April 2006 and updated in July 2007[66].

[66] http://www.defra.gov.uk/environment/airquality/publications/stratreview-analysis/index.htm

The AQSR undertook a detailed analysis of the economic benefits of air quality proposals, using a detailed bottom-up approach that modelled emissions and air quality concentrations; known as the impact pathway approach. This was advanced through the ExternE study (Friedrick et al, 2006), and used in recent policy analysis for DG Environment in CAFE (Clean Air For Europe) (Amman et al, 2005: 2006; Holland et al, 2005: 2006[67]) as well as the UK Air Quality Strategy Review (though the exact methods vary between EC and UK analysis). The method is summarised in the box below. key strength is that it evaluates physical impacts and then quantifies these impacts in economic costs, through a logical chain looking at burdens (e.g. emissions), through dispersion and exposure to quantification of impacts and valuation, i.e. the impact pathway approach.

Given the potential scale of change from the OCC targets, e.g. from a 26 to 32% carbon reduction by 2020, we recommend that a full impact pathway analysis could be justified to quantify and value the ancillary benefits of the interim targets.

However, it would also be possible to test the potential benefits across the range using damage cost estimates. Damage costs provide a way to approximately estimate the impacts and monetary values of changes in air pollution emissions. They provide values for the marginal external costs caused by each reduced tonne of pollutant emitted, estimated from underlying impact pathway studies.

Alongside the AQSR analysis, a set of damage cost values for the UK has been produced (Watkiss et al, 2007). These damage costs are based on values for a range of health impacts, including mortality and morbidity effects, and non-health impacts, such as damage to buildings and effects on crop yields, and also take account of both primary and secondary air pollution changes. The values of these were agreed following recommendation by the IGCB in 2005 and full methodology have been published alongside its updated third report (IGCB, 2007)[68]. The values are now recommended by the IGCB for appraisal in cross department guidance values for damage costs in the UK[69] and were applied in the analysis of the air quality ancillary effects of the EWP 2007[70].

It is recommended that OCC estimate the potential ancillary air quality benefits (monetised, and contribution to air quality objectives)) for the range of targets, and that this information is included in economic analysis of different targets, and input into the wider multi-attribute analysis.

[67] the European Commission's air quality programme CAFE (Clean Air for Europe – the methodology has been published in Holland et al, 2005: Hurley et al, 2005) has been used to undertake the benefits analysis for the future air quality in Europe. The CAFE approach does have significant differences to that used in the UK by Government, though generates similar comparative values.

[68] *The damage cost approach is intended for use across government, such as for project appraisals (project cost-benefit analysis) and Regulatory Impact Assessments (policy cost-benefit analysis). It is not, however, considered a replacement for detailed modelling and analysis. The use of damage costs is therefore only recommended for policies with a pollution reduction over a period of less than 20 years and: as part of a filtering mechanism to narrow down a wide range of policy options into a smaller number that are then taken forward for more comprehensive assessment; or where air quality impacts are expected to be ancillary to the primary objectives or are relatively small.*

[69] http://www.defra.gov.uk/environment/airquality/panels/igcb/guidance/index.htm

[70] http://www.berr.gov.uk/files/file39198.pdf

**The Impact pathway approach**

The usual approach taken for the detailed quantification of air quality benefits is referred to as the ‘impact pathway approach’. This follows a logical progression from estimation of emissions, through dispersion and pollution modelling and the calculation of receptor exposure, to quantification of impacts and their valuation.

The approach uses a logical and scientific approach, to build up the estimates of damages step by step. The approach is shown in the figure below. Following from the figure, impacts and damages under any scenario are calculated using the following general relationships:

$$impact = pollution \times stock\ at\ risk \times response\ function$$

$$economic\ damage = impact \times unit\ value\ of\ impact$$

Pollution may be expressed in terms of concentration or deposition. The term ‘stock at risk’ relates to the amount of sensitive material (people, ecosystems, materials, etc.) present in the modelled domain.

The final stage, valuation, is generally done from the perspective of ‘willingness to pay’ (WTP). Some elements of the valuation of health impacts can be quantified from ‘market’ data (e.g. the cost of medicines and care), though other elements such as willingness to pay to avoid being ill in the first place are clearly not quantifiable from such sources. In such cases alternative methods are necessary for the quantification, such as the use of contingent valuation. Where impacts arise in the future it is necessary to discount monetised values (but not impacts).

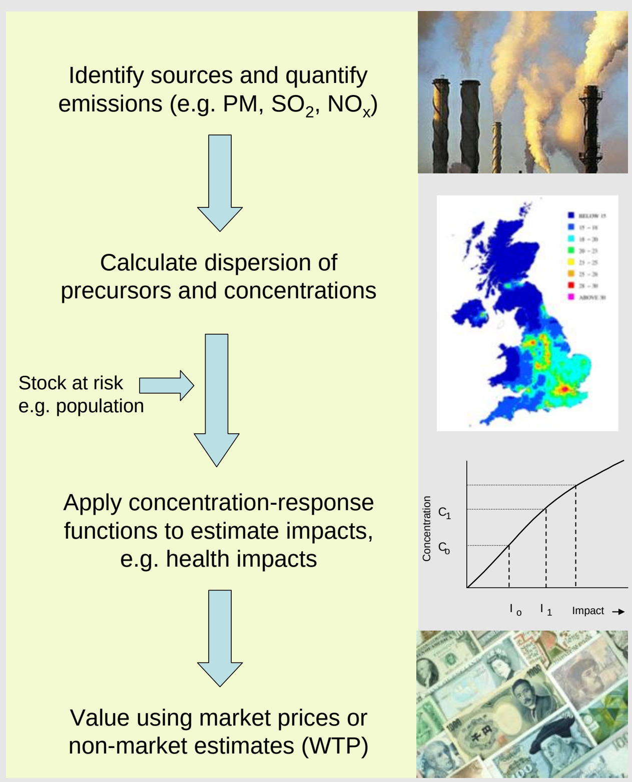


**Figure 5.2 Impact Pathway Approach**

### Other environmental benefits

Other environmental benefits from low carbon policies may include:

- In the agricultural sector, policies to reduce methane and nitrogen dioxide emissions from agriculture result in ancillary benefits to ecosystems, reduction in the use of nitrogen fertilisers lead to reduced eutrophication and acidification of ecosystems, benefits from agricultural GHG policies include: ecosystem and biodiversity benefits and improved water quality from ammonia emission reduction.
- Forests planted as carbon sinks could lead to ancillary benefits in improved biodiversity, wildlife habitats, landscape, timber supply and recreational opportunities, depending on the land type and forest management.

## Energy Security

Recent energy projections show an increasing trend towards energy imports in the UK, especially for oil and gas. The Energy White Paper (DTI, 2007) predicts that by 2020, around 80% of fuels are likely to come from overseas. The decline in indigenous reserves of oil and gas, as the North Sea matures, will mean a changing import balance and move to UK to a position of import dependence. The White Paper estimates that *by 2010, gas imports could be meeting up to a third or more of the UK's total annual gas demand, potentially rising to around 80% by 2020 on the basis of existing policies. The UK is also already a net importer of oil, and by 2020 imports could be meeting up to around 75% of the UK's coal demand.*

The White Paper recognises that this exposes the UK to global markets and the influence of other countries, specifically the potential for higher and more volatile energy prices, more complex international relationships with consumer and producing nations, and the risk of overseas disruption or supply interruptions. In terms of longer term security, many commentators have argued that gas exporters have an interest to sell and so long as adequate infrastructure exists to move gas to the UK, supplies should not be threatened. However, these studies also recognise that the growing dependence on imports (from a limited number of supplies) mean gas prices will be set on a less competitive market than is ideal.

There is a considerable literature on some these aspects, related to both security and diversity of supply (including disruptions, fuel price shocks), macroeconomic effects from imports, and energy security externalities. Important issues include:

- The large infrastructure costs associated with moving to a greater dependence on imports. This includes for example: strengthening the gas network; investing in gas interconnections with Europe; investing in gas storage infrastructure to match that in other importing countries (e.g. 20 – 25% reserve); investing in LNG infrastructure to access new exports; additional investment to strengthen continental gas networks and infrastructure to meet UK supply needs and for transit states to allow access to reserves further afield. Note in the absence of suitable infrastructure and storage/back-up capacity, the risk of price fluctuations or even supply shocks will increase.
- The macro-economic effects from moving towards a high level of dependence on imported energy (gas), i.e. imports will have a negative impact on the UK trade balance.

- The additional costs that are not reflected in producer and consumer prices, i.e. energy security externalities, and that can be reduced by using different fuels[71]. These include:
    - The effects associated with dependence on foreign energy petroleum supplies (and potentially future gas supplies). Most studies in this area are based on the US literature, and the excess payments for imports and indirect consequences of imports for the economy as a whole.
    - The effects on the economy from fluctuations in energy costs (particularly short-term shocks). These fluctuations may derive from disturbances in the world markets or from other shocks of a local or regional nature, such as failures in the natural gas or electricity delivery systems.
    - The additional foreign policy arrangements that the UK and Europe will need, in order to access competitively priced and reliable sources of gas from further afield. While it is difficult to split out energy (oil / gas) related expenditure from other political objectives, the costs of a strategic military presence to ensure the uninterrupted flow of oil is potentially significant for major importers[72].
    - The longer supply chains, such as gas supply from Russia, which increase the GHG and AQ emissions through the 'own-use' associated with gas compression and transport (the same issue arises with gas liquefaction), i.e. increasing life-cycle emissions (and externalities).

It is generally considered that low carbon technologies will have ancillary benefits from reducing dependence on imports and so increasing energy security, because of greater diversity of supply linked to increases in renewables, nuclear generation, coal generation with sequestration, as well as improvements in energy efficiency[73]. There are therefore potential direct and indirect benefits from different interim targets.

Some analysis of these effects and the potential difference across the range of interim targets is recommended (at least qualitatively, and perhaps quantitatively).

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[71] A wide range of possible energy security externalities have been identified. The ExternE study (EC, 1998: 2000) identified three kinds of energy security externalities: monopsony wedge, incomplete rent capture and macroeconomic externalities. The main emphasis in this study was on assessing these externalities using a collection of very simple models of the national economy, which was simple enough to be studied analytically. There is a larger US literature on the energy costs and externalities associated with reliance on foreign sources of oil for electricity generation in the United States. These include potential macroeconomic impacts such as inflation, unemployment, changes in the balance of trade, and monopsony effects (dependence on imported fuel - the 'monopsony wedge'). There are also studies of the effects on the economy from fluctuations in energy costs. These fluctuations may derive from disturbances in the world petroleum market or gas markets or from other shocks of a local or regional nature, such as component failures in the natural gas or electricity delivery systems. Work in the UK (e.g. Pearce et al, 1995) considered that both price shocks and uncertainties over supply could expose consumers to risk. The study also reported that over reliance on imported energy places countries at risk of supply interruptions, which have high costs (outages, labour effects). The potential externalities of a 10% unanticipated price shock were estimated as 1.0 pence/kWh for oil, 0.15 pence/kWh for gas, and 0.31 pence/kWh for coal. The study also assessed possible interruptions of supply and associated welfare losses due to unmet demand. The study quantified the dependence on imported fuel, fuel price uncertainty and macro-economic effects from price changes, and fuel supply interruption and macroeconomic effects of supply disruptions. A number of other studies (e.g. Murphy and Delucchi, 1998) have also assessed energy security externalities, including other issues such as infrastructure, and more contentious issues, e.g. with the broader military, diplomatic, or foreign policy issues where economics and energy are only a part.

[72] Some studies have estimated that US and UK military expenditure associated with actions to preserve Gulf oil supplies imply annual costs of $billions/year and external costs of $/barrel, though we do not consider these values can be used reliably.

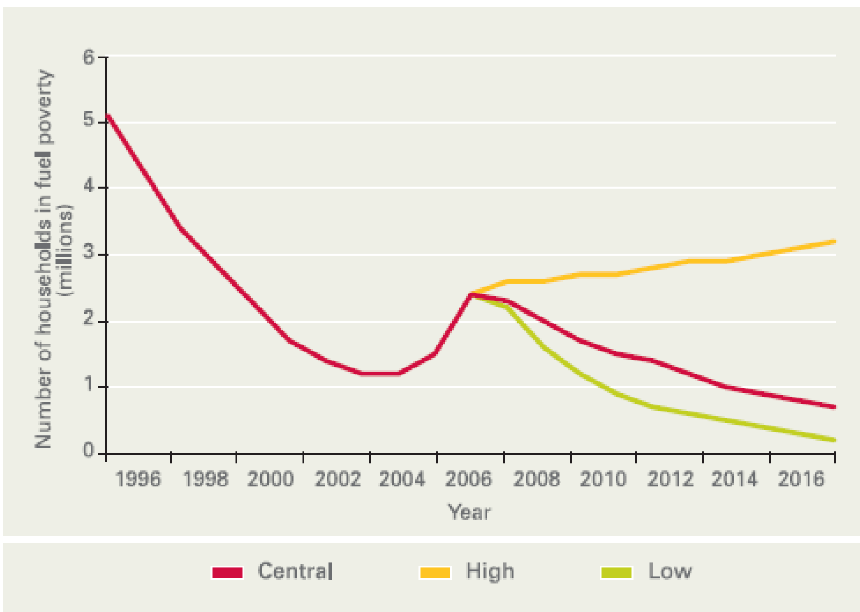
[73] Note some previous low carbon modelling in the UK has shown that under a 550ppm target, there is rapid uptake of natural gas with carbon sequestration. This would actually reduce the potential security of supply benefits of low carbon policies.

## Social Effects: Fuel Poverty

The Energy White Paper (DTI, 2007) sets out that the '*Our goal remains to ensure that every home is adequately and affordably heated'*, and reports that the number of households in fuel poverty[74] is still significantly lower than 1996: falling from around 6.5 million households to less than 4 million, though the price increases of recent years have reversed the downward trend.

The White Paper estimates that on the central price/income scenario it is estimated that 1.5 million households will remain in fuel poverty in 2010 and 700,000 in 2016 (see figure below). It also sets out that households remaining in fuel poverty will need to receive additional assistance if we are to meet our targets

**FIGURE 2.1.1 HISTORIC AND PROJECTED NUMBERS OF HOUSEHOLDS IN FUEL POVERTY IN ENGLAND, 1996-2016**




*Source: DTI, 2007*

- Positions in 2005 and 2006 are based on the modelling of the impact of income, energy prices movements and energy efficiency measures on the number of vulnerable households in fuel poverty.
- Positions from 2007 to 2016 are based on modelling and show central, low and high price scenarios. These are based on the fossil-fuel price assumptions published at the same time as the White Paper.

**Figure 5.3 Fuel Poverty (GB)**

A potential downside of a more ambitious interim target could be a knock on effect on fuel poverty, though presumably redistributive policies could be put in place to address this. An assessment of the potential fuel poverty impacts for the target levels could be assessed quantitatively as there are existing government models linking fuel prices to the number of households in fuel poverty and we recommend that this could be undertaken and input into the wider multi-attribute analysis of different target levels.

[74] The DTI definition of fuel poverty is when a household has to spend 10% or more of its income on energy to maintain a warm home. The causes of fuel poverty are the cost of fuel, the income of the household and the energy efficiency of the home.

## Other Effects: Employment, Trade, Competitiveness, Innovation and Public Finances

There are a number of other effects that are raised in the context of ambitious carbon targets, including effect relevant to macro-economic effects, competitiveness, innovation, technology spillovers, etc.

The short-to-medium-term macro impact of different carbon budgets can be assessed with a number of model, that can predict emissions and responses to carbon pricing and abatement measures - particularly reporting the GDP and pricing impact and impacts on different sectors, and some analysis in this area is warranted.

The effects of environmental legislation on employment, trade and competitiveness remain the subject of debate. A number of studies (OECD, 2004) have shown that effects from existing environmental legislation are low. However, there have been concerns that such effects might be more important for climate policy, given the large structural changes that would be required. These issues require some consideration, not least should stronger unilateral action be taken in the UK relative to Europe, and the effects on economic growth rates, underlying energy prices, the costs of technological options for increasing efficiency of energy use and reducing emissions, and the costs associated with structural change in the economy, etc, vs. potential benefits of first mover advantage, technological innovation, etc.

Finally, there is a need to take account of possible public finance costs in the decision making process. While this is not strictly necessary in a purely economic context, it will have resonance with government. Economically sound policies which require substantial increases in public spending may be less likely actually to happen. Therefore the broad public finance costs of different options and levels of abatement should be considered (and additional public spending required). Options which look otherwise appropriate but which require substantial public spending should be highlighted as such.

## Setting Budgets for the Interim Periods 2012 and 2017

The methodologies described in this report for setting 2020 targets in relation to some long-term goal for 2050 can also be applied with respect to the problem of setting interim carbon budgets for the periods 2012 and 2017. It is assumed that this division of effort between carbon budgets will take place once the 2020 target has already been decided. Various approaches to allocating across budget periods could then be taken:

- A simple linear interpolation between current emissions and the implied 2020 emissions could be made to give equal absolute reductions in each time period.
- The linear trend could be modified to account for the kind of ‘slow-response’ effects discussed in Appendix 2 and 3. Taking account of inertia in the economic response to climate change policy, one might expect less emission reductions in the earlier periods and greater emission reductions in the later periods (even with equally strenuous policy effort across the three budget periods).
- Given uncertainty in the final emission reductions to be achieved in 2020, together with uncertain costs, one might set carbon budget for the earlier periods to be more stringent than the later ones in order to account for the option value that this would bring in terms of making possibly tougher-than-expected 2020 targets achievable.

A more quantitative approach would be to take account of the expected evolution of abatement costs during the three periods using technology models or cost curves. A schematic is given below for how this allocation could be carried out using cost curves.

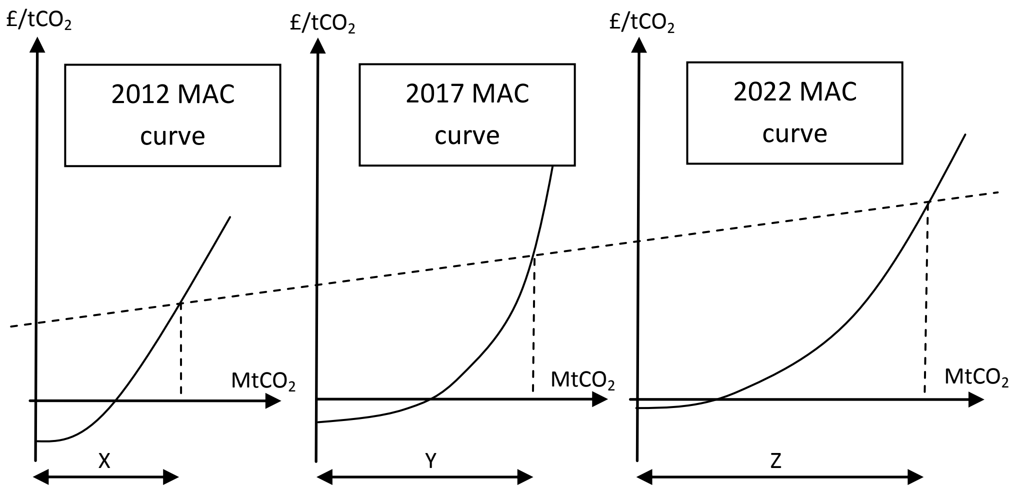
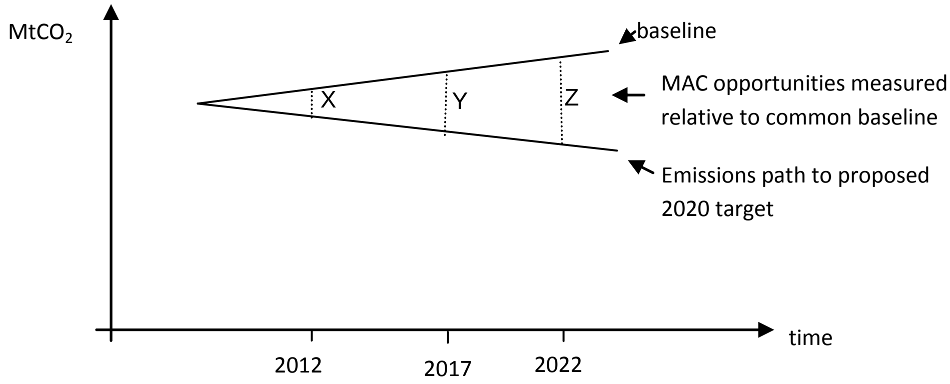



**Figure 5.4 Possible method for allocating effort between budget periods**

This methodology would give emission reductions in line with some proposed distribution of expected marginal costs over time. The dotted marginal cost line that connects the three curves in Figure 5.4 is shown to be increasing over time. This can be justified taking into account the expected increase in the shadow price of carbon over time (which results from an expected increase in the damage function over time). However, there may be other influences on the slope of this curve. For example considerations of option value in the face of uncertain 2020 targets might suggest setting a marginal cost that declines over time (consistent with aiming for a greater burden of effort early on in order to keep open the possibility of meeting more stringent targets later on).

An important clarification should be noted in relation to the representation of MAC curves. The schematic suggests that emission reductions of X, Y and Z would be set for the periods 2012, 2017 and 2022, and it is important to state what baseline these emission reductions are being measured against. The second schematic below clarifies that the cost curves are assumed to measure the achievable potential emission reductions at each point in time relative to some baseline emissions scenario that is common to all three cost curves as indicated below.




Appendix 5 provides further discussion on the importance of clarifying what policies are assumed to be included in the baseline, and the implications of this for the additional effort implied by the MAC curves.

This discussion on the allocation of effort between interim periods assumes that the role of banking and borrowing will be somewhat limited. The greater the degree of flexibility, the less important it will be to match these interim budgets with what is expected to be delivered on the path to 2020, except insofar as the failure to meet interim targets sends signals about the credibility of government targets and could dent investor confidence.

## Conclusions

The methods discussed above provide a firm analytical basis for making decisions. However, there are always a number of wider issues that need to be incorporated in any policy decision, i.e. frameworks such as cost-effectiveness and cost-benefit analysis are inputs to the decision making process, not a substitute for it. There is therefore a need to consider the additional issues that will be relevant for the CCC decisions, and how they can best be incorporated within a formal or non-formal decision making process.

The most important of these other issues includes:

- The political negotiations, especially with EU burden sharing. These are complicated by the nature of the EU proposals, with a lower starting level (20%) and a possible higher level (30%) dependent on the trigger of a stronger global position. The UK interim targets set by the CCC therefore dictate the negotiating position of the UK in these EU burden sharing agreements.
- Wider international negotiations, and also the stated aim of the UK to be influential in the area of climate change (to *lead the global effort to avoid dangerous climate change*).
- The underlying scientific knowledge about climate change.
- The impact of any targets on the UK economy, on taxation, public spending or public borrowing, or on UK competitiveness (particularly in specific sectors).
- The social impacts of the targets, especially the potential impact on fuel poverty.
- The likely level of domestic action and the availability of traded allowances.

- The contribution of traded vs. non traded sectors to the UK burden, allowing for any issues relating to supplementarity.
- Energy policy and the relationship with energy supplies and energy intensity, as well as other potential commitments (e.g. the EU renewables target).
- Other ancillary impacts or benefits.

One of the most important of these relates to Europe and the burden sharing negotiations. Even if the CCC decides on a higher 2020 target (towards 32% for example), e.g. on the basis of the methods advanced here, then there is still an issue on how to present the UK position at any European negotiations. This arises because of the two tier agreement, first in relation to a 20% unilateral EU target, and second, conditional on international action, the increase to a 30% target. Of course there are many additional complications if the latter occurs, as this would be associated with effectively a global deal of some type, and would change all of the considerations in relation to competitiveness issues, availability of CDM, etc. In very simple terms therefore, from a negotiating position, the UK might want to select a lower 2020 target initially (at or near 26%), consistent with the EU 20% target, to allow some headroom to increase this should the trigger for an EU 30% target come into force (i.e. to allow movement towards or up to 32%). Building in this type of contingency into the UK target may call into question UK government ambitions regarding global leadership on climate change (compared for example to going for 32% irrespective of EU targets). However, the credibility of setting UK targets that are entirely insulated from EU decisions also has to be questioned. It is probably better to explicitly incorporate this type of contingency into the targets than to make the option of such changes tacit, which would leave investors guessing whether or not targets would be revised according to international action. The EC itself has a methodology to allocate potential GHG targets to individual Member States (such as the UK). This method is still evolving, but it would be extremely useful for the CCC to work through this methodology to derive the implied starting point of the negotiations for the UK.

The second key area relates to ancillary benefits. We consider that these need to be addressed more explicitly (see earlier recommendations), particularly in relation to the potentially large ancillary benefits of air quality and security, as these provide immediate benefits (up to 2020) and are likely to increase with more ambitious targets. We recommend that are considered as part of the wider non-formalised analysis of the costs and benefits of different target levels. For example:

- Ancillary <u>air quality benefits</u>. Numerous studies have shown that air quality ancillary benefits of GHG mitigation are a significant benefit, offsetting a substantial proportion of mitigation costs. Whilst the full benefit of GHG reductions resulting from further climate action may only be experienced by future generations, the ancillary benefits of climate policy accrue to the current generation. These ancillary benefits are larger for more ambitious interim targets, i.e. a 32% target will achieve greater ancillary air quality benefits in the short-term than a 26% target. This can use the monetised damage cost estimates from Defra (IGCB) for air pollution emissions to provide costed estimates of the ancillary benefits of alternative target levels. Recent work undertaken by the EC estimates that the monetary co-benefits to the UK of achieving the joint EU targets (GHG reduction and renewables) are 2.3 to 6.5 billion Euro per year. It is recommended that OCC estimate the potential ancillary air quality benefits (monetised, and contribution to air quality objectives)) for the range of targets.
- Analysis of the <u>security of supply benefits</u>. The Energy White Paper predicts that by 2020, around 80% of the UK's fuels are likely to come from overseas, due to a decline in indigenous reserves of oil and gas, and a move to imported energy. As a result, the UK will

face greater exposure to developments in the global energy system. It will also be potentially affected by a number of costs, directly in market prices or as externalities. These include infrastructure costs to move to an energy importer, foreign policy arrangements, energy security externalities (including macro-economic effects of imports and energy supply risks (and/or volatility)). It is generally assumed that lower carbon technologies will have ancillary benefits from reducing dependence on imports and so increasing energy security. Some analysis of these effects and the potential difference across the range of interim targets is recommended (at least qualitatively, and perhaps quantitatively).

The third key area relates to ancillary impacts. This includes:

- Analysis of the potential social impacts of fuel poverty from different target levels. Energy price rises in recent years has reversed the trend of falling fuel poverty levels in the UK. A potential downside of a more ambitious interim target could be a knock on effect on fuel poverty (though presumably redistributive policies could be put in place to address this). An assessment of the potential fuel poverty impacts for the target levels could be assessed quantitatively (there are existing government models linking fuel prices to the number of households in fuel poverty).

The final set of ancillary effects relates to macro-economic effects, competitiveness, innovation, technology spillovers, etc. The short-to-medium-term macro impact of different carbon budgets can be assessed with a number of models, and some analysis in this area is warranted. Finally, there is a need to take account of possible public finance costs in the decision making process and options which look otherwise appropriate but which require substantial public spending should be highlighted as such.

As highlighted in the chapter 3, the use of formalised CBA could be used in assessing all of the four categories of non-carbon benefits, and we recommend such a framework be considered for many of the ancillary and economic effects of policies (e.g. air quality). This would allow the presentation of all non carbon costs and benefits of targets alongside their carbon effects. However, some of these 'other elements' may be difficult to monetise formally in practice. The work on monetisation is less well advanced in some important areas, such as energy security externalities, where the literature is controversial and monetised values have not been used in UK government regulatory impact assessment. This may mean that the analysis of non-carbon benefits is also undertaken within a non-formalised (i.e. Stern-like) consideration of costs and benefits.

Finally, the analysis of the costs of meeting these targets will also need to consider the use of emissions trading. For the sectors that have access to credits from international emissions trading schemes to meet their targets[75], the UK government is not in control of the extent to which emissions abatement is delivered within UK national boundaries and how much is purchased from the market. This balance will depend on commercial decisions being taken by companies in the choice of investments they make and the way they operate their plant. Nevertheless, the target set for the trading sector should be considered as contributing to the UK target whether or not it is delivered domestically.

For the non-trading sectors (e.g. domestic and road transport), the government will need to decide on behalf of the public how much to engage in international emissions trading vs. achieving emission reductions domestically. This will involve calculations of the economic

[75] This includes sectors that are within the scope of the EU-ETS, and may or may not include companies that are in the UK-ETS depending on the rules for use of CDM / JI credits in that scheme

consequences, in particular comparing the expected cost of domestic emission reductions compared to expected international credit prices. In addition to these basic economic considerations, there are a number of other factors that could be taken into account:

- The choice of whether to purchase allowances or make domestic emission reductions should involve not just a single scenario of expected costs at a given time, but should be a dynamic decision that takes into account cost and price uncertainties and recognises the potential for governments to adapt to new information regarding these uncertainties. For example, a decision to support domestic measures with a higher cost than the expected market price could act as a hedge against possible market price rises and/or greater than expected stringency of future targets. On the other hand, purchasing credits could be a robust strategy if there is the possibility of significant new information on costs of abatement, or if the costs of domestic emission reductions are particularly sensitive to their timing, in which case the use of trading could provide valuable flexibility. These types of dynamic decision-making criteria are discussed in more detail in Chapter 4 and Appendices 4 and 5.
- If target setting is to be carried out largely at the EU level, then the UK government may wish to engage in trading as a tool to manage delivery of UK targets in two main respects. Firstly, if the UK has information about the balance of pre-2020 and post-2020 costs which are not factored into the targets set by the Commission, then trading could be an appropriate way to smooth out these costs. This could include buying credits, but could also in principle include selling credits (through the JI route) if UK the balance of pre- and post-2020 costs suggests that it would be sensible to overshoot the targets set by the EU. Secondly, given that the EU may change from a 20% GHG target to 30% GHG target (contingent on signing an international climate agreement), then the UK government may well want to keep open the option of trading as a way of maintaining the flexibility to accommodate this shift in the target.
- The decision on trading sends contrasting political messages to different audiences. Purchasing international credits indicates faith in the general principle of emissions trading as well as in the integrity of the particular markets. On the other hand, investing in emission reductions domestically indicates that the government is committed to getting the economy onto a more sustainable footing, and perhaps strengthens the credibility of any attempt to take a leadership role in international negotiations.

# Chapter 6 Conclusions and Recommendations

## Discussion and Conclusions

The study has first outlined the overall framework for setting UK interim targets, set out in Chapter 1. The setting of interim budgets is strongly influenced from the 'top down' by: long-term global stabilisation targets; the global pathways of emissions to these long-term targets; and the UK's relative share in global emissions reductions (e.g. as a developed country). It is also influenced from the 'bottom up' by the UK's decisions on how much of its commitment to meet from overseas through international flexible mechanisms, and the relative share of reductions by sectors within and outside the emissions trading scheme. Finally it is influenced by external political negotiations with respect to the EU's 2020 GHG targets and the burden sharing agreement.

The decision on interim targets therefore sits within a much wider set of policy considerations. To complicate this, actual decisions are unlikely to flow smoothly from the global level at the top of the figure through to UK-level sectoral policy decisions at the bottom, and the decisions which the CCC will be advising on will be subject to various levels of negotiation, either within the EU or more broadly on the international stage, and over which the UK will different levels of control.

**Review of Existing Climate Change Targets**

The project has reviewed the existing approaches used for setting long-term and interim targets, whether at a global or national level, set out in Chapter 2. The review found a diverse range of approaches for setting targets. To understand the differences in these approaches, the project has developed a categorisation of decision entry points and related decision perspectives, shown in Figure 2.2. At the extremes, the entry points range from strong economic through to strong scientific-precautionary perspectives. However, many methods consider both economic and precautionary consideration, and all approaches consider some form of benefits and costs, though there are significant differences in whether they do this explicitly or implicitly.

The conclusions of the policy review are that:

- For both UK domestic policy, EU policy, and for most Country targets, the first step has been to set a long-term target. This has then been followed by the development of short-term targets on a path towards the long-term target. This is important for this study, as it highlights that it is not possible to separate the long and short-term policy domains.
- For long-term stabilisation goals, the approach that has been used for advising Governments has been a scientific-precautionary one, based around the available evidence and concerns about high levels of impacts associated with different temperature levels. There is little explicit consideration of the costs of stabilisation in these assessments. The adoption of the precautionary approach is due to the unusual attributes of climate change and concern over large-scale climatic events. It is these concerns that have led many to recommend cost-effectiveness analysis rather than cost-benefit.
- A greater focus on cost-effectiveness can be seen when long-term ambitions are translated into firm government commitments, where the precautionary approach is complemented by analysis of technical costs, as in the case of UK long-term and UK and EC interim targets. Such an analysis is undertaken to demonstrate that the long-term goals are technically

achievable and that costs of compliance are not dis-proportionately high. These approaches consider costs in detail using marginal abatement costs, but take predefined benefits as set by the political process and accepted in the precautionary targets. They do not undertake cost-benefit analysis (CBA), but they are a non-formalised comparison of costs and benefits.

- The Stern Review is another example of a non-formalised comparison of costs and benefits. Although the Review considered the results of formalised CBA, it did so as part of a wider, multi-attribute framework that placed more emphasis on measuring the environmental and social risks of climate change in their own, 'natural' units. Hence the Review did not recommend an optimal level of greenhouse-gas emissions.
- Other decision tools for setting targets (e.g. formalised CBA, multi-criteria analysis, tolerable windows) are only to be found in the academic and grey literatures.

Following from this, it is highlighted to the SCCC that:

- Actual (Government) climate-change policy / target setting does not adopt a strong economic perspective, nor has it favoured the use of formalised CBA. Instead it has used scientific evidence and political negotiations, driven by an underlying focus on the precautionary principle (inferred from the long-term targets). This is balanced by a consideration of cost-effectiveness, particularly when moving from long-term to interim targets.
- There are cases where different approaches are used for setting long-term and interim targets, with the latter generally including a stronger economic perspective at least in terms of the costs of policy action (at least as a check of technical and economic feasibility).
- More generally, across the broad range of stakeholders that are interested in long-term climate change policy, there is no consensus on which approach should be used for setting targets. The views of different stakeholders span the entire range of decision perspectives in the table above. The views of different individuals are set according to their underlying decision perspectives (e.g. economic vs. precautionary) and these perspectives are typically fixed, i.e. individuals rarely switch between perspectives, even as evidence emerges.
- It is already clear from the consultation preceding the Climate Change Bill that there is a wide diversity of views on both long-term and short-term targets, and also that most people see the two as inter-related. There is also a clear range of views that span the decision entry points above, e.g. from strong economic analysis associated with CBA, through to precautionary thinking (as in the Tyndall Centre report, 2007). Any approach that tries to ignore specific views or concerns across different stakeholders is unlikely to gain widespread support, and the choice of one particular framework over others will also lead to groups who do express strong disagreement.
- The diverse range of views has led some methodological approaches to advance the use of multiple perspectives and frameworks, i.e. using several of the approaches above in the same overall target setting approach in a <u>complementary</u> analysis, rather than trying to only focus on one single (overarching) method or framework (though we do highlight a central approach in the next section). Such an approach has a number of advantages: it can provide additional information that one framework alone cannot generate; it can help to achieve wider stakeholder buy-in to the process of target setting and; interestingly, it can examine how (and why) different decision approaches affect the choice of target level.

It is also considered that the challenge for the UK is to set short-term (interim) carbon emissions targets under multiple sources of uncertainty about the future evidence and the future course of policy. However, many of these uncertainties will be reduced in the future. Therefore the policy problem today is characterised by irreversible decisions under uncertainty, with the possibility of learning more to reduce these uncertainties in the future. The irreversible decisions include:

(i) the irreversible accumulation of greenhouse gases in the atmosphere, leading to climate damages;

(ii) irreversible investments in abatement capital;

(iii) irreversible investments in ‘dirty’ capital that emits greenhouse gases (often referred to as ‘lock-in’).

Such a problem suggests the existence of option values, i.e. the value of avoiding irreversible commitments until uncertainty is reduced. The study of these values is called options analysis. Formal options analysis comprises a number of mathematical approaches to quantifying the value of flexibility in decision-making. Decision-making is considered to be responsive to new information arising at some future date which helps the decision-maker maximise any gains and minimise any losses associated with uncertain outcomes. Options analysis essentially explores the value of ‘keeping options open’. As an example, does only doing 26% in 2020 close off options for achieving 80% in 2050? And does it close off options for meeting more stringent atmospheric concentration targets?

Options analysis has been most completely explored using cost-benefit analysis (CBA), yet the general framework can be applied to other less strongly economic methods. We recommend it forms the key overarching framework for tackling the analysis of interim targets, with potential different methodological approaches nested within this. The individual methods are reviewed in the next section. The discussion below focuses on the 2020 interim targets, but the preceding 5 year budgets are a subset of this overall target, and the same methodological issues apply.

**Review of Methodological Approaches for Setting Long-term and Interim Targets**

Following the initial policy review, the project has undertaken a detailed analysis of each of the possible methodological approaches for setting UK interim targets for the first three periods, consistent with the CCC objectives. This is presented in Chapter 3.

Each of methodological approaches has been reviewed in detail. Their relevance for the CCC, their advantages and disadvantages, and the practical issues arising in terms of their application has been considered. The summary was presented in Table 3.1. The main findings are:

- There are large differences between the methodological approaches, primarily relating to the decision entry point and perspective (as discussed earlier). The methods therefore range from a formalised cost-benefit analysis (CBA) at one end (strong economic) to a strong scientific-precautionary approach at the other (strong sustainability), though intermediate methods engage in explicit economic and precautionary considerations to some degree. Ultimately all approaches trade off benefits against costs, whether explicitly (e.g. as in the case of CBA) or implicitly (e.g. the adoption of a strong precautionary target implicitly assumes that the benefits outweigh potential costs). As different stakeholders have different entry points and preferences, they are likely to recommend approaches across the range of methods. We consider that it will be difficult to achieve a consensus- based approach through selecting one individual approach.
- While formalised CBA is the main recommended approach in the Green Book, the same document also recognises the precautionary principle, and therefore existing guidance can be used to justify any of the approaches.

- Existing UK policy for previous long-term and interim carbon targets has been set on the basis of a cost-effectiveness analysis of scientific-precautionary based targets. While there are potential issues of consistency in target setting (including precedents), there also many examples in Government where long-term and short-term policy use different methodological approaches (though note care must be taken to ensure that the value judgements and decision-making structures are consistent).
- The Government has recently set guidance for the use of a shadow price for carbon (SPC) in appraisal across all departments, for all policy decisions. This SPC is set on the basis of the Stern estimate of the social cost of carbon on a pathway to stabilisation at 550ppm $CO_2e$. For consistency and to reduce uncertainty, it should be ascertained whether the SPC used across Government is in line with the marginal abatement costs of achieving the 2020 interim targets. Note that the current SPC (based on global marginal social costs consistent with a 500 - 550 ppm trajectory) is itself conditional on international action.
- It is probable that the choice of interim targets in 2020 influences the achievability of long-term targets in 2050. This is particularly relevant for a precautionary approach, as well as in relation to the emergence of better information appearing later. It leads to the conclusion that any methodological approach should consider the option value of interim targets, i.e. what they imply for subsequent (particularly stricter) long-term targets.
- It is highlighted that the recommendations on methodology and targets depend on the objectives of the carbon budgets and the target setting approach as set-out in the Climate Change Bill, and agreed upon by the CCC. These could vary, for example between a strong objective towards global leadership, or towards providing certainty for business in investment and other decisions. From considering the Climate Change Bill and the recent supplementary statements and Treasury PSA Delivery Agreement 27 (*Lead the global effort to avoid dangerous climate change*) our interpretation here is towards a global leadership role and this informs our recommendations below.

The key question is what methodological approach should be used to set a target between 26 and 32% for 2020 (as well as the interim targets in earlier periods), i.e. to move from a bounded range to a discrete policy choice. Taking the findings into account, the team considers that:

- Cost-effectiveness analysis should be the central methodological approach adopted by the SCCC. It can be used to estimate the increase in costs associated with stronger levels of ambition (i.e. moving from a 26% $CO_2$ emissions reduction in 2020 to 32%). It can also be used to estimate the impact that tougher interim targets will have on the feasibility and cost of long-term targets. This options analysis (see below) is likely to be a key element of the CCC's decision.
- In relation to marginal abatement costs and cost curves, it is highlighted that uncertainty can be an important issue. It is also important to recognise that there is uncertainty over policy implementation (i.e. whether policy measures are realistic). The CCC should consider uncertainty in its analysis and MAC curves should ideally include ranges of costs rather than point estimates in order to inform a risk-based approach to decision making, and consider realistic policy outcomes.
- However, cost-effectiveness is a relative measure. It does not estimate the benefits of different targets. For this reason, while we believe it forms the core of the overall analysis, we also believe that it needs to be complemented with other approaches. These include a scientific assessment of the environmental risks and benefits of different interim targets in their 'natural units'. This would follow the methodology of the Stern Review and of IPCC in linking emissions targets with possible temperature increases and these in turn with impacts

on the environment on various dimensions such as food security, water availability and natural ecosystem health. For interim targets, rates of temperature increase should be afforded more emphasis than is usual in analyses of long-term targets, which focus on levels of temperature increase. Furthermore analysis should be carried out of political and social considerations such as EU burden-sharing and fuel poverty respectively.

- These other approaches provide important additional information that can help inform the CCC's decision, and they also are important in relation to the wide diversity of stakeholders. We believe this approach is likely to have a much wider acceptability to the broad group of potential stakeholders, as well as generating useful information that a single approach could not capture. A tiered approach to target setting is therefore recommended to implement this, and this is set out in more detail in the later section.
- In principle, information on the costs and benefits of different interim targets could be brought together within a formalised CBA, which could be used to recommend an 'optimal' emissions pathway. Formalised CBA has also been used to systematically explore the role of uncertainty, irreversibility and learning on interim targets. It is the only framework really capable of bringing the full range of information together quantitatively to estimate option values. However it is our assessment that the uncertainties around estimating the social cost of carbon (SCC, the marginal global damage costs of climate change) are currently too high to rely on this method to determine the CCC's decision. Rather, formalised CBA could play several important ancillary roles.
    - There is a need to investigate the consistency of current recommendations on the shadow price of carbon (SPC) used in Government appraisal in relation to the interim carbon budgets (and estimates of the marginal abatement costs of these budgets). In practical terms this would involve modelling, or meta-analysis of the literature, to calculate the SCC and MAC of the emissions pathway implied by the carbon budgets.
    - Formalised CBA can be used to understand in general terms the implications of various scientific, economic and social issues and can be periodically undertaken when new information comes to light on any of these issues as a means to 'check' the economic case for Government policy, comparing estimates of the marginal costs and benefits of recommended carbon budgets. A practical example would be to periodically calculate, for carbon budgets or for policies more generally, what SPC would be required as a minimum for the budget/policy to pass a cost-benefit test. However it must again be stressed that the resulting information is unlikely on its own to be decisive.
    - Other ancillary monetary benefits (air quality improvements) could be assessed within a CBA framework. Note that these benefits accrue immediately to the current generation (unlike the benefits of climate policy).

<u>The team recommends cost-effectiveness analysis as the central approach for the CCC, complemented by separate assessments of environmental, social and political factors as part of a multi-attribute framework (i.e. as part of a non-formalised analysis of costs and benefits). Formalised CBA can play a role here but cannot substitute for a multi-attribute approach, due to the uncertainties.</u>

Note that formalised CBA could be used in assessing the non-carbon benefits, and we recommend such a framework be considered for many of the ancillary and economic effects of policies (e.g. air quality). This would allow the presentation of all non carbon costs and benefits of targets alongside their carbon effects, though in practice, some of these 'other elements' may be difficult to monetise formally (see Chapter 5) and thus require a non-formalised (i.e. Stern-like) consideration of costs and benefits. .

As highlighted above, whilst formalised CBA provides a potentially powerful tool for setting carbon budgets, we believe that the current uncertainties in the Social Cost of Carbon (SCC) are too large to rely on it for setting interim UK budgets. However, there is a wider issue of consistency here, as the SCC has been used to set the Shadow Price of Carbon (SPC) in the current Government appraisal guidance. It is therefore essential that the SCCC ascertain whether the current SPC is in line with the marginal abatement costs of achieving the interim targets (derived above), to avoid potential inconsistencies in policy appraisal (and if necessary to seek to address these through the SPC). It is also highlighted that the SCCC may need to investigate the impact on the SCC (and SPC) from any changes in long-term targets, as the Social Cost of Carbon (SCC) is path dependent.

**Stabilisation Pathways: Linking Long-term and Interim Targets**

As the overall framework for target setting shows, there are a number of steps relating long-term international stabilisation goals to interim UK targets: (i) the examination of alternative emissions paths over time towards long-term targets, (ii) the consideration of the relative reductions in developed and developing countries, and (iii) the consideration of burden sharing within the EU.

In undertaking the first of these steps, it is necessary to take account of the relationship between global emissions and atmospheric concentration levels. This is set out in Chapter 4. This relationship is complex and uncertain, due to the role of sinks in the climate system and possible feedbacks between the effectiveness of these sinks and climate impacts. Nevertheless, simplified estimates can be made. Most analysis shows a relative insensitivity of final concentrations to the shape of the emissions path: therefore many different paths (with the same cumulative emissions) will lead to the same concentration. Much of the work related to calculation of emissions paths is therefore dedicated to identifying paths (or emissions corridors) that are realistic given constraints. These constraints include:

1. That the curve is smooth, in order to avoid very rapid changes in emissions trends
2. That the rate of change of emissions from one year to the next is limited (e.g. to below 3% per year) in order to reject paths that require a technically unfeasible decarbonisation rate.
3. That a more explicit treatment of abatement technology is introduced, allowing for projections of availability and cost of abatement which could vary over time (new technology)
4. That $CO_2$ emission profiles are optimised to achieve least-cost deployment of $CO_2$ abatement technologies, taking account of the expected evolution of technology costs over time.
5. That multi-gas emission profiles are optimised to achieve least-cost deployment of multi-gas abatement technologies over time.

The further one goes down this list of constraints, the more feedbacks are incorporated into the emissions path, and the more complex the model required. Typically, integrated models can provide the optimized profiles described in the final two bullets (as used in a wide range of literature, including the IPCC scenarios), whereas the constraints described in the first two bullets can be achieved through simple curve fitting calculations (also with an established literature including the Contraction and Convergence model, and the recent Ecofys study for Defra). Structurally simpler technology models described in the third bullet tend to be used at the policy analysis level, for example to look at the costs of achieving emission reductions in different sectors, and these can sometimes contain a richer and more detailed description of abatement technologies than integrated assessment models.

Regarding developed/developing country burden sharing, a number of approaches have been advanced for calculating emissions paths at the individual country level. These include (see Chapter 4):

- Contraction and Convergence (C&C).
- Common but differentiated convergence (CDC)
- Multistage.
- Global Triptych.
- Sectoral approach.

The order in which these two steps are carried out depends on the architecture of the international system. In some of the above proposed schemes, one would start by defining a global emissions pathway consistent with some pre-defined environmental target, and then proceed to divide these global emissions rights between countries / sectors etc (as is the case for example with the contraction and convergence approach). Other schemes (such as CDC and multistage) start at the other end by defining a set of actions and commitments appropriate to different countries, which then build up to an overall global emissions profile. This second approach is less environmentally determinate, the achievement of environmental goals becoming scenario dependent.

The project has reviewed the approaches, and the models used, to undertake the analysis of emissions paths and the allocation rules. A number of key messages emerge from this review.

- There are a number of approaches that can be used for pathway analysis. Very broadly these tend either to use complex models (e.g. Integrated Assessment Models) or simplistic pathways with constraints (e.g. Contraction and Convergence). There are some hybrid approaches, as in the models of Meinshausen.
- Integrated models provide a sound conceptual approach, integrating technology cost assumptions into the calculation of optimal pathways. However, their complexity can be a disadvantage for policy analysis applications. Although many of the assumptions on technology costs may be quite simplistic, they are often embedded in the model.
- In contrast, simple curve fitting approaches aim to use simple constraints on the rate of change of emissions. However, this reduces analysis of how constraints relate to technical constraints in the real world. The values chosen for the constraints make a significant difference to the choice (and availability) of different pathways.
- Therefore, for the setting of carbon targets and the policy frameworks being considered here, we recommend a central approach, based around hybrid approaches, which allows detail and transparency, and that can capture important issues such as technical potential, structural change to the economy, hedging and R&D etc. This involves some elements that link with the cost supply data.

Note, whichever approach is used, significant expert judgement is still required.

As well as the information about the cost-effectiveness of different interim targets, a consideration has been to highlight the need for a detailed pathway analysis for the SCCC, as part of the overall target setting approach for interim targets. This is defined here as options analysis. Given the uncertainty over a number of key elements of the costs, benefits and risks of different mitigation paths, and the potential for gaining better information in the future, interim targets should be considered in terms of their option value, to see whether they influence the achievability of later, long-term targets.

In very simple terms, it would seem sensible that any process that considers targets for 2020 should consider whether these close off options for 2050 (e.g. does a 26% target in 2020 make an 80% reduction in 2050 unachievable). This type of option analysis provides a useful framework within which more detailed economic analysis can be positioned in order to aid decision-making.

This type of options analysis method is complex in relation to climate change, and so the project has advanced the approach through some additional review and some preliminary analysis.

Note with respect to long term stabilisation targets, the issue of overshoot scenarios is also relevant here[76].

**Options Analysis Review and Case Study**

The study has then undertaken a review of the literature on options analysis (Chapter 4 and Appendix 3). This analysis has been conducted in the academic literature within a formalised CBA framework and has generated some useful insights. The effect on near-term emissions targets of learning depends on the interplay of at least three different irreversible investments/decisions:

(i) the irreversible accumulation of greenhouse gases in the atmosphere, leading to climate damages;

(ii) irreversible investments in abatement capital;

(iii) irreversible investments in 'dirty' capital that emits greenhouse gases (often referred to as 'lock-in'). In addition, theoretical contributions have emphasized that the structure of the decision-making problem or function matters, as do the choice of certain key parameters including risk aversion.

The results of these studies are ambiguous, in large part because these three irreversibilities point to different near-term strategies. (i) and (iii) suggest that emissions reductions should increase with the prospect of learning. (ii) suggests the opposite. Studies mostly from the 1990s tended to conclude overall that near-term emissions reductions should decrease (i.e. we should emit more), but did identify cases in which the latter was true. Coverage of the three irreversibilities outlined above was not always equal and, in general, the same concerns that are typically raised with CBA studies also apply here, including the contingency of results on value judgements that are controversial and debatable, and the incomplete coverage of climate-change impacts. In addition, these studies are highly aggregated and so are not useful in a direct way to the choice of 26% or 32%.

[76] In relation to the stabilisation pathway, and the range of interim objectives, pathways are often bounded for strict targets by the assumption of whether overshoot scenarios are allowed (i.e. scenarios that lead to an exceedance of say a 550 ppm level, before stabilisation back down to this level, and/or by implication, similar issues in relation to temperature). Overshoot scenarios allow almost any target to be achieved, but they also infer a change in risk associated with overshooting. Overshoot pathways that cause transient global temperatures to exceed those expected to correspond to the long-term target increase the possibility of crossing certain irreversible thresholds or 'tipping points' in the climate system, such as those triggering melting of the Greenland and West Antarctic Ice Sheet.

One recent study (Yohe et al., 2004; Science) has nevertheless advanced the analysis by looking beyond optimal policies to simply ask the question: what choice of near-term emissions path maximizes discounted global GDP, if the long-term target is uncertain. It finds that the best 'hedging' strategies imply rather strong emissions reductions in the near term, because of the benefit to having very low concentration targets such as 450 ppm open in the future. With lower or no emissions cuts over the next 12 years or so, it becomes very costly to achieve low concentration targets in the long-term, if they turn out to be chosen.

Following this literature review, the study has advanced an option analysis case study, looking at decision making under uncertainty, using the UK targets and emission path analysis. The aim is to test the likely importance of this kind of optionality by developing illustrative paths around the proposed interim and long-term targets being considered by the CCC. The results are summarised in Box 1 (and in Chapter 4 and Appendix 2). Based on this analysis, the team believes that there may be sufficient difference between the proposed 26% and 32% targets for 2020 to create an option value that should be incorporated into the decision-making process. These option values may arise as a result of the balance between pre- and post-2020 costs, and also as a result of closing off achievable (or at least globally consistent) stabilisation pathways. The team therefore recommend analysis of this type is undertaken by the CCC, as a complement to the cost-effectiveness approach outlined above.

**Box 1. Case Study**

The case study investigates the extent to which option value could be important with respect to two sources of uncertainty:

- **Uncertainty over the UK's 2050 targets**. The analysis looked at whether the choice of 26% vs. 32% for 2020 could affect the achievability of 60% or 80% in 2050.
- **Uncertainty over global $CO_2$ concentration (stabilisation) targets**. The consistency of different UK-level 2020 and 2050 targets with global emission paths to see whether some choices might be incompatible with global stabilisation targets.

Illustrative UK pathways were constructed using various assumptions similar to those found in the literature regarding constraints on the annual rate of emissions decline, and constraints on the ability to accelerate this rate. It was found that if no constraint is placed on the ability to accelerate the emission reduction rate, then emissions pathways in the period 2020-2050 do not differ significantly depending on the choice of 26% or 32%. The emission reduction rate required to achieve 80% reduction in 2050 given a reduction of 26% 2020 is 4.27% per year, compared to a rate of 4.00% reductions per year between 2020-2050 given a reduction of 32% in 2020. However, if (as is done in the literature) a constraint is put on the ability to accelerate emission reduction rates (equivalent to a slow-response scenario representing inertia in the economy, financial markets and technology development), then the emission reduction rate between 2020-2050 has to be 4.5% per year given a reduction of 26% in 2020, compared to 4.0% given a reduction of 32% in 2020.

If a further constraint is applied requiring the cumulative emissions to 2050 to be equalised between different pathways, then a much more significant differentiation between the initial choices emerges. In this case, given an emission reduction of 26% in 2020, the emissions reductions in 2050 must be 88% requiring an emission reduction rate of up to 6.8% per year.

The second type of optionality concerns uncertainty over global atmospheric concentration targets, and the required contribution from the UK in terms of emission reductions. Illustrative emissions pathways were constructed using the Contraction and Convergence model of the Global Commons Institute[77]. Figure ES1 shows the ranges of emission reductions in the UK consistent with different global concentration targets, depending on the date for convergence of per capita emissions (2040 convergence at the left-hand side of each range, 2060 at the right-hand side, and 2050 convergence shown by the solid bar).

This analysis suggests that there could be value in keeping open options to meet more stringent targets, although evaluation of this option value would require further analysis of the costs and benefits of different stabilisation targets. This conclusion needs to be tempered with some important caveats:

1. The values for the UK targets illustrated here are derived from one form of architecture for allocating emissions rights. Other architectures would give different results.
2. In the case of contraction and convergence, the convergence year is a sensitive variable. Other architectures will have their own sensitive variable that affect the result, and given the large range of possibilities, this type of analysis could give a wide range of compatibility between UK targets and global stabilization paths
3. Meeting a stringent UK-level target in 2020 does not necessarily buy the option of achieving a stringent global concentration stabilisation level. It is more accurate to say that it buys the UK a consistent bargaining position in the negotiation of future stabilisation levels, a lesser prize with consequently lesser (though not necessarily insignificant) option value.

This is shown in the figure in Chapter 4 (Figure 4.3)

[77] http://www.gci.org.uk/

Note the the existence of emissions trading affects the choice of the 2020 target itself. Although the total use of emissions trading is not something that the UK government can control, the existence of emissions trading could affect the 2020 choice for a number of reasons. A first-order effect is that emissions credits from international emissions trading (e.g. AAUs, CERs, ERUs) are expected to be cheaper than the marginal cost of reducing emissions domestically within the UK. The reduction in costs associated with trading should enable governments to be more ambitious than would otherwise be the case, since the availability of cheap credits reduces the marginal cost of meeting more stringent targets. Indeed, a simple least-cost approach would suggest only committing to domestic emission reductions whose marginal cost does not exceed the expected price of international carbon credits, and to purchase the remainder required to meet the target. The question is, what should this target be? From a methodological point of view, the existence of an unlimited supply of credits at a particular price poses problems when it comes to setting targets. If the price of these credits is below what is deemed to be an acceptable price to pay (i.e. if they are deemed cost-effective), there is no rational way to decide what quantity should be purchased.

In addition to this methodological problem, governments tend to engage in policies that lead to emission reductions at costs well above the price of international credits. There are several reasons why governments might want to support domestic reductions over international purchases:

- Uncertainty over future credit prices. There are many factors influencing the price of credits, and there will also be a feedback between demand for credits and the price. This effect may not be strong if only one country were to set a high demand for credits, but if all countries set targets in this way, prices would surely increase. Uncertainty over price is one reason for reducing dependency on external credits.
- Policies supporting domestic emission reductions could have a beneficial feedback in terms of increasing investor confidence within the UK, and reducing the costs of delivering emission reductions compared to expectations. This type of positive feedback could be important if learning effects are expected to be significant.
- Encouraging abatement options domestically (instead of buying international credits) may be justified in terms of buying options for the future. Again, if learning effects are expected to be important, then early reductions could lead to cheaper long-term abatement options than would have been the case if targets had been met purely through trading. This may be countered to some extent by arguments in favour of engaging in emissions trading now in order to build institutional capacity and experience if use of credits is expected to be a feature of meeting UK targets over the long term.

Independent of the fact that emissions credits are expected to be cheaper, there is also an important second-order effect of emissions trading which could encourage governments to set more stringent targets. The cost of reducing emissions is likely to be strongly tied to the timing of major infrastructure decisions such as turnover of capital stock in the power generation, transport and buildings sectors. To the extent that these opportunities for abatement are 'lumpy', the costs of meeting an emissions reduction target at a fixed date will be very sensitive to the timing of these opportunities with respect to the target date. Emissions trading can help to smooth out these costs over time, by allowing banking and borrowing between what are essentially arbitrary time periods. This smoothing effect will reduce the cost of meeting a particular target at a fixed point in time when abatement costs are uncertain.

In practice, the most useful way of thinking about the role of emissions trading is likely to be in terms of the flexibility it brings to responding to uncertain external factors. These might include for example unexpected changes in the economy, changes in technical costs of abatement options or shifts in the target imposed from outside the UK (an important example being the possible shift from a 20% GHG target to a 30% GHG target at the EU level). In other words, a pragmatic approach would be to set 2020 targets based primarily on an assessment of what could be achieved domestically at some cost that is deemed reasonable, and to use trading as a flexibility mechanism around that, taking account of the value of this flexibility to consider raising the stringency of targets[78].

**Political issues, ancillary effects, and wider issues**

The methods discussed above provide a firm analytical basis for making decisions. However, there are always a number of wider issues that need to be incorporated in any policy decision, i.e. frameworks such as cost-effectiveness and cost-benefit analysis are inputs to the decision making process, not a substitute for it. There is therefore a need to consider the additional issues that will be relevant for the CCC decisions, and how they can best be incorporated within a formal or non-formal decision making process. These aspects are considered in Chapter 5.

The most important of these other issues includes:

- The political negotiations, especially with EU burden sharing.
- Wider international negotiations, and also the stated aim of the UK to be influential in the area of climate change (to *lead the global effort to avoid dangerous climate change*).
- The underlying scientific knowledge about climate change.
- The impact of any targets on the UK economy, on taxation, public spending or public borrowing, or on UK competitiveness (particularly in specific sectors).
- The social impacts of the targets, especially the potential impact on fuel poverty.
- The likely level of domestic action and the availability of traded allowances.
- The contribution of traded vs. non traded sectors to the UK burden, allowing for any issues relating to supplementarity.
- Energy policy and the relationship with energy supplies and energy intensity, as well as other potential commitments (e.g. the EU renewables target).
- Other ancillary impacts or benefits.

One of the most important of these additional factors is the EU targets and burden sharing negotiations. Even if the CCC decides on a higher 2020 target (towards 32% for example), e.g. on the basis of the methods advanced here, then there is still an issue on how to present the UK position at any European negotiations. This arises because of the two tier agreement, first in relation to a 20% unilateral EU target, and second, conditional on international action, the increase to a 30% target. Of course there are many additional complications if the latter occurs, as this would be associated with effectively a global deal of some type, and would change all of the considerations in relation to competitiveness issues, availability of CDM, etc. In very simple terms therefore, from a negotiating position, the UK might want to select a lower 2020 target initially (at or near 26%), consistent with the EU 20% target, to allow some headroom to increase this should the trigger for an EU 30% target come into force (i.e. to allow movement towards or

[78] Also noting that in practice the level of emissions trading engaged in by companies in the trading sectors is outside of government control.

up to 32%). Building in this type of contingency into the UK target may call into question UK government ambitions regarding global leadership on climate change (compared for example to going for 32% irrespective of EU targets). However, the credibility of setting UK targets that are entirely insulated from EU decisions also has to be questioned. It is probably better to explicitly incorporate this type of contingency into the targets than to make the option of such changes tacit, which would leave investors guessing whether or not targets would be revised according to international action. Moreover, the EC itself has a methodology to allocate potential GHG reduction targets to individual Member States such as the UK. The proposed EC legally binding targets for non-EU ETS sectors and renewables are set out below. Alternative options have been proposed to share the overall level of effort from EU ETS sectors and are available from the EC. Based on the EC proposals the UK would be required to achieve a 16% reduction on 2005 levels for non-ETS sectors by 2020 and a level of effort from EU ETS sector equivalent to a 28% reduction (based on the EC's preferred option). Note that the emission reduction targets are relative to 2005, not 1990.

It is highlighted that within this framework, the discussion of burden sharing and EU targets is an important one. Indeed, it could be considered central to the decision over interim targets. It will therefore be extremely important for the CCC to work through the EU methodology to derive the implied starting point of the negotiations for the UK. This will need to involve a direct comparison between the EU burden sharing assumptions and the UK 26-32% range in equivalent terms, as these involve different metrics and time periods, i.e. the EU GHG reductions on 2005 levels vs. the UK $CO_2$ reductions on 1990.

The second key area relates to ancillary benefits. We consider that these need to be addressed more explicitly (see earlier recommendations), particularly in relation to the potentially large ancillary benefits of air quality and security, as these provide immediate benefits (up to 2020) and are likely to increase with more ambitious targets. We recommend that are considered as part of the wider non-formalised analysis of the costs and benefits of different target levels.

- Ancillary air quality benefits. Numerous studies have shown that air quality ancillary benefits of GHG mitigation are a significant benefit, offsetting a substantial proportion of mitigation costs. Whilst the full benefit of GHG reductions resulting from further climate action may only be experienced by future generations, the ancillary benefits of climate policy accrue to the current generation. These ancillary benefits are larger for more ambitious interim targets, i.e. a 32% target will achieve greater ancillary air quality benefits in the short-term than a 26% target. This can use the monetised damage cost estimates from Defra (IGCB) for air pollution emissions to provide costed estimates of the ancillary benefits of alternative target levels. Recent work undertaken by the EC estimates that the monetary co-benefits to the UK of achieving the joint EU targets (GHG reduction and renewables) are 2.3 to 6.5 billion Euro per year. It is recommended that sCCC estimate the ancillary air quality benefits (monetised, and contribution to air quality objectives)) for the range of targets.
- Analysis of the security of supply benefits. The Energy White Paper predicts that by 2020, around 80% of the UK's fuels are likely to come from overseas, due to a decline in indigenous reserves of oil and gas, and a move to imported energy. As a result, the UK will face greater exposure to developments in the global energy system. It will also be potentially affected by a number of costs, directly in market prices or as externalities. These include infrastructure costs to move to an energy importer, foreign policy arrangements, energy security externalities (including macro-economic effects of imports and energy supply risks (and/or volatility)). It is generally assumed that lower carbon technologies will have ancillary benefits from reducing dependence on imports and so increasing energy security.

Some analysis of these effects and the potential difference across the range of interim targets is recommended (at least qualitatively, and perhaps quantitatively).

The third key area relates to ancillary impacts.

- Analysis of the potential social impacts of fuel poverty from different target levels. Energy price rises in recent years has reversed the trend of falling fuel poverty levels in the UK. A potential downside of a more ambitious interim target could be a knock on effect on fuel poverty (though presumably redistributive policies could be put in place to address this). An assessment of the potential fuel poverty impacts for the target levels could be assessed quantitatively (there are existing government models linking fuel prices to the number of households in fuel poverty).

The final set of ancillary effects relates to macro-economic effects, competitiveness, innovation, technology spillovers, etc. The short-to-medium-term macro impact of different carbon budgets can be assessed with a number of models, and some analysis in this area is warranted. Finally, there is a need to take account of possible public finance costs in the decision making process and options which look otherwise appropriate but which require substantial public spending should be highlighted as such. The use of formalised CBA could be used in assessing all of the categories of non-carbon benefits, and we recommend such a framework be considered for many of the ancillary and economic effects of policies (e.g. air quality). This would allow the presentation of all non carbon costs and benefits of targets alongside their carbon effects. However, some of these 'other elements' may be difficult to monetise formally in practice. The work on monetisation is less well advanced in some important areas, such as energy security externalities, where the literature is controversial and monetised values have not been used in UK government regulatory impact assessment. This may mean that the analysis of non-carbon benefits is also undertaken within a non-formalised (i.e. Stern-like) consideration of costs and benefits.

Finally, the analysis of the costs of meeting these targets will also need to consider the use of emissions trading. For the sectors that have access to credits from international emissions trading schemes to meet their targets, the UK government is not in control of the extent to which emissions abatement is delivered within UK national boundaries and how much is purchased from the market. This balance will depend on commercial decisions being taken by companies in the choice of investments they make and the way they operate their plant. Nevertheless, the target set for the trading sector should be considered as contributing to the UK target whether or not it is delivered domestically.

For the non-trading sectors (e.g. domestic and road transport), the government will need to decide on behalf of the public how much to engage in international emissions trading vs. achieving emission reductions domestically. This will involve calculations of the economic consequences, in particular comparing the expected cost of domestic emission reductions compared to expected international credit prices. In addition to these basic economic considerations, there are a number of other factors that could be taken into account:

- The choice of whether to purchase allowances or make domestic emission reductions should involve not just a single scenario of expected costs at a given time, but should be a dynamic decision that takes into account cost and price uncertainties and recognises the potential for governments to adapt to new information regarding these uncertainties. For example, a decision to support domestic measures with a higher cost than the expected market price could act as a hedge against possible market price rises and/or greater than expected stringency of future targets. On the other hand, purchasing credits could be a robust strategy if there is the possibility of significant new information on costs of abatement, or if the costs of domestic emission reductions are particularly sensitive to their timing, in which case the use of trading could provide valuable flexibility. These types of dynamic decision-making criteria are discussed in more detail in Chapter 4 and Appendices 4 and 5.

- If target setting is to be carried out largely at the EU level, then the UK government may wish to engage in trading as a tool to manage delivery of UK targets in two main respects. Firstly, if the UK has information about the balance of pre-2020 and post-2020 costs which are not factored into the targets set by the Commission, then trading could be an appropriate way to smooth out these costs. This could include buying credits, but could also in principle include selling credits (through the JI route) if UK the balance of pre- and post-2020 costs suggests that it would be sensible to overshoot the targets set by the EU. Secondly, given that the EU may change from a 20% GHG target to 30% GHG target (contingent on signing an international climate agreement), then the UK government may well want to keep open the option of trading as a way of maintaining the flexibility to accommodate this shift in the target.
- The decision on trading sends contrasting political messages to different audiences. Purchasing international credits indicates faith in the general principle of emissions trading as well as in the integrity of the particular markets. On the other hand, investing in emission reductions domestically indicates that the government is committed to getting the economy onto a more sustainable footing, and perhaps strengthens the credibility of any attempt to take a leadership role in international negotiations.

There is also a need to take account of the emerging issue of leakage and related issues. These are potentially important, and it is recommended that the CCC consider the implications for the UK targets.

The methodologies described in this report for setting 2020 targets in relation to some long-term goal for 2050 can also be applied with respect to the problem of setting interim carbon budgets for the periods 2012 and 2017. It is assumed that this division of effort between carbon budgets will take place once the 2020 target has already been decided. Various approaches to allocating across budget periods could then be taken:

- A simple linear interpolation between current emissions and the implied 2020 emissions could be made to give equal absolute reductions in each time period.
- The linear trend could be modified to account for the kind of ‘slow-response’ effects discussed in Appendix 2. Taking account for inertia in the economic response to climate change policy, one might expect less emission reductions in the earlier periods and greater emission reductions in the later periods (even with equally strenuous policy effort across the 3 budget periods).
- Given uncertainty in the final emission reductions to be achieved in 2020, together with uncertain costs, one might set carbon budget for the earlier periods to be more stringent than the later ones in order to account for the option value that this would bring in terms of making possibly tougher-than-expected 2020 targets achievable.

A more quantitative approach would be to take account of the expected evolution of abatement costs during the three periods using technology models or cost curves (see main report for details, and important caveats).

## Recommendations

Overall, the challenge in setting interim carbon budgets for the UK is one of setting short-term emissions targets under multiple sources of uncertainty about the future. However, many of these uncertainties will be reduced in the future. On this basis, any methodological approach taken should consider the extent to which interim targets keep options open for setting targets in the longer term, thereby avoiding irreversible commitments.

On the basis of the methodology review, we recommend the CCC adopts a pragmatic and consensus based approach for setting targets, that that would address the uncertainty in decision making. The specific recommendations from the study are for a non-formalised economic approach, with the following steps:

1. To frame a range of long term UK carbon reduction goals. This range should consider alternative perspectives (stronger economic and stronger precautionary) and associated approaches for setting long-term targets.
2. To recognise the uncertainty over what the UK might want to achieve in the long term. Following from this, to use an options-based approach to keep different long term goals open. The options approach should consider the feasibility and costs of achieving the long term goals contingent on near / medium term action.
3. To set interim budgets based on a cost effectiveness approach (including option value), taking account of international agreements / commitments including EU burden-sharing. This analysis should take account of uncertainty in cost estimates and implementation.
4. To complement the steps above with an assessment of the wider ancillary risks and benefits of different interim carbon budgets including environmental, social and economic considerations (e.g. air quality, fuel poverty, energy security, employment, trade, competitiveness, public finances, innovation). The analysis of these non-carbon benefits could be undertaken within a formalised cost-benefit analysis framework (and presented alongside carbon effects), though uncertainties may necessitate a broader approach.

The recommended approach therefore uses cost-effectiveness analysis as the central pillar of a multi-attribute framework (a non-formalised comparison of costs and benefits). The recommendations focus on the 2020 interim targets, but the same methodological issues apply for the preceding 5 year budgets. Outlining the steps above in more detail:

- First, that the analysis should be centred around the analysis of cost-effectiveness. This requires detailed knowledge of marginal abatement cost-curves (currently being commissioned by OCC). These cost-curves will provide the preliminary information to assess whether the existing target (of 26 to 32%) is achievable and at what costs, and whether there are any step changes in marginal abatement costs across this range. This includes sectoral and composite cost curves (to identify overall marginal costs and to potentially allocate budgets sectorally), along with additional consideration of macro-economic impacts (e.g. on GDP and between sectors).
- Still within the framework of cost-effectiveness, we advance an options / hedging analysis. Whilst the large uncertainty around the optimum (or even preferred) long-term target remains, then a sensible consideration is to investigate whether the target set in 2020

precludes achievement of different targets later (e.g. does a UK 26% target in 2020 make a UK 80% reduction in 2050 unachievable[79].

- In addition, wider factors should be considered as part of a multi-attribute framework. This includes consideration of social aspects (e.g. fuel poverty), environmental aspects (e.g. ancillary air quality benefits), security aspects and economic aspects (e.g. macro-economic effects). It also includes a specific political element, with a key focus on the UK position for the EU 202 burden sharing negotiations, and how this might influence the choice of UK targets.
- Formalised CBA can play a supplemental role:
    - There is a need to investigate the consistency of current recommendations on the shadow price of carbon (SPC) used in Government appraisal in relation to the interim carbon budgets (and estimates of the marginal abatement costs of these budgets). Some CBA work using the SPC would therefore seem appropriate (as the SPC is path dependent i.e. according to a 500 or 550 ppm stabilisation path, there is a need to potentially expand the existing SPC analysis).
    - Other ancillary monetary benefits (air quality improvements) should really be undertaken as part of this assessment, particularly as these benefits accrue immediately to the current generation (unlike the benefits of climate policy).
    - Formalised CBA can be used to understand in general terms the implications of various scientific, economic and social issues and can be periodically undertaken when new information comes to light on any of these issues as a means to 'check' the economic case for Government policy, comparing estimates of the marginal costs and benefits of recommended carbon budgets (potentially for interim and long-term targets). However it must again be stressed that the resulting information is unlikely on its own to be decisive.
- The steps above consider a range of perspectives and frameworks, and investigate the differences that these would imply in the targets. It includes a strong economic approach based around cost-benefit analysis (using the SPC and values for other stabilisation targets), and a stronger precautionary approach based around keeping future ambitious stabilisation targets open. We believe the information from these different approaches, investigating different frameworks with the same input data, provides important information for different stakeholder groups, and strongly advocate that they are used as complements in the target setting process.
- Connected with the setting of interim domestic targets is the question of how much will be delivered domestically vs. purchased internationally. The availability of international credits potentially reduces the cost of meeting targets if the prevailing market price is lower than the cost of domestic measures. Even in the case where this cost difference is not large, emissions trading provides valuable flexibility to companies (and to the government) with respect to smoothing out the costs of meeting targets at fixed points in time when the costs of abatement might be quite sensitive to their timing (e.g. this could be the case in relation to the timing of the turnover of large capital infrastructure projects). The existence of emissions trading would therefore be expected to lower the costs of meeting any given target, suggesting that all else equal, more stringent targets could be taken on. Some sectors will have access to these emissions trading markets, but for those that do not, government will have to take a decision on the extent to which emission reductions are delivered

[79] Assuming that under international agreements, similar levels would be adopted by developed countries. This also applies to the next bullet.

domestically vs. internationally. This decision will involve a combination of economic and political considerations.

It is highlighted that currently the target range available to the CCC ranges from 26 to 32% in 2020, but could (in the future) be widened. The same approach also will inform the interim targets for the periods up to 2020. The method also has to be seen in the context of an existing 2050 target, but with considerations that this might change in the future.

# Chapter 7 Road Map

This final section aims to outline the recommendations into a structured and coherent decision-making process, or road map. This road map is necessarily a simplification of the many factors that could influence a choice of target. Some key framing assumptions behind the road map include:

- Firstly, the road map characterises the decision facing the CCC as a binary choice between a target of 26% or 32% reduction in the UK relative to 1990 levels. In reality, the CCC could choose a value somewhere in (or outside of) this range, and also go through similar processes for the earlier budget periods. However, presenting the problem as a binary choice helps to clarify the logical flow of the decision making process, and can therefore help to identify which are the pivotal questions that need to be answered in order to calculate an appropriate value in the range.
- Secondly, the road map characterises the UK-level decision as being framed within an uncertain global-level choice between stabilisation at a high or a low atmospheric concentration of $CO_2$. It does not specify what these concentrations are, but assumes that this global 'choice' would impact on the long-term (e.g. 2050) targets to be met by the UK. The relationship between global and UK-level emissions targets is not specified. As discussed in Appendix 2, this relationship will depend strongly on the broad architecture and on the specific assumptions used for allocating emissions rights.

The road map considers a series of questions which try to differentiate between the outcomes and cost implications of choosing either 26% or 32%.

The road map considers a series of questions which try to differentiate between the outcomes and cost implications of choosing either 26% or 32%. The road map is split into two parts. The first part of the road map is concerned with factors that relate to conditions pertaining prior to 2020. These include estimates of the relative cost of the two options, ancillary costs and benefits affecting the choice, and issues of political economy, most notably the effect of targets set at the EU-level.

The second part of the road map takes into account how the 2020 target will affect post-2020 targets. In particular, it considers the balance of pre-2020 and post-2020 costs, given that the level of abatement achieved prior to 2020 may affect the cost (and possibly the achievability) of abatement post-2020.

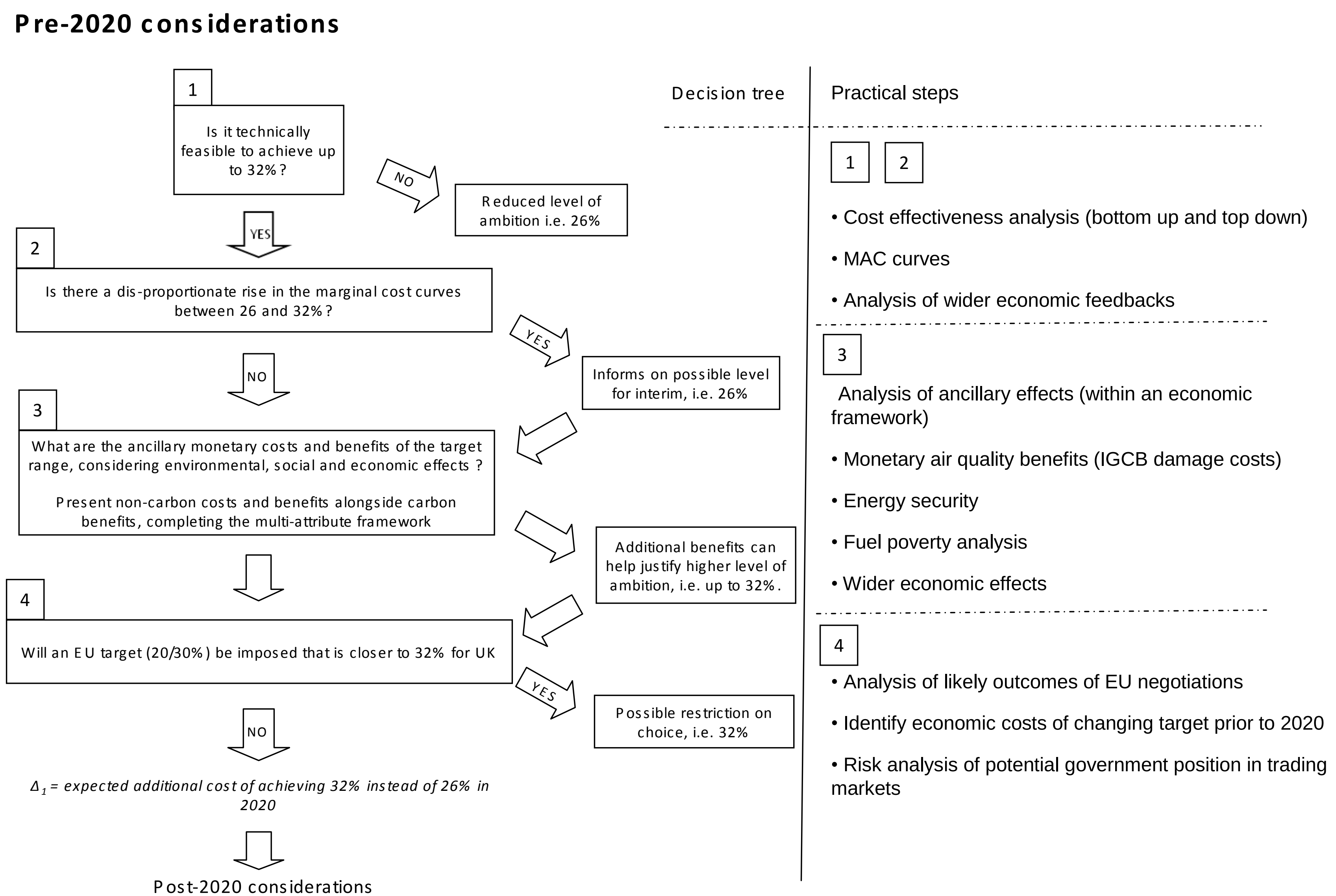



**Figure 7.1 Schematic Decision Process, or Road Map (Pre-2020 Considerations)**

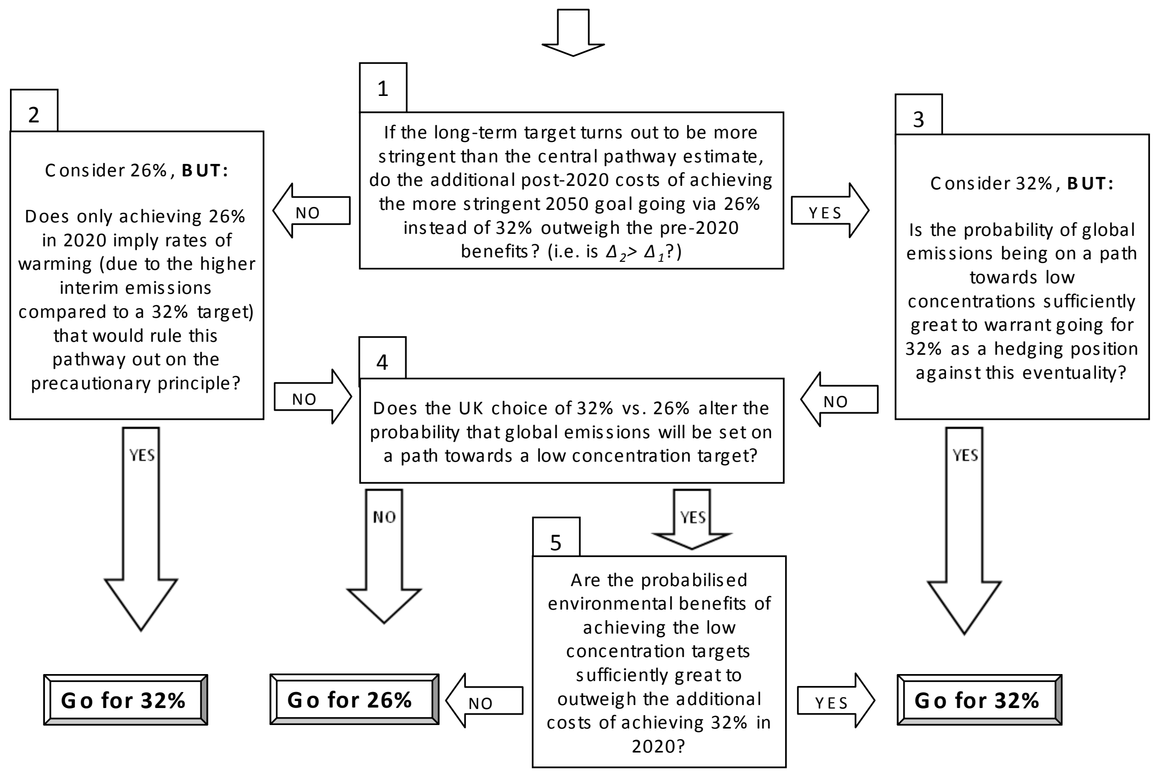
## Post 2020 Considerations

Framing an Options Problem

The problem is illustrated as a decision tree, choosing between two discreet values of 26% and 32% for the 2020 target in the face of uncertainty with respect to the UK's 2050 goal, together with uncertainty in the global emissions path and environmental target. Note that there are many other uncertainties for which options analysis could be carried out.

Suppose that the cost-effectiveness and pathways analysis suggested that 26% would be a suitable central estimate for the 2020 reduction target, but that because of uncertainty in the 2050 target, there may be value in going for a more stringent 32% reduction because it could turn out cheaper if the long-term target ends up being more stringent than expected.

Call $\Delta_1$ the expected additional cost of achieving 32% instead of 26% in 2020.
Achieving the more stringent 2050 target will be harder if only 26% reduction has been achieved in 2020. Call this expected difference in post-2020 costs (discounted to today's values) $\Delta_2$.




Practical steps

1

- Abatement cost analysis pre- and post-2020
- Costs of accelerating emission reduction rates
- MAC curves
- MARKAL

2

- Risk analysis of tipping points
- Sensitivity to rates of warming

3

- Analysis of likely political outcomes of UNFCCC negotiations

4

- Analysis of strength of causal link between UK and global emissions targets

5

- Assessment of the implied climate benefits accruing to the UK of shifting to a more ambitious global stabilisation level

**Figure 7.2 Schematic Decision Process, or Road Map (Post 2020 considerations)**

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