Carbon Valuation in UK Policy Appraisal: A Revised Approach

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Executive Summary

With the onset of binding carbon budgets applying across the UK economy, a robust approach to valuing emissions is vital in order to ensure that Government takes full account of climate change impacts in appraising and evaluating public policies.

The previous approach used within Government to carbon valuation in policy appraisal, called the Shadow Price of Carbon, is based on estimates of the lifetime damage costs associated with greenhouse gas emissions drawn from the Stern Review (known as the Social Cost of Carbon, or SCC).

This paper sets out a revised approach to valuing carbon in policy appraisal, following a review undertaken within Government in the course of 2008 and early 2009. It concludes that the approach, based on estimates of the SCC, should be replaced with a target-consistent approach, based on estimates of the abatement costs that will need to be incurred to meet specific emissions reduction targets. The case for change is motivated by the considerable uncertainty that exists surrounding estimates of the SCC. The change will have the effect of helping to ensure that the policies the UK Government develops are consistent with the emissions reductions targets that the UK has adopted through carbon budgets and also at an EU and UN level.

Under the new approach, the precise valuation methodology differs according to the specific policy question being addressed:

- For *appraising policies that reduce / increase emissions in sectors covered by the EU Emissions Trading System (ETS),* and in the future other trading schemes, a '**traded price of carbon'** will be used**.** This will be based on estimates of the future price of EUAs and, in the longer term, estimates of future global carbon market prices;

- For *appraising policies that reduce / increase emissions in sectors not covered by the EU ETS* (the 'non-Traded Sector') a **'non-traded price of carbon'** will be used, based on estimates of the marginal abatement cost (MAC) required to meet a specific emission reduction target;

- In the longer term (2030 onwards) consistent with the development of a more comprehensive global carbon market, the traded and non-traded prices of carbon will converge into a single traded price of carbon;

- For the purposes of *setting emissions reductions targets and global stabilisation goals*, **formal modelling evidence, including evidence on the social cost of carbon** will continue to be an important input. In practice, given the imperfect nature of our knowledge, these will be supplemented by political judgement and the outcomes of international negotiations.

The purpose of this paper is to: assess the case for adopting the new approach; provide an overview of the empirical work undertaken to implement it; and present the new values. The new values are as follows:

- A short term traded price of carbon of **£25 in 2020**, **with a range of £14 - £31.**

- A short term non-traded price of carbon of **£60 per tonne CO_2e in 2020, with a range of +/- 50% (i.e. central value of £60, with a range of £30 - £90).**

- A long term traded price of carbon with a value of:
  - **£70 per tonne of CO_2e in 2030, with a range of +/- 50% (i.e. £70 central estimate, £105 high estimate and £35 low estimate).**
  - **£200 per tonne of CO_2e in 2050, with a range of + / - 50% (i.e. £200 central estimate, £300 high estimate and £100 low estimate).**

- Linear interpolation is used to form a price series between 2020 and 2030, and 2030 and 2050.

These new values will be used in Government appraisal from now on and have been used to appraise policies and proposals set out in The UK Low Carbon Transition Plan.[1] In relation to future reviews, the non-traded price and long term traded price will be reviewed in the event of significant changes to emissions reductions targets (e.g. following the outcome of international negotiations and at the time of setting the level of carbon budgets). In practice this means that the non-traded and long term traded prices will be reviewed in 2011 taking into account the outcome of the international negotiations in Copenhagen and the setting of the fourth carbon budget. Thereafter, the values will be reviewed every five years, in line with the carbon budget setting process. The short term traded price will be reviewed more regularly, alongside periodic updates of fossil fuel price scenarios.[2]

[1] DECC (2009) The UK Low Carbon Transition Plan (July 2009).
[2] These are generally updated around once a year.

1. Introduction

This paper sets out a revised approach to valuing carbon in policy appraisal, following a review undertaken by senior Government economists in the course of 2008 and early 2009. It replaces the Shadow Price of Carbon (SPC), the previous methodology used to value carbon in UK policy appraisal.

1.1 Why value carbon in policy appraisal?

The fundamental purpose of assigning a value to the GHG emissions that arise from potential Government policies is to allow for a more objective, consistent and evidence-based approach to determining whether such policies should be implemented. Carbon values are used in the framework of broader cost benefit analyses to assess whether, taking into account all relevant costs and benefits (including impacts on climate change), a particular policy may be expected to improve or reduce the overall welfare of society.

With the onset of binding carbon budgets applying across the UK economy, a robust approach to valuing emissions is vital in order to ensure that Government takes full account of climate change impacts in appraising and evaluating public policies and projects, whether those policies are intended to reduce emissions or are likely to have the effect of increasing emissions. Such policy decisions often involve making choices between competing policy objectives, and assigning a value to carbon helps ensure that such choices are made in a transparent fashion and in a way that is most cost effective for UK society as a whole.

In this respect, it should be noted that making any policy decision – to proceed or not with an investment or policy proposal - involves assigning an *implicit* value to carbon. Making valuation *explicit* helps to:

- Ensure the climate impacts of policies are fully accounted for;
- Ensure full account is taken of the evidence in decisions;
- Ensure consistency in decision making across policies; and
- Improve transparency and scrutiny of decision making

... all of which should lead to better policy making.

Policies and projects that are likely to have a material impact on emissions include:

- policies where one of the primary purposes is to reduce emissions, including trading schemes such as the EU Emissions Trading System and standards and regulations designed to improve energy efficiency;
- policies that put an explicit price on carbon such as taxes and subsidies;
- investments in infrastructure and projects that are relatively carbon-intensive, including certain investments in the power and transport sectors; and

- investments in low carbon infrastructure that serve to displace or defer higher intensity investments. These also include certain investments in the power and transport sectors.

The approach adopted to valuing carbon can have a significant impact on the assessment of the costs and benefits of these policies and other policies that have less obvious, but potentially significant, carbon impacts (such as policies that increase the demand for road transport).

It should be stressed that the carbon values discussed in this paper apply whatever the type of policy or project being appraised, providing there is some material impact on emissions. It is not the aim of this report to discuss how these policies should be designed but rather to provide carbon values to be used in the economic appraisal of these policies. Guidance on the design of policies to reduce emissions is provided in a separate DECC / Defra publication.[3]

Detailed practical guidance for analysts on how to apply the carbon values in appraising policies is available on the DECC website.[4]

1.2 Previous reviews of the value of carbon

In December 2007, the Government published a paper outlining a revised approach for the valuation of climate impacts in project and policy appraisal.[5] This approach updated the previous 2002 guidance[6] on valuing greenhouse gas emissions in appraisal. The Government's revised approach allowed more recent evidence – from the Stern Review[7] - to be incorporated into the way in which climate impacts are accounted for across Government. It set a value for emissions changes in 2007 of £25.5/tCO_2e[8] (in 2007 prices), rising at a rate of 2% per annum in real terms. Thus this revised methodology continued to use

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[3] The issue of how to design policies to reduce emissions is dealt with in a separate paper "Making the right choices for our future" (March 2009) available at http://www.defra.gov.uk/Environment/climatechange/research/pdf/economicframework-0309.pdf

[4] "Greenhouse Gas Policy Evaluation and Appraisal in Government departments" (December 2008) available at http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/greengas-policyevaluation.pdf

[5] "The Social Cost Of Carbon And The Shadow Price Of Carbon: What They Are, And How To Use Them In Economic Appraisal In The UK" (Defra, 2007). Available online at: http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/background.pdf
An early draft of new guidance was peer reviewed by a group of academics in August. These peer reviews were published in January, alongside a response to the comments.

[6] Clarkson, R. and K. Deyes (2002). Estimating the social cost of carbon emissions. Government Economic Service Working Paper 140. London, HM Treasury. Available at: http://www.hm-treasury.gov.uk/d/SCC.pdf

[7] Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge, UK, Cambridge University Press. Available at: http://www.hm-treasury.gov.uk/sternreview_index.htm

[8] 'CO_2e' refers to carbon dioxide equivalent. Non-CO_2 greenhouse gases have a global warming potential (GWP) ascribed to them. This describes their warming potency relative to carbon dioxide. For example, methane has a 100 year GWP of 21 – its CO_2 equivalency is 21 tonnes.

the social cost of carbon (the lifetime damage costs associated with incremental greenhouse gas emissions) as the basis for valuation.

In the 2007 paper, the Government committed to reviewing the value of carbon used in appraisal in 2008 and in particular to considering whether the carbon values used in policy and project appraisal should continue to be based on estimates of the social cost of carbon - i.e. a figure that is based on the present value of the lifetime damage costs associated with GHG emissions - or whether an alternative 'target consistent' approach should be used. This would involve valuing carbon on the basis of the marginal abatement cost (MAC) required to achieve a specific emissions reductions target.

The paper anticipated that this review would take place when sufficient information on abatement costs at the UK level and internationally had been developed. Through the work on carbon budgets conducted by Government and the Committee on Climate Change, and the work on global carbon financial flows carried out within DECC, Government economists have access to several sources of abatement cost data (including the integrated UK MAC model and the international Global Carbon Finance or GLOCAF model) that, along with wider evidence on global abatement costs, allows the target consistent approach to be implemented.

The conclusions of the review – that we should move to a 'target-consistent' approach to carbon valuation – are set out in the rest of this paper. Under this approach, from now on, the appraisal of individual policies will be based on explicitly target-consistent values of carbon. These will be based on a '**traded price of carbon'** for appraising policies that reduce / increase emissions in sectors covered by the EU ETS (and in the future other trading schemes) and, in the short term, a **'non-traded price of carbon'** for appraising policies that reduce / increase emissions in sectors not covered by the EU ETS). In the long term, a single traded price of carbon will be used. For the purposes of setting emissions reductions targets and global stabilisation goals, **formal modelling evidence, including the social cost of carbon** will continue to be an important input.

The purpose of this paper is to set out the case for adopting the new approach, to provide an overview of the empirical work undertaken to implement it and set out the new values for carbon to be used in appraisal.

1.3 Overview of the paper

The rest of this paper is structured as follows:

- Part 1 contains the rationale for the change in approach, and comprises three chapters:
    - Chapter 2 discusses the variety of possible approaches to valuing carbon;
    - Chapter 3 discusses the previous approach, based on estimates of the Social Cost of Carbon, and sets out some of the difficulties in using this approach; and,
    - Chapter 4 sets out the new, 'target-consistent' approach, based on estimates of abatement costs, and discusses the targets that should be taken into account in implementing such an approach.

- Part 2 presents an overview of the approach taken to estimate the new values. It comprises:
    - Chapter 5 provides an introduction to the quantitative analysis;
    - Chapter 6 sets out the approach to estimating the traded price of carbon up to 2020 and new values;
    - Chapter 7 sets out the approach to estimating the non-traded price of carbon up to 2020 and new values;
    - Chapter 8 describes the approach to setting the long run price of carbon and presents the new values;
    - Chapter 9 combines the analytical work into a carbon price schedule, compares the results with evidence from the Stern Review and discusses how frequently estimates should be revised;
    - Chapter 10 considers the use of damage costs and other evidence to inform target setting; and,
    - Chapter 11 discusses the revision of the carbon valuation methodology and the new carbon values.

- Part 3 describes how the new approach to carbon valuation will be applied in practice:
    - Chapter 12 considers the use of carbon valuation in policy making;
    - Chapter 13 addresses reporting and auditing requirements; and,
    - Chapter 14 discusses potential international applications.

- Annex 1 summarises the implied non-traded price of carbon for a range of MACC scenarios that have been analysed.

- Annex 2 provides an overview of the GLOCAF model.

- Annex 3 provides a comparison of GLOCAF with other model estimates.

- Annex 4 shows a comparison of Traded and Non-traded Prices of Carbon with the Previous Shadow Price of Carbon from 2008 – 2050 (£2009).

- Annex 5 provides results of the audit of the use of the Shadow Price of Carbon.

- Annex 6 provides a short bibliography of works referenced.

Any comments on this document should be sent to climatechangeeconomics@decc.gsi.gov.uk

Part 1: Rationale for revising the approach to carbon valuation

2. Alternative approaches to valuing carbon

There are several possible methods for assigning a value to carbon:

- basing it on the social cost of carbon, i.e. estimates of the damage caused by emissions released into the atmosphere;
- calculating it with reference to the marginal abatement costs consistent with a given emissions reduction target; or
- setting it equal to the market price of carbon observed in an emissions trading scheme such as the EU Emissions Trading System (EU ETS).

Under certain conditions, these three approaches will produce the same result. This chapter sets out those conditions, before considering why they do not currently apply. This forms the background for the more detailed discussion of alternative approaches in the rest of this paper.

Finding the optimal emissions stabilisation goal

In tackling climate change, the optimal emissions stabilisation level is found where the marginal cost of abatement (the marginal cost of action) is equal to the marginal damage cost (otherwise known as the Social Cost of Carbon – i.e. the marginal benefit of action). This is a dynamic condition:

$$MAC = SCC \text{ over all } t= 1, 2, \ldots,n$$

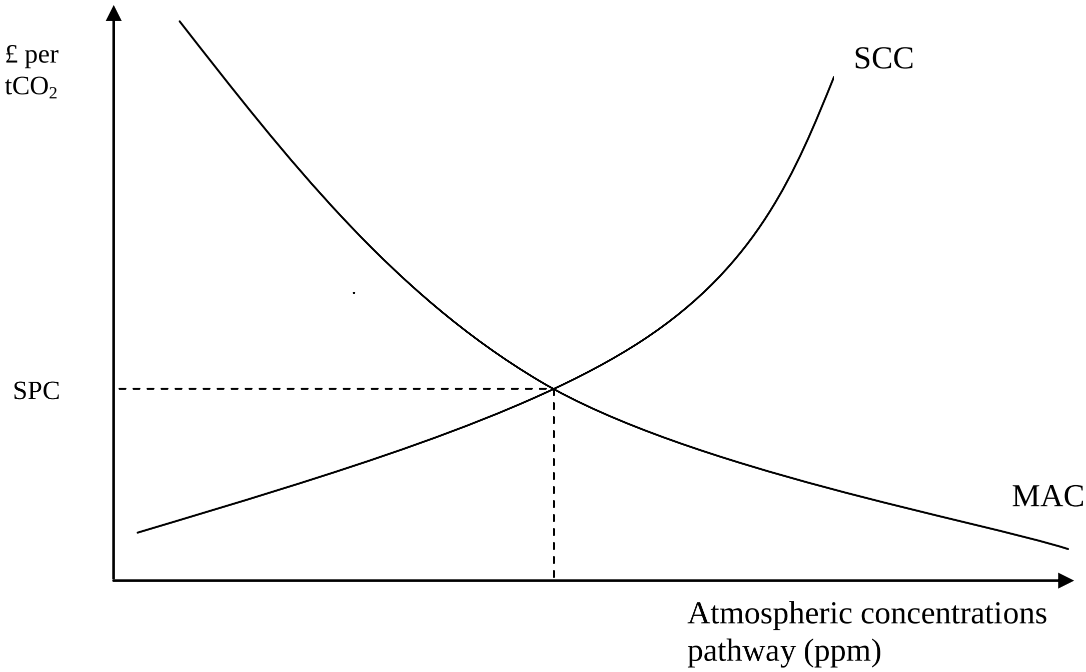
Figure 2.1 illustrates how a rational economic policy-maker with perfect information might approach the problem of optimising an emissions reduction strategy. Given complete information on the social cost of carbon (which in this diagram increases with the level of atmospheric concentrations)[9], and marginal abatement costs over time, an optimal concentration could be reached.[10]

Marginal abatement costs are shown to be rising as atmospheric concentrations fall. For any given level of technology, the marginal abatement cost required to reach lower concentration stabilisation goals will clearly be higher. This is because the additional effort – additional emissions reductions – that is associated with more challenging goals will entail a movement up the abatement curve until the necessary reduction has been achieved.

[9] Please see chapter 3 below.

[10] In the case of climate change, the stock nature of emissions (they inhabit the atmosphere for several hundred years) means that there are some uncertainties going forward regarding the relationship between emissions and concentrations, specifically regarding any unknown atmospheric feedbacks.

Figure 2.1: Comparison of SCC and MAC Associated with Different Stabilisation Goals[11]



In the diagram (Figure 2.1), the optimal stabilisation goal is found where the MAC = SCC, as explained above. The optimal concentration that is identified implies a level of aggregate emissions that is consistent with reaching that scenario. In theory, once the optimal stabilisation goal is identified, the price of carbon consistent with the damage cost on the optimal stabilisation pathway is also that which will produce sufficient abatement to reach that stabilisation goal. In principle, this is the appropriate value of carbon for use in policy appraisal.

Furthermore, if there were a fully comprehensive international trading scheme in place covering all emissions, with a cap set consistent with the optimal stabilisation goal, then the market price of carbon would also be equal to both the MAC and SCC for the stabilisation goal.

In practice, however, this set of conditions does not currently hold. First, there is no fully comprehensive trading scheme from which to infer a single market price of carbon for the whole economy. Second, there is considerable uncertainty surrounding estimates of damage costs and, to a lesser extent, abatement costs, as a result of which, it is very difficult to identify the optimal goal with a strong degree of certainty. Third, partly as a result of this uncertainty, emissions reductions targets may be informed by a variety of factors not limited to the economic and scientific modelling evidence, including

[11] This exposition is not identical to a traditional marginal abatement/marginal damage diagram which would have the x-axis measuring quantity of emissions. In the traditional approach, the MAC curve represents the additional cost of reducing emissions by one unit. Here we take the MAC as a more dynamic concept – it measures the price that is required to produce the emissions reductions that will lead to the atmospheric concentrations pathways on the x-axis.

ethical considerations and the reality of international negotiations on ‘burden sharing’, which may result in highly differentiated emissions reductions for individual countries. In the absence of a comprehensive global trading regime, these different emissions reductions targets will translate into very different marginal abatement costs for individual countries.

As a result of these factors, the three approaches to setting the value of carbon discussed above may produce different answers. The following chapters in Part 1 discuss the different approaches given this uncertainty, and consider the different contexts in which they should be used.

The next chapter considers the approach used to value the previous shadow price of carbon – using the social cost of carbon.

3. Use of the Social Cost of Carbon

3.1 Overview of the previous approach

The value of the SPC was based upon an estimate of the Social Cost of Carbon (SCC). As noted above, the SCC is the marginal damage cost associated with an incremental emission of GHG, summed over its lifetime and discounted back to the year of emission. The SCC estimate on which the previous SPC was based was drawn from the Stern Review. Specifically, it was the SCC from the review which is consistent with an atmospheric concentrations scenario of 550ppmCO_2e.

Why is it necessary to specify the atmospheric concentrations path on which the SCC is based? The modelling from the Stern Review found that the value of the SCC depended upon the prevailing atmospheric concentrations when that tonne of GHG is in the atmosphere. This results from the interaction between three important factors:

1. The concavity of the relationship between emissions and the increase in temperature: i.e. additional emissions produce decreasing impacts upon temperature.

2. The convexity of the relationship between damages and temperature: i.e. damages increase more than proportionately with temperature.

3. Discounting: The discounting regime used in the Stern Review - particularly the endogeneity of the discount rate, but also the fact that lower rates were used than in some other studies - also had an impact.[12]

For the results identified by the Stern Review to occur, the second effect must 'outweigh' the first, subject to the third.[13] It should be noted that there is a debate in the modelling world surrounding this path-dependency. Some other modelling exercises have not identified such a relationship.

[12] The discount rate used in the Stern Review was endogenous and low, two characteristics which allowed the stated results to emerge more clearly. The endogeneity (of the growth component) of the discount rate used in the Stern modelling is important. It allows the discount rate to vary according to the growth path – for those pathways with higher atmospheric concentrations, and so higher damages from climate change, the growth rate, and hence the discount rate, will be lower. Therefore the present value of a given level of economic damage is greater on pathways with higher damage costs. In addition, the fact that the Stern Review discount rate was low meant that the different impacts caused by the two underlying factors, together with endogenous discounting, are really able to emerge. This is especially important in the case of climate change damages which occur far in the future.

[13] Please refer to Simon Dietz's peer review comments of Defra (2007). Available at: http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/simon-dietz.pdf

The Government's 2007 paper[14] outlined the argument for adopting a shadow price consistent with a 550ppm pathway (this argument is covered in greater depth in the publication). The paper noted that our goal is that substantial action will be taken by the world to achieve major emissions reductions, and the Stern review provides an appropriate range to consider in assessing what the outcome of that action will be (450 - 550ppmCO_2e). To be conservative, the paper argued that a value should be adopted at the top of that range (since this implies a higher SPC). Using an SPC consistent with atmospheric concentrations significantly above 550ppmCO_2e might lead the UK, or any other individual country, to do too much relative to other countries and to the goal and adopting an SPC consistent with concentrations below 550ppm might lead us to do too little, given current uncertainties.[15]

3.2 Potential issues with the SCC approach

As noted in the 2007 paper, this approach raises an important question concerning its consistency with the emissions reductions targets to which the UK is committed. These targets exist at three levels:

- internationally, through the Kyoto Protocol: As part of the EU 'bubble', the UK received a burden-share of the required EU effort, which itself was stipulated under the Kyoto Protocol;
- at the EU level, through the traded (emissions covered by the EU ETS) and non-traded (non-EU ETS emissions) sector emissions reductions obligations that will be placed on the UK through the EU climate change and energy package; and
- at the UK level, through the 80% 2050 emissions reduction target set in the Climate Change Act and carbon budgets that have been set following advice from the Committee on Climate Change. Carbon budgets are mandatory emissions reductions targets covering five-year periods. Three periods will be set ahead at any one time, initially for 2008-2012, 2013 – 2017 and 2018 – 2022.

Given these commitments, a compelling question to consider is whether the value of the SPC would allow for sufficient abatement activity to take place to allow the UK to meet its binding emissions reductions goals. A further, broader question that needs to be considered is whether the SCC consistent with a 550ppm stabilisation pathway (if applied globally[16]), would actually lead the world to that goal. In other words, would such a price be consistent with the marginal abatement costs that would need to be incurred in order to reach the global stabilisation goal?

[14] http://www.defra.gov.uk/environment/climatechange/research/carboncost/index.htm

[15] It should be noted that these arguments were made in light of the intended use of the SPC – to appraise individual policies, in relation to any one of which it could safely be assumed that the global stabilisation level was exogenous. Under the revised approach, the SCC will only be used in considering significant changes to the emissions reductions targets themselves. In this context, the above approach – assuming global effort is invariant to action in the UK – is no longer valid. This is discussed in greater detail in chapter 8.

[16] Clearly applying any carbon price to the UK alone will not allow the world to reach a 550ppm pathway, as a result of the small percentage of global emissions from the UK. Concerted global action would be required to achieve such a goal.

As discussed in Chapter 2, the optimal solution would involve finding the SPC that is based on an SCC consistent with a certain ppm stabilisation, and that allows sufficient abatement to be undertaken to enable the stabilisation target to be met. However, in practice there are two key reasons why this theoretical optimal solution may not in practice produce results that are consistent with our emissions reductions obligations. The first relates to the empirical challenges of estimating the global optimal solution and the social cost of carbon associated with it, and the second relates to the process of dividing up the burden of achieving that overall stabilisation goal into individual country emissions reductions targets. These problems are discussed in turn.

Challenges in estimating the global optimal solution and the SCC: use of Integrated Assessment Models

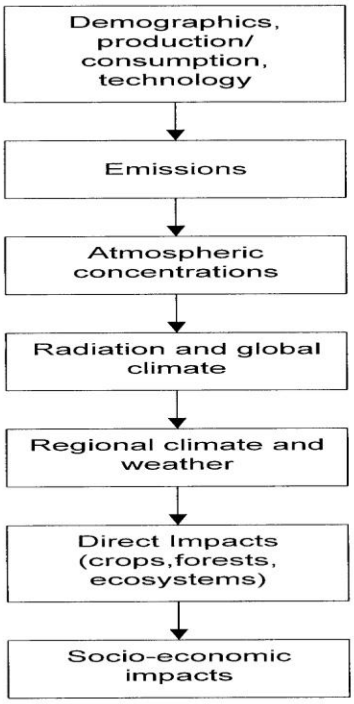
Identifying the optimal stabilisation goal, emissions reductions pathway and the corresponding SCC is a very challenging process, involving empirical uncertainties – scientific and economic - and ethical debates at various levels. Integrated assessment models (IAMs), as their name implies, attempt to integrate climate and economic modelling in order to estimate the impacts of climate change. They produce estimates of the impacts based on assumptions surrounding population and economic growth, the damages associated with changing climate, the discount rate etc. From this, a figure for aggregate damages for various scenarios can be derived.

Figure 3.1 illustrates the methodology of one of the leading IAMs: PAGE (2002)[17] used for the Stern Review and Defra's Shadow Price of Carbon guidance. Social cost of carbon estimates are an output of this approach.

Clearly, this enterprise is a very challenging one, involving a 'chain' of modelling and assumptions over several layers – both economic and scientific – and a series of complex projections over more than a hundred years.

[17] Hope (2006), Yale Symposium on the Stern Review (2007), available online at: http://www.ycsg.yale.edu/climate/forms/FullText.pdf

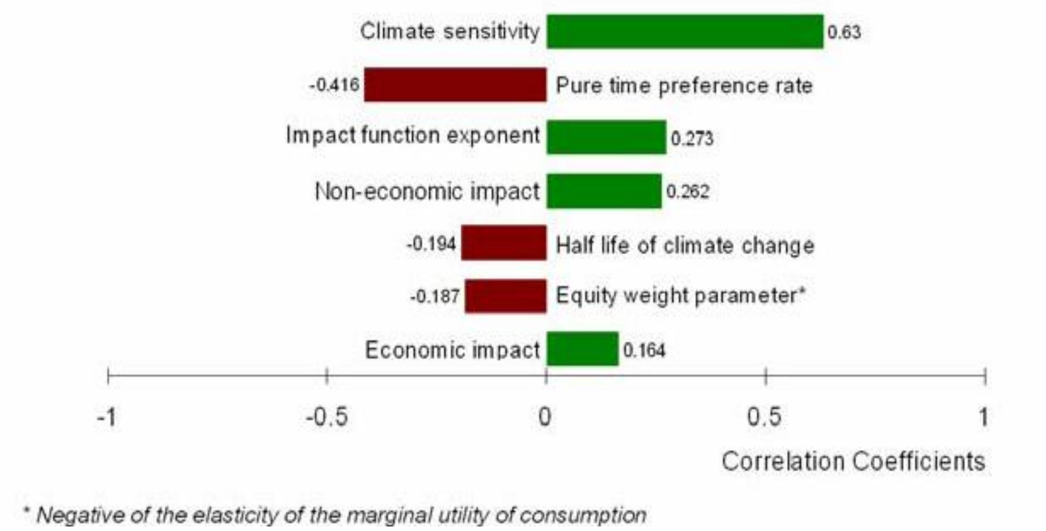
Figure 3.1: Integrated assessment modelling - Summary



Source: Hope (2005)

Figure 3.2 below summarises a few of the major uncertainties and their correlation with estimated damages from the PAGE 2002 model (as used for the Stern Review). As can be seen, assumptions regarding both economic and scientific factors can have a major impact if they are changed, demonstrating how the level of uncertainty involved can translate into different estimates for damages.

Figure 3.2: Sensitivity of SCC estimates to different modelling parameters



Source: Hope (2006)[18]

[18] C. Hope (2006), Yale Symposium on the Stern Review (2007), available online at: http://www.ycsg.yale.edu/climate/forms/FullText.pdf

Of particular relevance to this consideration of the social cost of carbon is the uncertainty that exists over the valuation of climate change damage. We have increasingly rich knowledge of climate change impacts, but they are extremely difficult to value precisely in the form of an integrated model. For this reason an approximation is used – a so-called ‘damage function’.

The damage function in integrated modelling tends to be highly stylised. For example, some models use simple functions with an exponent of 2, i.e. a quadratic function. Convex damage functions are standard, and seem reasonable, as it is likely that each increment of temperature change brings a larger incremental change in damage. However, the evidence for using a quadratic, rather than, say, a cubic function is not strong.[19] Changing assumptions can have significant impacts on results.

The PAGE2002 model (used in the Stern Review, and therefore the basis of Defra’s Shadow Price of Carbon guidance) uses a distribution for the value of exponents, with a range of parameter values of < 1, 1.3, 3 >. As such, the uncertainty around the exponent in damage functions is reflected in this distribution. The Stern SCC estimates are mean values of the range of SCC estimates that arise from modelling many different combinations of PAGE2002 model runs. Whereas the mean will reflect a range of potential outcomes, for public policy choices which are concerned with risk of very bad outcomes, it would be sensible to consider the SCC distribution on the whole, rather than just the ‘average’ (of the modelled) outcomes.

PAGE’s probabilistic approach to modelling provides a more sophisticated approach to modelling than some others, by avoiding single values for parameters. The random combination of parameters allows for various combinations of assumptions for different parameters, a valuable characteristic. However, it has been suggested that even this approach is incomplete as the number of parameters and their possible values mean that it is not possible to model all potential combinations. As a result, the distribution of SCC outcomes may be truncated (at both ends, although the concerns are on the up side where there are the uncertainties over catastrophic impacts). Combined with the fact that the parameter values at the extremes of parameter distributions are less likely to be picked, it could be that such extremes are underrepresented in sampling.

A further part of this uncertainty relates to risks of very damaging, or indeed catastrophic, outcomes. Knowledge around the science and economics of such possibilities is not currently well understood. While knowledge of where so-called ‘tipping points’ may be is increasing, the economic damages that may occur at such tipping points are not well understood, and neither is the speed at which impacts accrue. If these are not modelled completely – which is not

[19] Stanton, Ackerman and Kartha (2008) “Inside the Integrated Assessment Models: Four Issues in Climate Economics”. Somerville, MA, Stockholm Environment Institute -- U.S. Center. Available at: http://www.sei-us.org/WorkingPapers/WorkingPaperUS08-01.pdf

possible if knowledge is incomplete - then estimates of the social cost of carbon are also incomplete.

As a result of the above, there is a high degree of uncertainty in estimates of the social cost of carbon. As noted in DEFRA (2005), estimates of the social cost of carbon range from zero to over £1000/tC, depending on uncertainties in climate and impacts, coverage of sectors and decision variables.
In addition to the uncertainties in modelling the impacts that are included in the model, there are some impacts which are altogether excluded from modelling.

As noted by some of the peer reviewers of the previous Defra SPC paper, current SCC estimates may be an underestimate of the SCC. This is because of the presence of some unquantified (and hard to quantify) impacts such as socially contingent effects. These are the second-round impacts of climate change, such as the cost of mass migrations from inundated countries. Had such impacts been quantified, the SCC (and of course aggregate damage costs) would have been higher. Therefore, basing the optimal course of action solely on estimates of the social cost of carbon may lead to less than optimal trajectories of emissions. As noted in the Stern Review itself, "*the results presented [below] should be viewed as indicative only and interpreted with great caution. Given what is excluded, they should be regarded as rather conservative estimates of costs".*[20]

In addition, Stanton, Ackerman and Kartha (2008) also note that damages are often modelled as reductions in income in a given year, whereas it is likely that some will actually impact upon the capital stock, therefore having multi-period effects.

Finally, it is very difficult to determine the optimal solution based on the social cost of carbon when there is path-dependency present. Path dependency requires an atmospheric concentrations pathway to be chosen in order to adopt a particular SCC. But atmospheric concentrations are themselves optimised, based on an equalisation of the SCC and marginal abatement costs (dynamically). Since the SCC is itself dependent on concentrations, there is a clear problem of endogeneity present.

It is important to note that this uncertainty does not mean that the estimation of climate change damages through Integrated Assessment Models (IAMs), and other outputs of these modelling exercises can be discarded. It is vital that targets be set using the most robust evidence available and Government continues to invest resources into improving understanding of the underlying science (through Hadley centre climate modelling) and economics (through further Integrated Assessment Modelling). Chapter 10 sets out the further work in hand to improve our knowledge of damage costs.

[20] Stern et al (2006)

Other evidence informing the global optimal solution

Given the significant uncertainties in estimates of the social costs of carbon based on integrated impact assessment modelling, such modelling should only be one input into the target-setting decision-making process. In particular, decisions on targets will also take other scientific information, and the associated uncertainties, into account and will be supplemented by other judgements – e.g. regarding the acceptable level of risk that we wish to bear of potentially catastrophic events owing to extreme temperature rises.

The relationship between the concentration of greenhouse gases (GHG) in the atmosphere and the temperature rise at 'equilibrium' (i.e. after temperatures have had time to adjust to the concentration of greenhouse gases) is summarised in Table 3.1. There is uncertainty in how much the climate system will respond to GHG concentrations through feedbacks, and consequently there is a range of possible equilibrium temperatures for any stabilised level of greenhouse gases. Decision-makers may take such evidence into account during the target-setting process.

Table 3.1: Temperature at equilibrium for different GHG concentrations.

Stabilisation level (ppmCO_2–eq)	**Temperature increase at equilibrium** (relative to pre-industrial temperatures)	
	Best estimate	*Likely* range (i.e. 66% chance)
350	1.0°C	0.6 – 1.4°C
450	2.1°C	1.4 – 3.1°C
550	2.9°C	1.9 – 4.4°C
650	3.6°C	2.4 – 5.5°C
750	4.3°C	2.8 – 6.4°C

Source: Technical Summary of WG I's Report to the IPCC AR4.

The relationship between GHG levels and temperature can be used to calculate the probability that equilibrium temperatures will be exceeded at different stabilisation levels. For example, Table 3.2 shows the probability that equilibrium warming will exceed 2°C for different stabilisation levels.

Table 3.2: Probability that temperature rise will exceed 2°C at equilibrium for different stabilisation levels.

Stabilisation level ($ppmCO_2$–eq)	**Probability of exceeding 2°C at equilibrium** Average and (minimum-maximum)
350	7% (0-31%)
450	54% (26-78%)
550	82% (63-99%)
650	92% (82-100%)
750	96% (90-100%)

Source: Meinshausen (2006).[21]

Scientific evidence also shows how emissions need to change to achieve stabilisation goals. For instance, the WG III Report of the IPCC's Fourth Assessment Report concluded that in order to stabilise greenhouse gas concentrations at about 450ppm (giving a best estimate of 2.1°C warming at equilibrium), global CO_2 emissions would need to peak by 2015, fall to at least 50% below 2000 levels by 2050 and continue to decrease thereafter (as shown in Table 3.3).

Table 3.3 Emission pathways to stabilisation

Peaking year for CO_2 emissions	Change in global CO_2 emissions in 2050 relative to 2000 (%)	CO_2–eq concentration at stabilisation (ppm)	Global average temperature increase above pre-industrial at equilibrium (°C)
2000-2015	-85 to -50	445-490	2.0 - 2.4
2000-2020	-60 to -30	490-535	2.4 - 2.8
2010-2030	-30 to +5	535-590	2.8 - 3.2
2020-2060	+10 to +60	590-710	3.2 - 4.0
2050-2080	+25 to +85	710-855	4.0 - 4.9
2060-2090	+90 to +140	855-1130	4.9 - 6.1

Source: Technical Summary of WG I's Report to the IPCC AR4.

The relationship between GHG emissions and atmospheric GHG concentrations is uncertain because the way in which the carbon cycle will respond to changes in climate is not yet fully understood. This, combined with the uncertainty in the relationship between GHG concentrations and temperature, means that the temperature change that will result from any given emissions pathway is also somewhat uncertain.

[21] M. Meinshausen (2006) "What Does a 2°C Target Mean for Greenhouse Gas Concentrations? A Brief Analysis Based on Multi-Gas Emission Pathways and Several Climate Sensitivity Uncertainty Estimates." in H. Schellnhuber, et al., eds. *Avoiding Dangerous Climate Change* (Cambridge University Press, New York, 2006).

The Committee on Climate Change's analysis indicates that if global emissions peak in 2016 and then fall at between 3% and 4% per year, with emissions of other greenhouse gases falling at consistent rates, there is a 37-44% chance that temperatures will remain below 2°C in 2100. If, however, they peak in 2028 and then fall by 3% per year, there will only be a 17% chance of temperatures being under 2°C in 2100.[22]

Decision-makers must take into account the risks of different levels of warming, and adopt a target with an acceptable level of risk. The higher the temperature change, the greater the risk of dangerous climate change impacts.

The Committee on Climate Change (CCC) took each of these factors into account when formulating its advice to the Government regarding the appropriate long-term emissions reduction target for the UK. Specifically, they evaluated the scientific evidence and concluded that in order to minimise the risks of dangerous climate change, the central estimate (i.e. 50/50 probability) of temperature rise in 2100 should be kept as close as possible to 2°C above pre-industrial levels and that the probability of 4°C should be kept to very low levels (below 1%). They then identified emissions pathways that met these criteria, and used these to calculate the emissions reductions needed by the world, and by the UK, to follow these pathways. Based on this analysis, they recommended a reduction in emissions for the UK of 80% below 1990 levels by 2050, and this has been set in law through the Climate Change Act.

In its advice, the CCC recognised the possibility of significant discontinuities in damage costs. For example, its recommendation that future emissions should only allow a very low probability (less than 1%) of a global temperature increase of 4°C was based on the recognition that exceeding 4°C could have potentially catastrophic, but very difficult to value, outcomes. The possibility of such tipping points is one key argument for a move away from marginal damage cost estimates in appraising individual policies, and towards a target-consistent approach, once the overall target has been set.

The UK Government funds world-leading climate research and modelling at the Met Office Hadley Centre (MOHC)[23], aimed at reducing uncertainty in climate science that will narrow the range of uncertainty in temperature projections. The Government is also funding new research under the AVOID programme[24] that integrates mitigation analyses with climate science on dangerous climate change, to increase understanding of likely global, regional and local impacts and their environmental and social consequences. For the UK, the Government has recently published its UK Climate Projections 2009, based on probabilistic modelling undertaken by the MOHC. These will provide information to a wide range of decision-makers on a range of possible climate futures in the UK during the remainder of this century.

[22] Building a low-carbon economy – the UK's contribution to tackling climate change. The First Report of the Committee on Climate Change, December 2008.

[23] http://www.metoffice.gov.uk/climatechange/
[24] http://www.avoid.uk.net/

Burden Sharing

As a result of the uncertainties discussed above, the SCC that formal integrated assessment models would suggest is consistent with a given stabilisation goal may not be equal to the marginal abatement cost that would need to be incurred to allow the world to reach that goal.

However, even if that uncertainty could be overcome, a second issue is raised by the fact that UK emissions reductions targets are derived not just by a global stabilisation goal but also by international agreements that divide up the burden of achieving an overall emissions reductions goal into individual country commitments. In the absence of a comprehensive trading regime, these commitments will imply different marginal abatement costs for each individual country.[25] It therefore follows that there is no reason to believe that a global SCC – even if we were confident it was accurate - will be consistent with a particular country's emissions reductions targets, so long as a comprehensive international trading regime is not in place.

[25] With a global trading regime, there will be a single marginal abatement cost, which all participants will face. The initial burden sharing decision will not affect this. This is discussed further below when we consider valuing emissions reductions in sectors covered by the EU ETS.

4. An alternative approach to valuing carbon

Chapter 3 showed that adopting a damage cost-based approach would not necessarily lead to a carbon price in appraisal which is consistent with reaching a given emissions reductions target. Policymakers and negotiators may set a target of 450ppm, 500ppm or 550ppm but this does not necessarily mean that the SCC corresponding to these levels is consistent with:

- the global marginal abatement costs required to reach such a goal; or
- the marginal abatement costs that would need to be incurred in the UK to enable national emissions reductions targets to be met.

This chapter proposes an alternative approach for valuing the carbon impacts of policies and projects in impact assessments, known as the 'target-consistent' approach. This revised approach addresses this problem and will be used from now on, helping to ensure that policy design and appraisal are consistent with the emissions reductions targets to which the UK is committed.

We first introduce the concept of target-consistent carbon valuation, before arguing that the precise methodology for valuing carbon should differ according to the specific policy question being addressed. The three policy questions are:

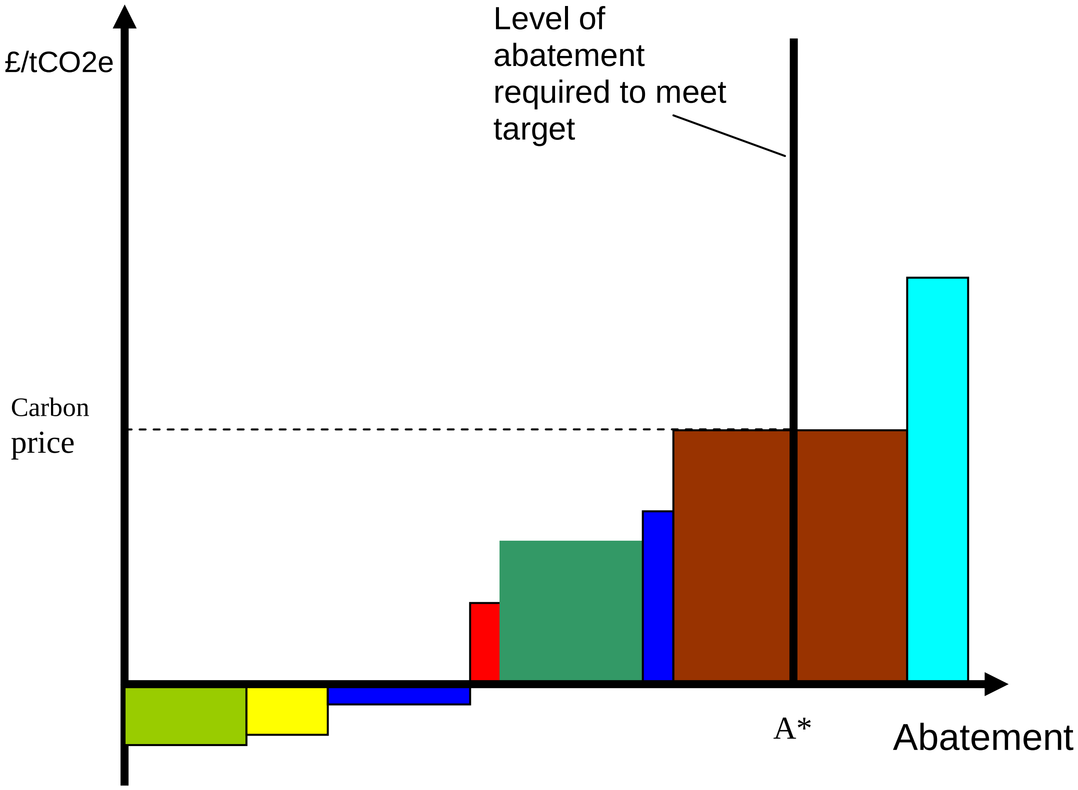
- How should we value carbon for the purposes of evaluating policies that have an impact on emissions in sectors of the UK economy covered by emissions trading?
- How should we value carbon for the purposes of evaluating policies that have an impact on emissions in sectors of the UK economy not covered by emissions trading?
- How should we value carbon for the purposes of setting and appraising new emissions reductions targets?

4.1. Revised approach: an explicitly 'target-consistent' carbon price

A MAC-based or 'target-consistent' price of carbon involves setting a value of carbon that is consistent with the level of marginal abatement costs required to reach the targets that the UK has adopted – either at a UK, EU or international level. This is illustrated, in simplified form, below in Figure 4.1 which illustrates how a 'target-consistent' carbon value would be set. From our understanding of emissions projections and abatement options, we can determine the effort level, A*, that is required in order to meet the UK's targets. Reading across from the abatement curve produces the carbon valuation level that is required in order to be 'target-consistent'.[26]

[26] This particular abatement curve relates to the non-traded sectors, as described below.

Figure 4.1: Abatement cost curve



This alternative approach has been suggested by several commentators, including some of those who peer reviewed the first draft of the Government's shadow price of carbon paper. The paper published in December 2007 announced that Government economists would consider the case for adopting this approach.[27]

4.2 Why adopt a "target consistent" approach?

The target-consistent approach to policy appraisal outlined above clearly marks a departure from standard social cost benefit analysis in which, as under the previous SPC, the value of an externality is based on estimates of its social cost. It is therefore important to be clear about the argument for moving in this direction in the field of climate change.

The preceding chapter set out a key problem with the use of the social cost of carbon in policy appraisal – it is very difficult to value accurately the damage that climate change will create in the long term. Further, climate change impacts are likely to be highly non linear, with temperature increases above 2°C leading to potentially catastrophic, but uncertain and very difficult to value, outcomes. Both of these characteristics raise fundamental problems for calculating marginal damage costs and provide the key argument for a move away from social cost of carbon estimates in appraising individual policies, and towards a target-consistent approach, once the overall target has been set.

[27] http://www.defra.gov.uk/ENVIRONMENT/climatechange/research/carboncost/

The use of a 'target-consistent' approach in appraising policies that have climate change impacts will also have two types of beneficial outcome:

(i) Meeting targets: The revised approach will provide greater levels of confidence that climate change targets can be met. Using a value of carbon that is not equal to the carbon price implied by agreements will lead to either over or underachievement relative to targets.

Adopting an explicitly target-consistent valuation will also strengthen the cost effectiveness of policy-making: having such a value focuses attention on reaching our targets at least cost, preventing expensive emissions reduction policies or policies that, by increasing emissions, will need to be offset elsewhere, would impose a disproportionate cost on the rest of the economy.

Finally, at the EU level the approach will minimise the risks of potentially costly infraction proceedings against the UK.

(ii) Avoiding potential free-riding: The global public good nature of GHG emissions means that there is an incentive for countries to hope that others act, whilst free-riding on the action taken by the world. This is most acute with GHG emissions because of the perfectly-mixing nature of GHGs, leading to their global public good characteristic.

In this context, a situation in which all countries independently adopted carbon prices based on their own social cost of carbon valuation exercises would exacerbate the risk of free riding, since such estimates are likely to vary considerably and may not be consistent with agreed international obligations.[28] The use of a target-consistent approach, if used internationally, should minimise the scope for such free riding.

It is important to recognise that the revised approach would not render evidence on climate change impacts obsolete. As discussed in section 4.5, such evidence is central in ensuring targets are set at the right level.

4.3 Which targets to use in setting target-consistent carbon values in the short term?

Moving to the revised approach would require us to define the targets from which to determine marginal abatement cost. In doing so, it is helpful to distinguish between short-term and long-term targets. Unsurprisingly, we generally have more concrete information about the emissions reductions required for short-term than for long-term targets – indeed we will have annual trajectories until 2020 (for our European targets) and five yearly carbon budgets, initially from 2008 - 2022 as set out under the Climate Change Act. This section considers short term targets while the following section considers longer term targets.

[28] There has been interest in the UK approach to the SPC from other countries and international institutions and we have an important opportunity in adopting a new approach to send a strong signal about how emissions reductions targets should be mainstreamed in policy development internationally.

Short term emissions reductions targets for the UK exist at the UN, EU and UK level. In relation to UN targets, the UK has a national target under the Kyoto protocol to cut greenhouse gas emissions to 12.5% below 1990 levels in the period 2008-12. The UK is projected to meet this target - UK greenhouse gas emissions were 20.7% below 1990 levels in 2006 (including the effect of the EU ETS). UN targets will of course be revisited when a post 2012 global deal is secured, but then EU and UK targets will be determinative.

In relation to EU targets, there is a fundamental distinction between the traded sector of the economy, and the non-traded sector. The traded sector of the economy relates to all emissions which are covered directly, or indirectly (i.e. electricity ***use***), by the EU Emissions Trading System. The non-traded sector covers the remainder of the emissions in the economy.

The European Commission's Climate and Energy Package has given the UK binding emission reduction targets in the traded (i.e. an allocation of EU allowances), and the non-traded sectors.[29] The details of this package stipulate that the UK must reduce emissions by 16% from 2005 levels by 2020 in the non-traded sector. In the traded sector, the UK has been allocated a share of the overall ETS cap for phase 2 and will have a share in phase 3.[30] In total, these targets amount to a 34% reduction (on 1990 levels) for UK greenhouse gas emissions (in the case of a European Union emissions reduction scenario of 20% below 1990 levels).

- It is a key argument of the approach set out here that a clear distinction needs to be drawn between these two sectors in determining the appropriate value for carbon in the short term, as this allows for a more accurate appraisal of policies, with respect to the costs and benefits to the UK, and is consistent with our European obligations. We therefore propose that, for *appraising policies that reduce / increase emissions in sectors covered by the EU ETS* until 2020 a '**traded price of carbon'** would be used**.** This would be based on estimates of the future price of EUAs;
- For *appraising policies that reduce / increase emissions in sectors not covered by the EU ETS* (the 'non-Traded Sector') until 2020 a **'non-traded price of carbon'** would be used, based on estimates of the marginal abatement cost (MAC) required to meet the UK's non-traded sector emissions reduction target.

The sections below set out the revised approach to valuing emissions in policies affecting these sectors in more detail, before exploring in greater detail the pros and cons of the dual price approach.

[29] Some uncertainties remain, for example over the final size of the UK allocation of allowances from the ETS New Entrants Reserve.
[30] Determined by the sum of allowances auctioned by the UK Government and allowances freely allocated to installations in the UK.

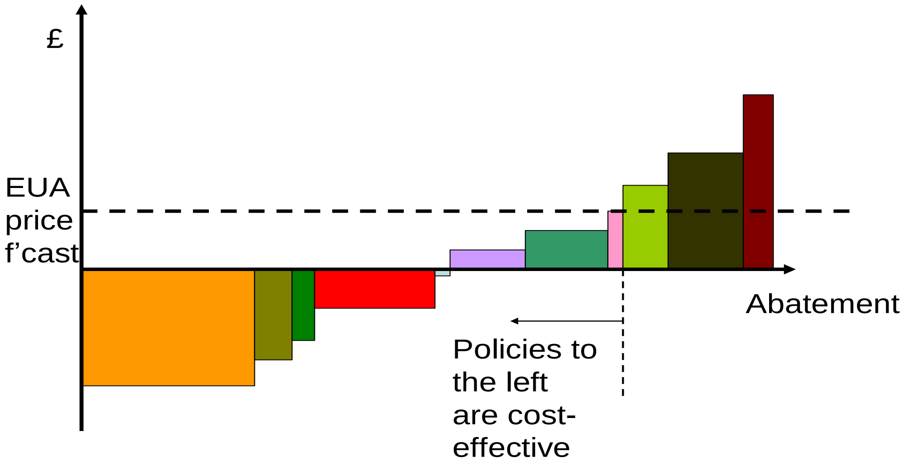
The traded sector

In the traded sector, UK emissions are capped under the EU ETS. Any emissions savings made under capped sectors will result in a re-allocation of the allowance to elsewhere in the EU – emissions reductions in this sector do not result in any additional emissions reductions globally within any given cap phase (and make no difference to the UK's net carbon account). This is not to say that they should not be pursued – they are a necessary contributor to meeting caps by helping to reduce emissions at least cost. For example, without downstream energy efficiency measures the cost of meeting our EU ETS obligations would be far higher, leading to a large burden (and potential competitiveness issues) on the energy-intensive sectors of the economy which are directly covered by ETS.

Valuing changes in emissions in the traded sector

It is not appropriate to value policies that increase or reduce emissions in the traded sector using the social cost of carbon. This is because, under the EU ETS, traded sector emissions are capped at an EU level: policies targeting capped sectors do not therefore reduce aggregate emissions, but rather enable the UK to meet a given cap. The value to UK society of an emission reduction is the opportunity cost of not reducing that emission. Clearly, in the traded sector, this is equal to the EU allowance price rather than the social cost of carbon.[31, 32]

Figure 4.2: Abatement in the traded sector



[31] UK Government appraisal guidance reflects this: http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/greengas-policyevaluation.pdf

[32] To be precise, the value to the UK is very slightly in excess of the EU allowance price. By reducing demand for allowances by one unit, there is not only the benefit of reduced allowance costs for that traded emission reduction, but in addition there is the effect the reduced demand of one unit has on the equilibrium market price. In reality, this effect is close enough to zero to be ignored for marginal policy appraisals as the overall market of 2 billion tonnes of CO_2e is likely to dwarf any emissions changes. The same applies for increases in emissions, and the cost of these. In the case of policies with significant emission reductions/increases, it is sensible to test whether this applies.

Figure 4.2 above illustrates the process of valuing emissions 'reductions' in the traded sector. It shows how valuing abatement at the EUA price would lead to the rational outcome that abatement of emissions covered by ETS will occur up to the EUA price. Abatement delivering emissions reductions below the forecast traded sector price will produce a net benefit for the UK as the cost incurred to deliver the emission reduction is less than the benefit of the emission reduction (the EUA price). Clearly, the opposite is the case for abatement measures delivering reductions above the forecast traded price – the cost of such reductions exceeds the benefit.

The non-traded sector

As explained above, the non-traded sector refers to those emissions occurring outside the EU ETS (direct and indirect). The EU has agreed a non-traded target for the UK of emissions reductions of 16% below 2005 emissions (in the case of the EU target remaining at emissions reductions of 20% below 1990 levels by 2020).

The Committee on Climate Change (CCC) made its recommendations on UK carbon budgets[33] in December 2008 and the Government set the level of budgets on 1st June 2009. Should the carbon budgets adopted at some point in the future imply binding targets in the non-traded sector that are more stringent than those given by the EU, these targets would become the relevant yardstick for the non-traded price of carbon.

In the non-traded sector we propose that a 'Non-traded price of carbon' would be used to value emissions changes in sectors not covered by ETS. Again, the opportunity cost of emissions would be the cost of the marginal emissions reduction. Figure 4.1 above provides an illustration of a MAC curve in the Non-traded Sector.

This framework means that both the traded and non-traded sectors would be brought into line, in terms of the basis of assessment – both would be based on the necessary abatement costs required to meet targets. Clearly, the traded sector figure is more visible, in that it has a market-revealed price – the EU allowance price. For the non-traded sector, Government and the CCC have been building up knowledge regarding abatement costs. The abatement options in the curve will also be informed by a number of policy decisions, and negotiations at the EU level regarding access to project credits (as well as the UK Government position on such access). The methodology for calculating the two prices is described in Part 2 of this paper.

Why two carbon prices in the short term rather than one?

In an ideal world only one price of carbon would exist across all sectors to enable emissions reductions to be delivered cost-effectively. Indeed, it is such an important tenet of environmental economics that applying a single carbon

[33] Building a low-carbon economy – the UK's contribution to tackling climate change. The First Report of the Committee on Climate Change, December 2008.

price across the economy is more efficient than having multiple prices that the proposal here to use two prices for *valuation and appraisal purposes* requires further discussion. This section provides that discussion by setting out the arguments for the revised approach and by comparing it with an alternative, single price approach to carbon valuation in the short term (in a situation in which different parts of the UK economy are in fact facing different emissions reductions targets).

The EU Regime

In framing this discussion, a key issue to recall is that there are currently separate EU targets in the traded (ETS) and non-traded (non-ETS) sectors. Current European Commission proposals mean that these are not fungible – the consequence of this is that emissions in the traded and non-traded sectors are essentially different 'commodities', and the approach to valuing carbon needs to reflect this reality. It would not be sensible to use a carbon price to appraise policies in the non-traded sector that is derived from traded sector targets, or vice versa. The reality is that the existence of different targeting regimes is likely to entail different implied target consistent prices across the economy, at least in the short-term.[34]

The existence of two carbon prices is not theoretically optimal from an efficiency perspective, but it is the reality facing the UK economy, and given this reality, the most cost effective regime is to have the implied prices reflected in valuations in the different sectors. This is why it is necessary to have traded and non-traded sector prices for appraisal purposes – in order to reflect the actual costs and benefits of emissions increases and reductions, *given the targets in place*. If, for example, the non-traded price of carbon is much higher than the traded price of carbon, this is a signal that the target in the non-traded sector is much more stringent for the UK and therefore that more effort will be required to meet it. It may *also* be a signal that the balance between the respective targets is unequal and that policy makers should look to rebalance them in the long run, to the extent to which this can be negotiated. For the purposes of our revised approach to carbon valuation, we assume that this equalisation of prices is indeed achieved in the long run (i.e. that in the future any such inefficiencies can be eliminated). This is discussed further below.

[34] As noted below, we assume that this discrepancy ceases to exist in the longer term – from 2030 onwards.

The difference between capped and uncapped emissions

There is a more fundamental argument for treating emissions in capped sectors differently to those in uncapped sectors. The impact of capping emissions and allowing the free trade of allowances is to turn carbon into a commodity which has different characteristics to uncapped carbon. Under the ETS, policies that reduce physical emissions in the UK will not reduce global emissions, which will be set by the cap. Instead they displace emissions reductions elsewhere and produce resource cost savings to the UK valued at the market price (the EUA price), reducing the overall costs of meeting the cap and, if large enough, reducing the marginal cost, and hence the carbon price.

In the rest of the economy (the non-traded sector) emissions are not capped. This means that, in policy appraisal terms, we are dealing with two distinct commodities: resource costs valued at the allowance (EUA) price (the marginal abatement cost) in the traded sector, and carbon valued at the marginal abatement cost in the non-traded sector. The box below explores the possible implications of valuing these different commodities at a single price for appraisal purposes.

Box 4.1: What would be the impact of using a single set of carbon values for policy appraisal in the short-run?

This paper argues that, given the binding nature of the policy regime described above, a policy economist undertaking a cost benefit analysis would have to make a distinction between impacts in the traded and non-traded sectors to avoid a misallocation of resources. It is helpful to consider the implications if, instead, a hybrid value was used in policy appraisal, perhaps derived by averaging the marginal abatement cost in the non-traded sector and the EUA price. If the empirical analysis contained later on in this document is correct then the hybrid value would be between the lower EUA price and the higher non-traded price of carbon.

In the traded sector this would lead to a higher value being applied to resource cost savings than their true expected value – the expected future EUA price. So, for example, in the traded sector, a policy which incentivised carbon savings (T) at a cost above the EUA price could be deemed to be cost-effective. If the policy cost £A/t above the EUA price, then the total costs of delivering a set amount of carbon savings, the EU cap, would increase by (£A)*T.

In the non-traded sector, the hybrid value would be below the marginal cost of meeting the non-traded sector target and so would deem policies that were part of a least cost delivery of the non-traded target to be cost-ineffective. Either the hybrid value would lose its relevance for the selection of policies to deliver the target (i.e. it would be ignored), or it would imply that insufficient abatement policies would be developed to meet the non-traded sector target. The lower hybrid value would also deem policies that increase emissions to be more cost-effective than they would under the target-consistent value and, at the margin, some emissions increasing policies would go ahead that otherwise would not. This would mean either that the target is missed or that new abatement policies would need to be delivered at or above the marginal abatement cost, leading to a higher cost of meeting the target and a net welfare loss to society.

Potential dynamic issues arising from having two values
One potential risk associated with the revised approach is that – insofar as the current split of effort between the traded and non-traded sector is inefficient - the inefficiency of the policy regime may become entrenched in the long term by the use of the two values in appraisal (e.g. through locking in more carbon intensive infrastructure in one sector compared to the other).

However, this risk is mitigated under our the revised approach, which sees long run traded and non-traded values converge in 2030, as discussed below. Under this approach, the impacts of policies that have primarily short run effects (e.g. a short lived tax that temporarily affects behaviour) will be appraised correctly as outlined above while those that have long run effects will see their longer run impacts appraised using a single price, thereby avoiding the problem of locking in any inefficiencies in the current regime. Furthermore, as outlined above, the existence of the two prices can act as a useful way to highlight any inefficiency in the current regime, and encourage action to be taken to reduce it.

In summary, replacing the shadow price of carbon there will be a “traded price of carbon” and a “non-traded price of carbon”. These two different values provide responses to two distinct, but related sets of questions. The non-traded price of carbon provides an answer to the following questions:

“What is the maximum marginal abatement cost that will need to be incurred to ensure we can meet our emissions reductions targets in the non-traded sector? What value should we assign to carbon for appraising policies that increase emissions in the non-traded sector?”

... while the traded price of carbon answers the question:

“What is the maximum cost per tonne abated that we should be prepared to incur in developing policies to reduce UK emissions in the traded sector? What value should we assign to carbon for appraising policies that increase emissions in the traded sector?”

4.4 Which targets to use in setting carbon values in the long term?

Longer-term (post 2020) targets are less well specified than those applying in the short term. For example, the UK does not have binding targets imposed by the EU, in terms of an annual trajectory of required emissions reductions. However, following advice from the CCC, Government has adopted a 2050 target for reducing emissions by 80% relative to a 1990 baseline, and this has been set in law in the Climate Change Act.

In its analysis, the CCC approached the setting of an 80% target by working back from a global stabilisation goal, to the global agreement on emissions reductions required to meet it, to a target for the UK via an assumption about the appropriate burden-sharing regime. The CCC's recommendation is to limit emissions in order to aim for a 'central expectation' of global temperature increase of equal, or close to, 2°C. It also aims to ensure that a 4°C global temperature increase is reached only with very low probability (less than 1%).

The CCC analysis suggests that in order to achieve such objectives in 2100, it is necessary for global emissions to fall to 20-24 billion tonnes CO_2e by 2050 (a 50-60% reduction below current levels), and fall further to 8-10 billion tonnes by the end of the century. Such action would imply CO_2e concentrations of 460-480ppm in 2200. The CCC believes an 80% reduction in UK emissions is consistent with such a goal. We propose that, for the longer-term, the traded and non-traded prices of carbon should be consistent with this goal, which has been adopted by Government.

Distinction between traded and non-traded sectors in the long term

In principle, valuing carbon in the long term could follow the same split between the traded sector ('traded price of carbon') and non-traded sector ('non-traded price of carbon'). However, while this split is a reality of the current EU targets, there is no reason to assume that this barrier between ETS and non-ETS sectors of the economy will be maintained in the long term. Indeed, since this is not an economically desirable situation in the long run – a single carbon price allows emissions reduction targets to be met at least cost – it is reasonable to assume that in the long run this divergence will be removed.

Accordingly, in the empirical work of Part 2 we assume that in the long run – from 2030 onwards - there will be a comprehensive global trading regime in place and therefore no distinction between the traded and non-traded sectors of the economy. Therefore, the traded-and non-traded sector carbon prices for use in appraisal will converge by 2030, to be replaced by an international carbon price derived from global abatement cost models.

The long term traded price of carbon

In the longer term, it is not appropriate to look at a UK-specific perspective alone. Climate change is a global problem that will require a global response. The long-term vision is of a world operating under a binding emissions cap, with that cap set with the objective of reaching a globally-agreed stabilisation scenario. In such a world, it is likely that there will be comprehensive international trading of emissions allowances, as there is currently in the EU ETS. Under the assumption of GHGs becoming an internationally traded commodity, emissions reductions in the UK would be weighed up against the possibility of purchasing allowances from the global carbon market. This situation would be replicated elsewhere so that all countries weighed up domestic abatement options against the alternative – allowances purchased from elsewhere. In other words, each country would seek to reduce emissions as cost-effectively as possible, whether at home or by buying in allowances from other countries. The barometer of this decision is the price at which emissions allowances can be bought and sold.

The result of such tradability is that, for all emissions which are in the traded sectors, there would be a single global carbon price. This price is the marginal cost of emissions reductions – i.e. the marginal abatement cost – and therefore this is the relevant carbon price, at which goals can be met at least cost, in the longer term.

As the longer-term carbon values would be based upon the international carbon price, the relevant analysis needs to focus on international emissions projections, abatement costs and targets. There is a wide range of different abatement cost models that forecast the abatement costs associated with various stabilisation goals to 2050 and beyond. The models vary in their structure, some being bottom-up energy systems models, others general equilibrium models. The Government's Global Carbon Finance (GLOCAF) model[35] is an example of an abatement cost model that uses such information in order to project long-run carbon prices into the future. This combines abatement cost information from energy CO_2, as well as forestry/land-use and non-CO_2 sources. This, itself, is combined with emissions trajectories that are generated in order to be consistent with certain stabilisation goals. A more detailed description of GLOCAF is given in Annex 2.

The carbon prices generated under such an approach are consistent with the abatement costs required in reaching the chosen trajectory, just as with UK targets. In the international context, however, emissions reduction targets are the proximate, rather than ultimate, objectives. The emissions reductions targets are the stepping stone towards the ultimate aim of specific stabilisation targets. As such, long-term abatement cost models generate the necessary emissions reduction path to meet a stabilisation goal.

What does this imply regarding the effort from individual countries? A single global carbon price should not be confused with equal effort on the part of countries. First, in a world without trading a single carbon price may imply very different levels of effort from countries as a result of different underlying abatement costs. But more importantly, and fundamentally, having a global carbon price says nothing about burden-sharing in a world with a comprehensive trading regime. It is not necessary to know how burdens are shared in order to determine the appropriate price forecast – as long as trade is free, the abatement cost information that we have will produce different global carbon prices for different stabilisation concentrations. From this a schedule for the carbon price can be determined, without making any assumptions about burden-sharing. It may be that the UK allocation means that we are a large net importer, for example, but given free trading the price estimate is not affected.

[35] See: http://www.occ.gov.uk/activities/gcf.htm

The combination of short and long term targets will determine the 'effort curve' over time – i.e. what our required abatement is to move from business-as-usual projections to the target. Clearly, the effort curve - alongside the prevailing marginal abatement costs - will determine how the value of carbon would change over time.

4.5 What would be the role of the SCC under this revised approach?

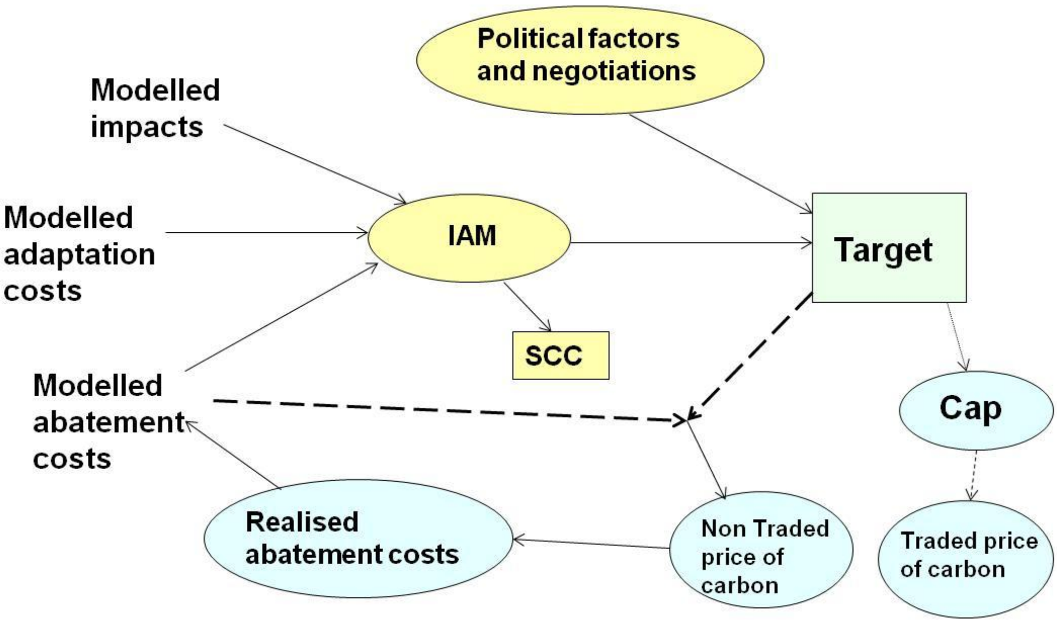
The revised approach proposal will not render the social cost of carbon obsolete. As outlined above, the SCC represents our understanding at present of the magnitude (in monetary terms) of the quantifiable impacts of incremental GHG emissions, although some impacts may be excluded or modelled incompletely (as described in Section 3). Therefore there is one particular type of policy appraisal, in which it would still be appropriate to use evidence relating to damage costs and the SCC. This is when the appraisal is of the costs and benefits of overall climate change frameworks where the targets themselves are being set. Clearly a target-consistent value of carbon could not be used in order to inform target-setting exercises, as this would be circular.

Using damage costs alongside other evidence in setting targets would allow an assessment to be made of whether the targets that are being set are broadly in line with estimates of the costs of climate change, whilst recognising that there are uncertainties around the estimation of climate change damages and also that there are other factors that feed into such target-setting exercises.

The interrelationship between the SCC, traded and non-traded prices of carbon under the revised approach is set out in more detail in the diagram below. The SCC is not used in individual policy appraisal, rather it should be used higher up the chain, to contribute in the setting of targets. More accurately, it would be the outputs of IAMs on the whole in finding the optimal level of concentrations that would be used (and from which the SCC is an output).

The diagram below illustrates the interrelationship between the revised new values for carbon. In the diagram, the traded and non-traded prices of carbon represent the revised target-consistent approach, whereas the SCC/IAM evidence is the figure that would be used to inform target-setting.

Figure 4.3: Interactions between the SCC, Traded and Non-Traded Price of Carbon



As shown in Figure 4.3, IAMs and other factors (politics and negotiations etc, as described above) would lead us to adopt a target. From this target and our knowledge of abatement costs, we can derive target-consistent values for carbon. It is important to note the feedback loop that would be in operation – if realised abatement costs are higher or lower than expected, then this would feed into the modelling for IAMs and other such exercises, possibly leading to a reassessment of targets. Equally, new information on damage costs would feed into any reassessments of targets.

The revised approach will therefore ensure that economic and scientific evidence is helping both to inform the setting of the goal, and the way in which policies are developed to meet the goal, in a transparent fashion. If, for example, the evidence suggested that the target-consistent price of carbon was so out of line with estimates of the social cost of carbon that the stabilisation goal is called into question, the appropriate response would be to seek to adjust the targets – through the processes that exist for doing so – rather than retain the targets, but adjust the value of carbon to a level that is inconsistent with them.[36]

In the course of 2009 there has been a process underway across Government for setting carbon budgets for the next 15 years, in the light of the CCC's recommended levels. This process has been used to revise our valuation of carbon to ensure it is set on a 'target consistent' basis. The quantitative work that has been undertaken to inform this exercise is described in more detail in Part 2 of this document.

[36] This example assumes that the disparity is not due to a particularly stringent or lax burden share for an individual country.

Part 2: Quantitative Framework

5. Introduction to quantitative analysis

Part 1 of this document considered the rationale for and overall approach associated with moving towards using abatement rather than damage costs as the basis for valuing carbon. Part 2 provides the empirical counterpart to the previous section, setting out how the traded and non-traded prices of carbon have been quantified.

5.1 Estimating target-consistent carbon prices

The previous approach to valuing carbon in appraisal – basing it on an estimate of the social cost of carbon – is set out in Part 1 of this paper. Such an approach relies on modelling climate damages from integrated assessment modelling.

Moving to a target-consistent valuation requires in-depth abatement cost modelling. Evidence on abatement costs is continuously improving, particularly recently across government. This review draws on work that has been carried out within government on national and international abatement costs. There are important methodological issues to be considered with such an approach, which are explored at a general level in the following sections of this chapter and in more detail, as they relate to the detailed estimation of the traded and non-traded prices of carbon, in Chapters 6, 7 and 8.

5.2 Overview of methodology

The steps required in order to estimate a target-consistent price are, in theory, fairly straightforward. For a given set of emissions projections and emissions reductions targets, in each year, there is a gap between baseline emissions and the target consistent emissions levels. This gap needs to be filled by reducing emissions. Clearly, the level of emissions reductions which are required in any given year will have an impact upon the marginal abatement cost – assuming a rising marginal abatement cost curve[37] – and therefore the target-consistent price of carbon. This is illustrated below. Figure 5.1 shows an illustrative emissions gap, produced by a divergence of baseline and target emissions levels. Figure 5.2 demonstrates how the information on the gap - with required abatement in year 10 of 'X' - is fed into a MAC curve to produce a value for the price of carbon.

[37] The standard assumption to make regarding abatement costs is that they are rising with the quantity of abatement required (or at least they are non-decreasing). This is intuitive, as the abatement curve represents the supply of abatement measures, which like other supply curves is upwards sloping – supply will increase the higher the price. Abatement measures clearly follow such a pattern as successive measures cost increasing amounts per unit abatement.

Figure 5.1: Baselines, targets and gaps

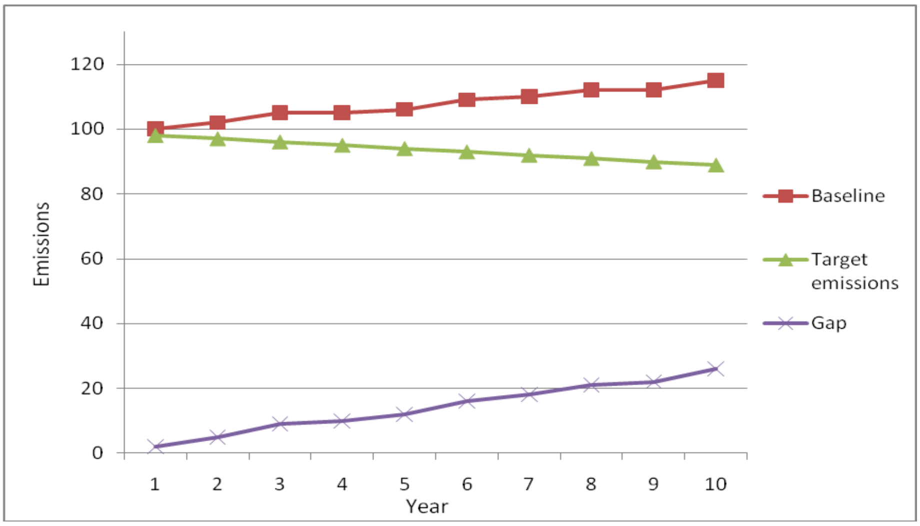
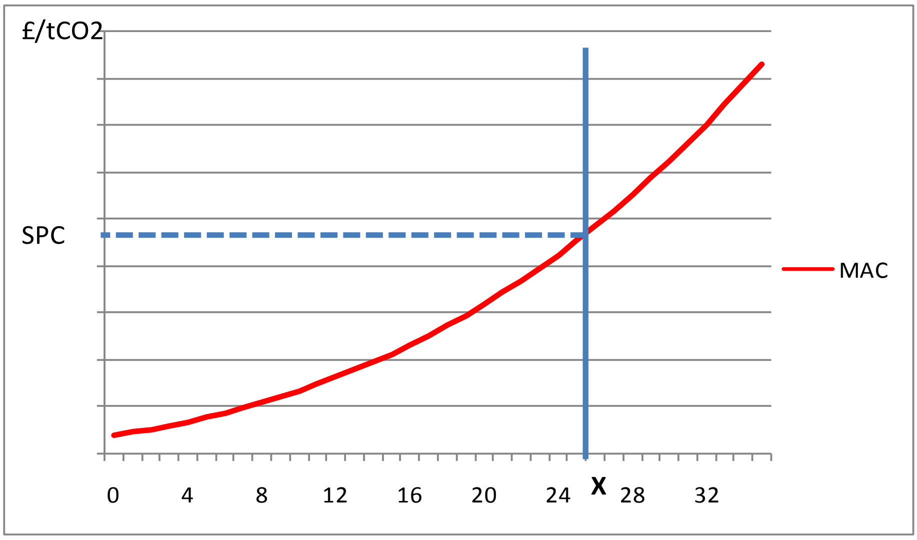


Figure 5.2: Gaps and marginal abatement cost curve (MAC)



5.3 Emissions projections

It should be noted that it is important to ensure that the abatement cost curves being examined are consistent with emissions projections. For example, if a policy is targeting a certain portion of abatement and emissions projections already account for this then the relevant abatement potential needs to be removed from the abatement curve. If this is not done, the abatement potential will be double-counted, leading to an overly-optimistic view of additional abatement options(i.e. in addition to that foreseen in emissions projections), and resulting in a carbon valuation which is lower than that required to be target-consistent. Additional emissions reductions are not relative to a flat baseline of today's level of emissions, but are relative to a business as usual trend that may be increasing, decreasing or, flat.

The importance of using robust emissions projections is clear. If a flat baseline was used when the BAU is in fact increasing then the target-consistent price of carbon would be under-estimated, and equally the target-consistent price would be over-estimated if the BAU trend was decreasing. The BAU trend for global emissions is rising, whereas that of UK (including current policy measures) emissions is falling.[38]

Short-term emissions projections are taken from the DECC Energy Model. The model can be briefly summarised as below:

- The DECC Energy Model is a partial equilibrium model of the UK energy market.
- The demand side comprises over 150 econometric relationships of historic fuel demand for Residential, Transport, Industry, Service and Agriculture sectors.
- The supply side comprises data on every major power producer and other energy producing industries.
- The model requires a number of assumptions, principally on fossil fuel prices, economic growth and demographics.

Although these projections are subject to uncertainty (as with any forecasting tool) and are revised periodically, they represent the best available evidence on which to base estimates of the necessary emissions gap.

[38] Please see the latest projections, available online at: http://www.berr.gov.uk/files/file48514.pdf

6. Approach to estimating the traded price of carbon in the short-term

Chapter 4 set out the rationale for adopting a traded price of carbon for the traded sector of the economy. This chapter sets out how the short term traded price of carbon has been estimated for use in policy appraisal.

Observed market prices could be the best short term estimates of the traded price of carbon for the 2008-2020 period but, because the EUA forward market provides reliable prices only up to 2012, this is not possible. Two possible approaches are available to overcome this problem. A first method would supplement observed prices with modelling estimates where market data are not available. A second approach would rely exclusively on marginal abatement cost modelling, either from the European Commission or DECC internal models. This chapter assesses these two alternative approaches and adopts a modelling approach based on the DECC model.

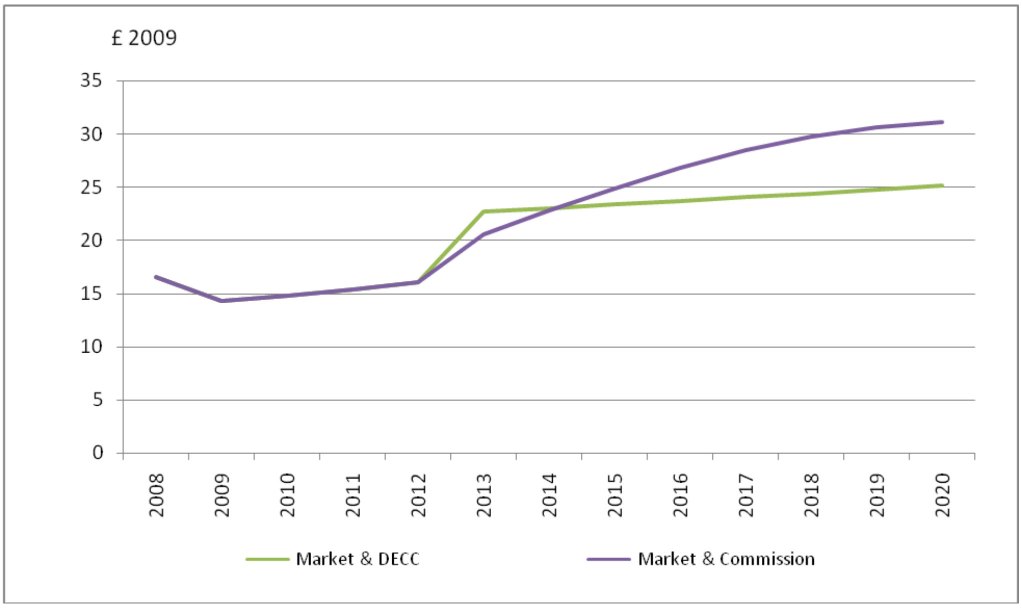
6.1 Market and model based estimates

Observed market values could be used to estimate the carbon price in the traded sector but this is possible only up to 2012 because no market price estimates are available for the 2013-2020 period. This problem could be overcome by complementing the observed values with estimates derived from a model.

Over the Phase II of the EU ETS (2008-2012), the traded price of carbon could be proxied by the EUA forward curve that represents the market's view of the allowances price in the rest of Phase II. For instance, the average price of the futures contract for each year of Phase II could be used, perhaps based upon daily prices for the past 12 months preceding the publication of the schedule.

Unlike Phase II, there are no market data available for Phase III. Indeed, the EUA forward curve currently only extends to 2014, and it has been reported that little interest has been shown in the 2013 and 2014 contracts; trade has so far been only symbolic. Thus, in the absence of a liquid traded market for allowances post-2012, estimates of the traded sector can only be obtained from a model (see below for a discussion). One problem with combining market and model based estimates is that it implies a significant jump in the carbon price in 2013 (see Figure 6.1). For instance, if the European Commission's model is used the carbon price would increase from £16 in 2012 to £21 in 2013.

Figure 6.1: Market and model based estimates



6.2 Model based estimates

The approach discussed above derives the estimates of the traded price of carbon up to 2020 as a combination of market data and modelling estimates. Alternatively, model based estimates (either from the European Commission or from DECC) could be used for the same purpose. These two modelling approaches and the resulting price schedule are discussed below.

DECC's carbon price model provides an estimate of the average price over the 2008-2020 period. This estimate is determined as an equilibrium price in the carbon market under the assumption of unlimited banking between compliance years within and between Phase II and III. The demand side is driven by the amount of abatement effort as proxied by the difference between the total cap on emissions in the EU ETS and BAU emissions. The supply of EUAs is primarily determined by the sum of abatement possibilities from short term fuel switching potential in the electricity generation sector and the supply of CDM credit.

Underlying fossil fuel price assumptions are an important driver of DECC's carbon price model (Table 6.1) and the different fuel price scenarios can lead to carbon price differences of up to 15 £/t (from low to high). Low fossil fuel price assumptions translate into a lower carbon price as a fall in the price of oil and gas (relatively to the coal price) would make fuel switching from coal to gas (the main source of abatement in the power sector) more attractive and incentivises abatement at lower carbon prices.

Table 6.1: DECC model's average price estimates over the 2008 – 2020 period under different fossil fuel price assumptions

Fossil fuel price assumption	Carbon price (2009 £/t)
Low	13.0
Central	23.0
High	28.7

The estimated carbon price needs to be adjusted to take into account the opportunity cost of investing in EUA as opposed to hold the money in cash. This opportunity cost (or "cost of carry" in the economic parlance) is measured with the risk free rate as proxied by the EURIBOR (a nominal rate of 3.5% was used in this section), which is felt the most representative of the European nature of the ETS.[39]

In the EU ETS impact assessment, the European Commission provided an estimate of the carbon price of €40 (in 2005 prices) in 2020. This estimate was based on partial equilibrium PRIMES[40] on the bases of several policy assumptions including meeting the overall GHG emission reduction, the RES and biofuel targets. But it is still unclear whether this estimate refers to the price in 2020 or to the average inter phase price. In the following we have assumed that the estimate refers to the carbon price in 2020 and discounted the recommended carbon price in 2020 using the EURIBOR rate to obtain the price schedule for the 2008-2020 period (see Table 6.2 below). Another problem with the European Commission's approach is that we do not have direct access to the modelling used and so we would not be able to flex crucial assumptions such as the fossil fuel prices.

In addition to the European Commission estimates, four other long term model based forecasts of the EUA prices in 2020 have been considered. Two of these forecasts fall within the range produced with the DECC carbon price model but are above our central estimate. By contrast, the New Carbon Finance and Deutsche Bank forecasts are well above the range. One important difference between the New Carbon Finance and the DECC internal estimates is that the former has relaxed the perfect foresight assumption over the 2008-2020 period. This is considered the main explanation for the significantly higher 2020 forecasts provided by New Carbon Finance. In comparison with the DECC model, the Government has limited information on the structural assumptions underlying these additional forecasts. Therefore, it would be difficult to achieve a carbon price that is consistent with other assumptions (e.g. fossil fuel price, GDP etc) used across government department.

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[39] This definition of the opportunity cost of investing in the EUA is quite conservative relative to estimates provided by other private investment banks. For instance, one bank includes a 5% premium on top of the risk free rate in order to capture the fact that investing in EUAs is likely to be riskier than investing in government bonds and investors are risk adverse.

[40] http://ec.europa.eu/environment/climat/pdf/climat_action/analysis.pdf

Table 6.2: Carbon Price Forecasts in 2020

Carbon Price Forecasts	Date	2009 GBP
New Carbon Finance[41]	May-09	36.8
DB Research[42]	May-09	34.9
Barclays Capital[43]	May-09	28.8
Societe Generale[44]	May-09	27.3
European Commission[45]	IA 2008	31.1
DECC Carbon price model (central fossil fuel prices)	Latest	25.1 (14.2-31.3)

6.3 Comparing the results of the two approaches

The table below reports estimates of the traded price of carbon adjusted for the cost of carry up to 2020 using the two approaches discussed above. The price estimates are expressed in 2009 prices and converted in pounds using the five year average of the £/€ nominal exchange rate.

As discussed above, DECC carbon price estimates are sensitive to changes in fossil fuel price assumptions. By contrast, DECC does not have access to the model used by the European Commission to estimate the carbon price in 2020 and therefore cannot assess its sensitivity to such changes.

On the assumptions made above, estimates from the European Commission tend to be lower than DECC's (at central and high fossil fuel price assumptions) at the beginning of the period but they become closer toward the end.

For comparison, the carbon price estimates obtained with this approach are slightly below the previous SPC values for the 2008-2020 period. The traded carbon price is within a range between £12 and £26 in 2008 and between £14 and £31 in 2020 whereas the SPC increases from £27.2 in 2008 to £34.4 in 2020.

[41] New Energy Finance, May Deep Dive
[42] Deutsche Bank, Global Markets Research, "Carbon Emissions, The long and the short of it" (May 2009)
[43] Barclays Capital Carbon Market Standard (May 2009)
[44] Société Générale Commodities Research, Fundamentals Update (May 2009)
[45] http://ec.europa.eu/environment/climat/pdf/climat_action/climate_package_ia_annex.pdf

Table 6.3: Traded carbon price profile (£2009)

(£2009)	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
DECC Low FFP	11.9	12.1	12.3	12.4	12.6	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.2
DECC Central FFP	21.0	21.3	21.6	22.0	22.3	22.6	23.0	23.3	23.7	24.0	24.4	24.7	25.1
DECC High FFP	26.2	26.6	27.0	27.4	27.8	28.2	28.6	29.1	29.5	29.9	30.4	30.8	31.3
European Commission	9.7	11.7	13.7	15.9	18.2	20.5	22.8	24.9	26.8	28.5	29.8	30.7	31.1
Market with European Commission	16.6	14.3	14.8	15.3	16.0	20.5	22.8	24.9	26.8	28.5	29.8	30.7	31.1
Market with DECC (central)	16.6	14.3	14.8	15.3	16.0	22.6	23.0	23.3	23.7	24.0	24.4	24.7	25.1
Previous value of SPC	27.2	27.7	28.3	28.8	29.4	29.9	30.5	31.2	31.8	32.4	33.1	33.7	34.4

6.4 Recommended approach

Observed market prices would be the best estimates of the traded price of carbon for the 2008-2020 period but this is currently not possible for the whole period because the forward market provide reliable prices only up to 2012. As discussed above, complementing observed market data with modelling estimates is likely to lead to significant jumps in the carbon price schedule. Further, observed market data are likely to be relatively volatile requiring very frequent updates if the data are to be accurate, potentially undermining the stability of the policy appraisal regime. The EU ETS market is rapidly developing with prices changing rapidly. While it is important that estimates are up-to-date, there are also important considerations in terms of the stability of estimates for appraisal guidance and the time-dependence of our policy assessments.

On balance, for the reasons above **a modelling based approach was exclusively used to derive the estimates of the traded sector for the 2008-2020 period** rather than a combination of observed market data and modelling. The issue then is whether these estimates are based on the European Commission or the DECC modelling approach.

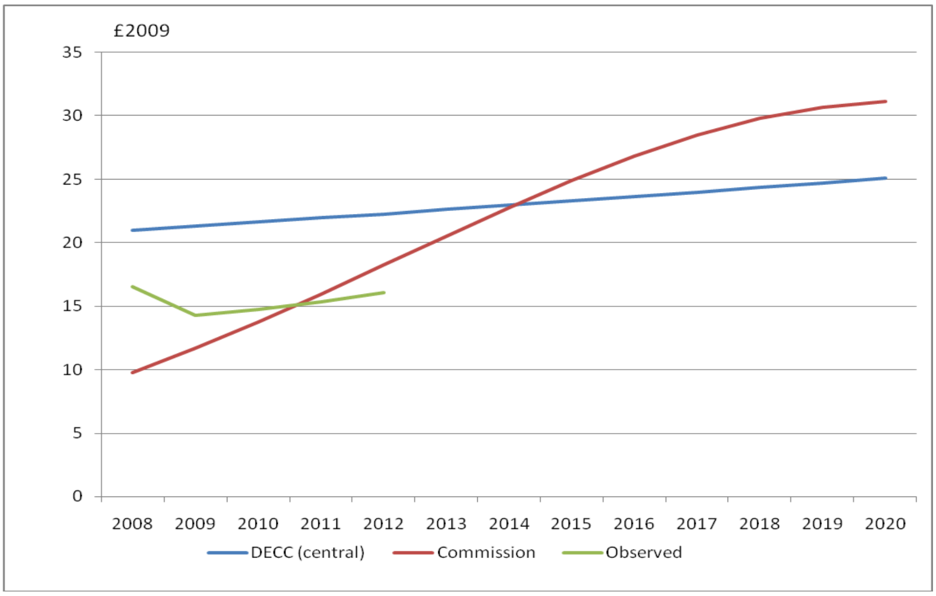
The carbon price profile inferred from the European Commission's estimates is steeper than the DECC internal projections (assuming central fossil fuel price assumptions) suggesting a lower carbon price at the beginning of the 2008-2020 period and a higher carbon price at the end of the period (Figure 6.2). Relative to observed market prices up to 2012[46], DECC (central fossil fuel price assumption) estimates have tended to be higher than observed prices

[46] This is proxied by the average price of the futures contract for each year of Phase II based upon daily prices for the past 12 months preceding the publication of the schedule. Latest EUA forward price included 20 May 2009.

whereas the European Commission estimates have generally been lower than the observed prices until 2010 but higher in 2011 and 2012.

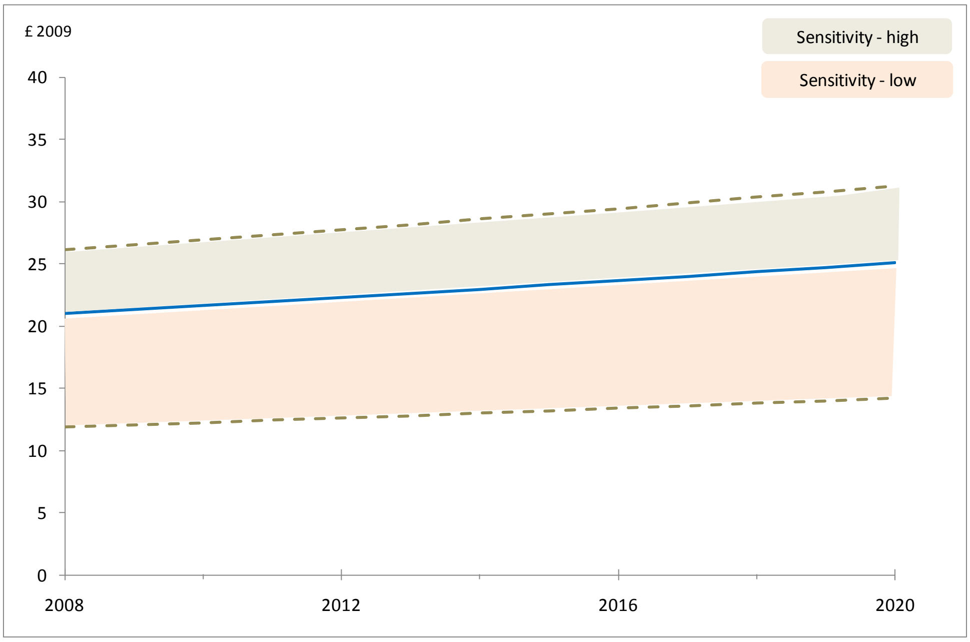
There are several reasons for basing our estimates of the traded carbon price on the DECC internal carbon price model. First, and crucially, in contrast to the European Commission's estimates, the underlying assumptions and model structure used in the DECC model are well understood, readily available and may be adjusted as desired. Second, use of the DECC model would provide consistency between internal analyses of the EU ETS and wider analyses. For example, the DECC carbon model estimate have been already used in the overarching impact assessment to evaluate the costs for the UK in the traded sector. Finally, using the DECC internal carbon price model would be consistent with the approach taken by the Committee on Climate Change in their recent report to estimate the carbon price in 2020.

Figure 6.2: DECC vs. European Commission price profile



We have therefore estimated the short term traded price of carbon using the DECC model and derived the range of estimates by running the model under low, central and high fossil fuel price assumptions. Using this approach, the short term traded price of carbon in 2020 is £25 (central estimate) with a range of £14 (low sensitivity) and £31 (high sensitivity). The new values are shown graphically in Figure 6.3.

Figure 6.3: Short term traded carbon price (2008-2020)



7. Approach to estimating the non-traded price of carbon in the short-term

7.1 Summary

The 2020 targets for UK emissions reductions in the 'traded sector' and the 'non-traded sector' are distinct and non-fungible. Part 1 of this paper therefore argued that, up to 2020, a separate traded sector price of carbon and non-traded sector price of carbon are required. This chapter provides the empirics underlying the valuation of the non-traded price of carbon up to 2020 and presents the new values.

The marginal abatement cost (MAC) curves developed by the Committee on Climate Change have been used as the basis for the empirical work alongside analysis provided by Government Departments.[47] **The MAC curves represent feasible technical abatement potential and should not be confused with policy options.** The resulting non-traded price of carbon provides a benchmark against which the cost-effectiveness of UK policy options affecting emissions in the sector can be assessed. **The policies developed to meet carbon budgets, which have been assessed against this new benchmark, are presented in The UK Low Carbon Transition Plan (2009).[48]**

A number of specific issues are raised in the chapter in relation to the application of these curves to the task of producing new values. A way forward has been suggested in each case, and a range of scenarios considered, **leading to a new central estimate of £60/tCO_2e in 2020 with a range of +/-50% (i.e. £30/tCO_2e low sensitivity and £90/tCO_2e high sensitivity).**

7.2 Methodology for valuing the target consistent non-traded price of carbon

The non-traded price of carbon will be used both for policies that reduce greenhouse gas emissions in the non-traded sector and policies that increase them. Where a policy can reduce emissions at a cost below the non-traded price of carbon it is delivering part of the least cost potential from the UK economy – the policy is therefore cost-effective. Where a policy is increasing emissions but the benefit from the policy per unit increase in emissions is greater than the non-traded price of carbon, social welfare would be increased by allowing the policy to increase emissions and introducing the marginal abatement policy to deliver compensating reductions in emissions.

[47] Department of Energy & Climate Change, Department for Transport and Department for the Environment, Food and Rural Affairs.
[48] http://www.decc.gov.uk/en/content/cms/publications/lc_trans_plan/lc_trans_plan.aspx

A value of the non-traded price of carbon that is either too high or too low will compromise its usefulness. A figure that is too low will result in some cost-effective policies appearing non cost-effective. It will downplay the costs associated with policies that increase emissions and understate the cost of introducing a compensating policy. A figure that is too high will be too forgiving in the judgement of which carbon reduction policies are cost-effective and overly prohibitive of policies that increase emissions.

For these reasons it is important to develop a methodology that, to the best available data, provides a realistic assessment of the marginal cost of meeting the UK's non-traded sector target.

There are several requirements for the process of providing a valuation for the non-traded price of carbon. The analysis requires:

- An abatement cost curve defined against a given baseline;
- A target for emissions reductions;
- A decision on the cost and volume of abatement to include in the abatement cost curve, covering both domestic abatement and access to overseas carbon credits; and
- A method of translating a point estimate into a price schedule.

7.3 Defining the abatement cost curve

Policy or technical MACs?

There are in principle two basic methodological options for defining an abatement cost curve for the purposes of calculating the non-traded price of carbon: (i) a 'by policy' MAC curve; and (ii) a 'feasible technical' MAC curve. A 'by policy' MAC would bring together all the appraisals of the level of abatement that different *policies* (actual and potential) are expected to deliver, by when and at what cost. A 'feasible technical' MAC, in contrast, would be based on assessments of the abatement that could be brought about by the *actions and behaviour of individuals and firms* (e.g. installing insulation). Under this approach, technical potential from measures could be adjusted to reflect limitations on feasibility such as supply side constraints, and the cost of the abatement adjusted to reflect the average anticipated policy costs of delivering the measures.

The choice between policy or technical feasible MACs in part involves trading off the greater accuracy of individual assessments of the former (since they can incorporate specific information on policy costs and the deliverability of abatement through policies) and the greater independence and comprehensiveness of the latter. **Having considered the options above we have used the 'feasible technical' approach to calculate the non-traded price of carbon (i.e. one based on technical potential, adjusted for feasibility).** This should:

- provide greater assurance over the comprehensiveness of the analysis;

- provide a stronger external benchmark for policy appraisal thereby avoiding risks of circularity; and
- relate more clearly to the work carried out by the CCC (which developed a technical potential MACC).

The abatement cost data produced by the Committee on Climate Change (CCC) has been used as a starting point for the analysis. The CCC's work has produced the most comprehensive UK MACC model yet produced, covering all sectors and all six Kyoto Greenhouse Gases. This has been supplemented with further evidence and analysis from government economists.

Policy costs

Including estimates for the average anticipated policy costs of delivering the measures is one way to adjust the technical potential to reflect feasibility limitations.

Viewed from the perspective of the end-user, the non-traded sector is characterised by millions of diffuse and relatively small sources of emissions. Policies to accelerate the uptake of abatement technologies and methods in these sectors will necessarily involve some policy costs. These policy costs will be included in the cost-effectiveness calculation for the policy. If the non-traded price of carbon, based as discussed above on technical measures, does not include any allowance for policy costs, then arguably it is not providing an equivalent comparator.

However, there are difficulties adjusting the cost of abatement to reflect policy costs. The costs of current policies could be used as a guide, but if these policies are relatively costly to run, this would entrench the idea that this level of policy cost is acceptable; policy costs are likely to differ significantly by measure and may be expected to be higher where barriers to behaviour change are high. This is likely to be the case particularly for negative cost abatement potential.

The recent report on global abatement costs from McKinsey and Company[49] notes that:

"The external sources that we have looked at to understand the order of magnitude of these [policy] costs often estimate them between from below 1€ to 5€ per tCO_2e, again with big variations across sectors"

Given the fact that policy costs may differ significantly for different policies, it is challenging to include them on an objective basis in the valuation of the non-traded price of carbon, without specific reference to the likely policy regime. However, in order to make some provision for policy costs, the McKinsey estimates have been included in the MACCs, which form the basis of the

[49] 'Pathways to a low carbon economy, version 2 of the Global Greenhouse Gas abatement curve' - 2009

carbon price estimates, included within the empirical analysis in this chapter and Annex 1.

Which baseline to use?

Defining an abatement cost curve also involves choosing an appropriate baseline. **For this exercise, the baseline that was used in the Energy White Paper (UEP29) has been chosen as the baseline against which to measure abatement potential, with updated fossil fuel prices consistent with the DECC fossil fuel price scenarios published in May 2008.** This baseline does not include the impact of any policies included in, or announced since, the Energy White Paper. The key reasons for using this baseline (rather than, for example, the most recent published emissions projections) are that the latter assume delivery of a number of policies that are to be appraised and evaluated using the non-traded price of carbon, notably in the Government's 'summer package' of policies setting out how it intends to meet carbon budgets. Moreover, the CCC has also used this baseline, aiding consistency and transparency of approach.

7.4 Setting a target for emissions reductions

Having developed the abatement cost curves, the marginal cost of delivering any given level of domestic abatement can be calculated. To value the non-traded price of carbon it is necessary to know what level of additional abatement is required.

The level of the target is established by the setting of carbon budgets and the UK's international obligations. The first three carbon budgets, announced at Budget 2009, mirror the UK's obligations under the EU Climate and Energy Package which requires that UK emissions in the non-traded sector are no more than 310.4MtCO_2e in 2020.[50] Comparing this to the baseline level of emissions in 2020 under UEP 29, 352.9MtCO_2e provides the figure of 42.5MtCO_2 for the target level of abatement in 2020.

One complication is that the EU package allows banking of over-compliance into future years, and borrowing from future years to meet a shortfall. While comparing the baseline emissions for 2020 to the target of 310.4MtCO_2e provides an indication of the annual abatement that will be necessary, this is only an approximation. The optimal profile for UK abatement could be to do more in 2020 than implied, or indeed less. For the purposes of the non-traded price of carbon calculation, no banking or borrowing is assumed in 2020.

7.5 Cost and Volume of abatement potential included in the abatement curve

The CCC carried out a highly challenging task in pulling together an economy wide UK MACC. The analysis to produce a non-traded price of carbon begins

[50] The equivalent "interim Carbon Budget" level in the non-traded sector is 1559MtCO_2e for the period 2018-22, Building a low-carbon economy - the UK's contribution to tackling climate change, Committee on Climate Change, 2008.

with the abatement potential identified by the CCC, with their judgement of both the cost and the volume available, and contained within the UK MACC model (which allows potential abatement to be filtered by traded and non-traded sector). This judgement has then been supplemented with further analysis and evidence from within government.

The CCC MACC model provides a judgement of what level of abatement it is feasible to deliver by 2012, 2017 and 2022. The feasible potential for intervening years can be interpolated. This produces a feasible MACC that can be used to value the non-traded price of carbon. However, there are reasons to consider adjusting the costs and feasible potentials identified by the CCC to enhance the analysis, relating to the following areas:

- constraints on feasible delivery from international agreements/policies and their effect on abatement potential ;
- abatement potentials from demand side measures in transport ;
- inclusion or exclusion of non-CO_2 GHG abatement potential;
- inclusion or exclusion of project credits ; and
- inclusion or exclusion of air quality impacts and other ancillary costs

Feasible potential and international agreements

In several policy areas, measures that could be implemented to deliver carbon targets are driven by international agreements. This is most notably the case for the transport sector. In December 2008 agreement was reached on new car CO_2 standards for Europe as a whole. This agreement requires co-ordination between the UK and Europe as a whole.

For the new car CO_2 standards, the EU agreement does not prescribe the efficiency of cars that are bought in any one member state; the target is for sales across the EU as a whole. The UK could pursue policies to drive a faster take up of energy efficient cars, relative to the rest of Europe, in order to exploit the potential that the analysis indicates is cost-effective. Further, including the underlying potential from transport would enable the non-traded price of carbon to be an indicator of the optimality of our international agreements and help to influence future negotiations of international constraints. (The non-traded price of carbon will be used to assess policies that the UK has agreed to at the European level. For this reason it would be preferable to base it on the underlying potential in the UK rather than taking international constraints as a starting point).

Transport abatement potential both by technology, without consideration of the international constraint (CCC assessment) and by policy (Government) has been considered in the empirical analysis presented at the end of this chapter and in Annex 1.

Abatement potentials from demand side measures in transport

One area of potential disagreement between the Government's view and that of the CCC is likely to relate to demand side measures in transport and the abatement they could feasibly deliver. Where there is a well-evidenced basis for taking a different view, adjustment of the MACCs enhances the accuracy with which the non-traded price of carbon is identified, and the cost-effectiveness of policy making overall.

The CCC has identified greater technical potential for emissions abatement from transport than the Government's assessment of potential based on policy measures. In part, this is explained by the constraint the EU new car standards regulation will place on feasible potential, but it also reflects the CCC's significantly more optimistic view of the potential abatement delivered through 'soft' behavioural measures, such as extension of the existing 'smarter choices' programme and the provision of eco-driving lessons. Government analysis suggests that, while there is expected to be cost-effective potential from behavioural measures in transport, the level of the savings is highly uncertain, both in terms of the response of individual drivers and the length of time that drivers maintain these more efficient driving techniques. In the analysis presented at the end of this chapter and in Annex 1, we have drawn on both CCC and Government estimates in constructing scenarios for calculating the non-traded price of carbon.

Inclusion or exclusion of non-CO_2 GHG abatement

The CCC advice on December 1 2008 stated that non-CO_2 GHG abatement should not be relied upon to deliver carbon budgets, but rather should be targeted as part of prudent budget management. The reasons given were that emissions of non-CO_2 GHG are more volatile and uncertain to forecast than those for CO_2, that there are measurement problems and that policies to reduce non-CO_2 emissions, particularly from agriculture, are undeveloped and so judgements of feasibility are less certain.

If the CCC advice were followed, and a strategic decision was taken to plan to deliver the non-traded target using CO_2 abatement options then in principle there is an argument for excluding non-CO_2 abatement from the MAC curve to value the non-traded price of carbon.

However, an alternative view would be that the fact that policies to deliver non-CO_2 abatement are undeveloped provides a stronger argument for including them in the curve. The very purpose of the non-traded price of carbon is to encourage the development of policies that deliver the lowest cost potential, and concerted policy development for the delivery of non-CO_2 GHG would be a dividend for both the decision to include all GHGs in the Climate Change Act, and for the analysis that has been carried out by the CCC.

The UK inventory is currently not very sensitive at measuring non-CO_2 emissions. For instance the emissions from livestock are calculated by multiplying the number of animals by an emissions factor. Reducing their emissions by changing their diet or reducing gut-living parasites would not be recorded in the inventory as it currently stands. However, the inventory methodology is flexible and with scientific evidence can be made more sensitive. There is in principle no reason why, following the introduction of a policy in the agriculture sector, the inventory methodology could not be updated to capture the change in emissions that result.

In principle, we would propose that non-CO2 GHG abatement should be included in the MAC curve used to value the non-traded price of carbon. The feasible level of abatement from non-CO_2 GHG remains uncertain however. For this reason in the analysis contained at the end of this chapter and in Annex 1, **sensitivities are considered where there is a 'low feasible' delivery of non-CO2 abatement, or where only the abatement from waste is actually feasible. Analysis is also carried out where there is no non-CO2 GHG abatement potential included to illustrate the implications of accepting the CCC advice and taking a strategic decision not to rely on non-CO2 GHG abatement.**

Inclusion of Project Credits

By purchasing project credits the UK could reduce the level of domestic abatement in the non-traded sector that policy is required to deliver. The EU Climate and Energy package places a limit on the use of project credits in the non-traded sector of 3% of 2005 emissions from 2013 onwards. This is 11.2MtCO_2e per year (although banking of previous under-use is allowed). It would not be feasible to include a greater level of credits than this in the analysis as it would entail failure to comply with our internationally agreed obligations.

However, the Government has committed to aim to meet the first three carbon budgets (2008-2022) without the use of project credits in the non-traded sector. A legal limit of zero has been set on the use of credits for the first budget period, outside the EU ETS, therefore, purchasing project credits are not considered as a technical measure to be included on the MACC. This is in line with the advice of the Committee on Climate Change, and puts the UK in a good position to make the transition to the tighter budgets to be set following an international deal on climate change mitigation, and EU level negotiations to share out an EU target among Member States.

In the analysis contained in this paper, it is therefore assumed that the UK's non-traded target will be delivered through domestic abatement only.

It is likely that project credit purchase will play an important part in making up the additional effort required to meet tighter carbon budgets following a global deal. In this case, assumptions will be revised in line with Government decisions on credit purchase after the new budgets are set.

Air quality impacts and other ancillary costs

It is appropriate that the non-traded price of carbon should also include ancillary costs and benefits, where these can be accurately quantified.

The CCC MACC analysis does not include valuations of the air quality impacts of abatement technologies. In general there is a strong synergy between climate change policy and air quality. However in some cases, most notably residential bio-mass heating, there is a tension.

Economists from Defra have quantified the air quality impacts of increased or reduced use of different fuel types. These figures show that the damage costs of burning bio-mass for heat in an inner city area are as high as 30p/KWh – vastly larger than the carbon benefits - meaning that the feasible potential that the CCC identified from residential bio-mass needs to be adjusted. The damage costs associated with burning bio-mass depend on location. The cost-effectiveness of residential biomass therefore needs to be differentially adjusted to account for whether the home is located in the inner city, urban, suburban or a rural setting. For all residential bio-mass potential this pushes blocks of potential further to the right in the MAC curve, compromising their cost-effectiveness. Even for rural bio-mass, where the damage costs are the least, the cost-effectiveness is impaired by £50/tCO_2e.

In the analysis below, the air quality impacts of use of residential biomass are included in the relevant scenarios.

Other ancillary costs have been valued in the measures contained in the MAC curves. Comfort taking has been included for domestic energy efficiency measures, both by reducing the volume of abatement delivered by the measures and in the calculation of their cost-effectiveness.

The Rebound Effect

The abatement potential identified in the CCC analysis takes into account the “rebound effect”. This is the change in driver behaviour following any increase in fuel efficiency. An improvement in fuel efficiency means that less fuel is required to drive a given distance, and hence fuel costs are reduced. It would therefore be expected that drivers would respond to this reduction in the cost of driving in a number of ways, such as increasing the mileage driven (expected to be the largest impact), and/or taking extra comfort when driving e.g. increasing the use of air-conditioning, seat heaters and so on. The implications of this rebound effect are that the fuel and CO_2 saved as a result of improvements in fuel efficiency are lower than might be expected when only first round effects are considered.

The CCC adopted a hybrid approach for transport measures – the volume of abatement was adjusted downward to reflect a rebound effect from measures that reduced the marginal cost of driving. However, the cost-effectiveness of these measures was not adjusted to take account of the additional congestion costs associated with this rebound. In principle demand side measures could be implemented to avoid the rebound effect – in this case the cost-effectiveness figures calculated by the CCC would be appropriate but the volume of abatement would be understated. Alternatively if no complementary demand side measures were implemented then the CCC’s assessment of the cost-effectiveness of transport measures would be over-optimistic but the volume of abatement would be appropriate.

The results of the Government analysis for both abatement potential and cost-effectiveness is presented assuming that measures are not in place to counter the rebound effect.

7.6 Method of translating a point estimate into a price schedule

Separate MACs could be produced for each year up to 2020. This would enable a schedule for the non-traded price of carbon to be produced that reflected the marginal cost of meeting the target for each year. However, we have not chosen to follow this approach. Instead MAC analysis is performed for the year 2020 and then the non-traded price of carbon for the years running up to this is calculated using a cost of carry.[51]

Producing separate MAC analysis for each year would produce a spuriously accurate price schedule. Further, there is the flexibility for banking and borrowing of emissions between years – there are no hard targets for any individual year - either in carbon budgets or in the EU package. For these reasons, significant discrepancies between the marginal cost of meeting the non-traded target trajectory for individual years are not realistic. It would be cheaper for the government to over-comply with non-traded targets in the years where abatement is relatively cheaper and use the spare abatement to contribute towards emissions reductions in the relatively expensive years. Therefore, a cost of carry approach has been used to achieve a smoothing of the price of carbon over the budget periods.

7.7 Key Results

The following six MAC curves, along with the further empirical analysis contained in Annex 1, have informed the adoption of a range of values for the non-traded price of carbon in 2020 of £30 to £90/tCO_2e with a central value of £60/tCO_2e.

Analysis that includes all the CCC's high feasible potential in the MAC curve, including non-CO_2 GHG and abatement potential from 'soft' transport measures at zero cost produces a valuation for the non-traded price of carbon of £49/tCO_2e. However, the potential included in this curve for transport measures is greater than Government analysts expect the measures could deliver.

Analysis using the CCC's high feasible potential but excluding the 4MtCO_2e of 'soft' transport behavioural measures values the non-traded price of carbon at £63/tCO_2e. While there is agreement that there is some potential from 'soft' measures, overall the CCC identify higher transport abatement potential than Government analysis. The 4MtCO_2e of 'soft' transport measures identified by the CCC are subject to considerable uncertainty. They were not explicitly

[51] For consistency with the traded carbon price, a nominal cost of carry of 3.5% has been used.

costed in the CCC analysis, so their position on the MACC is uncertain, along with their magnitude of abatement. Excluding these behavioural measures therefore proxies for a view of feasible abatement from transport that is closer to the Government analysts' view.

Analysis using the CCC's high feasible potential but taking a more conservative view of the feasibility of the deliverable potential from non-CO_2 GHGs also values the non-traded price of carbon at £63/tCO_2e; owing to the immaturity of the analysis in this area there is considerable uncertainty over what it will actually be feasible to deliver by 2020.

A higher value for the non-traded price of carbon, of £92/tCO_2e, is derived using the CCC's high feasible potential for all sectors other than transport, for which a cautious Government estimate of feasible delivery (net of rebound) is used. This MACC assumes a new car CO_2 policy scenario of 115g/Km of CO_2 in the UK by 2020. This also includes all the feasible potential identified from non-CO_2GHG. Internal Government estimates of policy costs and air quality considerations are also included.

Analysis using the CCC's high feasible potential for all sectors other than transport, Government estimates for feasible delivery (net of rebound) of transport, and a new car CO_2 policy scenario of 95g/Km of CO_2in the UK by 2020 (includes re-bound), results in a lower non-traded price of carbon, of £63/tCO_2e. This also includes all the feasible potential identified from non-CO_2 GHGs. Government estimates of policy costs and air quality considerations are also included.

A lower bound value for the non-traded price of carbon, of £33/tCO_2e, is derived using the CCC's high feasible potential for all sectors other than transport, for which Government estimates of feasible delivery (net of rebound) is used. This also includes all the feasible potential identified from non-CO_2 GHG. The lower bound estimate assumes a new car CO_2 policy scenario of 95g/Km in the UK by 2020 and measures to counter the rebound effect. Government estimates of policy costs and air quality impacts are also included.

Table 7.1: MACC abatement scenarios.

Scenario	Description	Comment	Implied value for non-traded value of carbon
1	CCC high feasible all sectors	All potential identified by the CCC, from all sectors included in the MAC curve	**£49/tCO_2e**
2	CCC high feasible all sectors, excluding 'soft' transport behavioural measures	4 mtCO_2e of abatement potential identified by the CCC from 'soft' transport behavioural measures is excluded. Was not explicitly costed by the CCC, and their view of potential from transport is CO_2 higher than the potential identified by DfT	**£63/tCO_2e**

3	CCC high feasible, but low potential from non-CO_2 GHG abatement	Only waste non-CO_2 abatement potential included in the MAC curve – uncertainty over the feasibility of non-CO_2 abatement.	**£63/tCO_2e**
4	CCC high feasible for sectors other than transport cautious Government assessment of feasible transport abatement. Includes policy costs and air quality impacts.	Government assessment of feasible abatement potential for transport used, allowing for rebound effect. Assumes new car CO_2 policy scenario of 115g/Km of CO_2 in the UK by 2020. Includes all non-CO_2 abatement potential.	**£92/tCO_2e**
5	CCC high feasible for sectors other than transport, Government assessment of feasible transport abatement. Includes policy costs and air quality impacts.	Government assessment of feasible abatement potential for transport. Assumes new car CO_2 policy scenario of 95g/Km of CO_2 in the UK by 2020(includes re-bound). Includes all non-CO_2 abatement potential.	**£63/tCO_2e**
6	CCC high feasible for sectors other than transport, Government assessment of feasible transport abatement and measures to counter the rebound effect. Includes policy costs and air quality impacts.	Government assessment of feasible abatement potential for transport. Assumes new car CO_2 policy scenario of 95g/Km of CO_2 in the UK by 2020(measures to counter re-bound). Includes all non-CO_2 abatement potential.	**£33/tCO_2e**

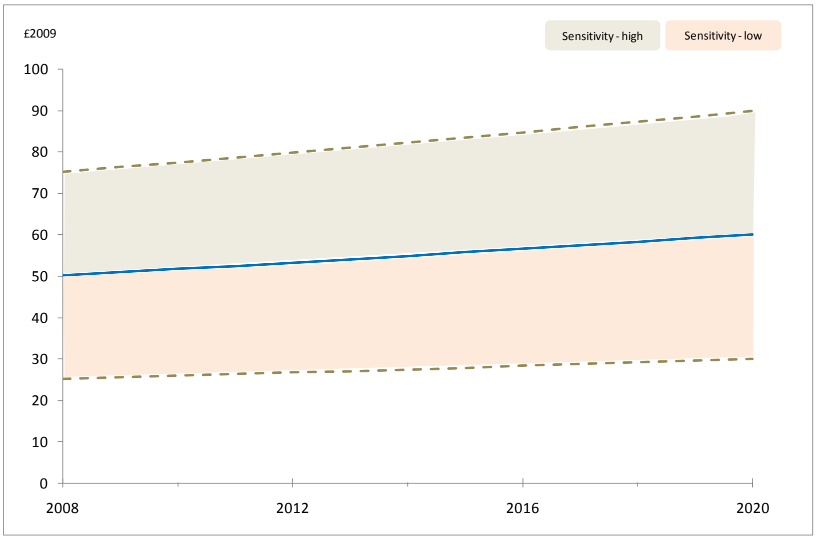
To avoid spurious accuracy in the sensitivity range these figures have been rounded. As shown in Figure 7.1, revised values for the non-traded price of carbon in 2020 are:

- **Lower bound: £30/tCO_2e**
- **Central: £60/tCO_2e**
- **Upper bound: £90/tCO_2e**

Table 7.2: Non-traded price of carbon schedule

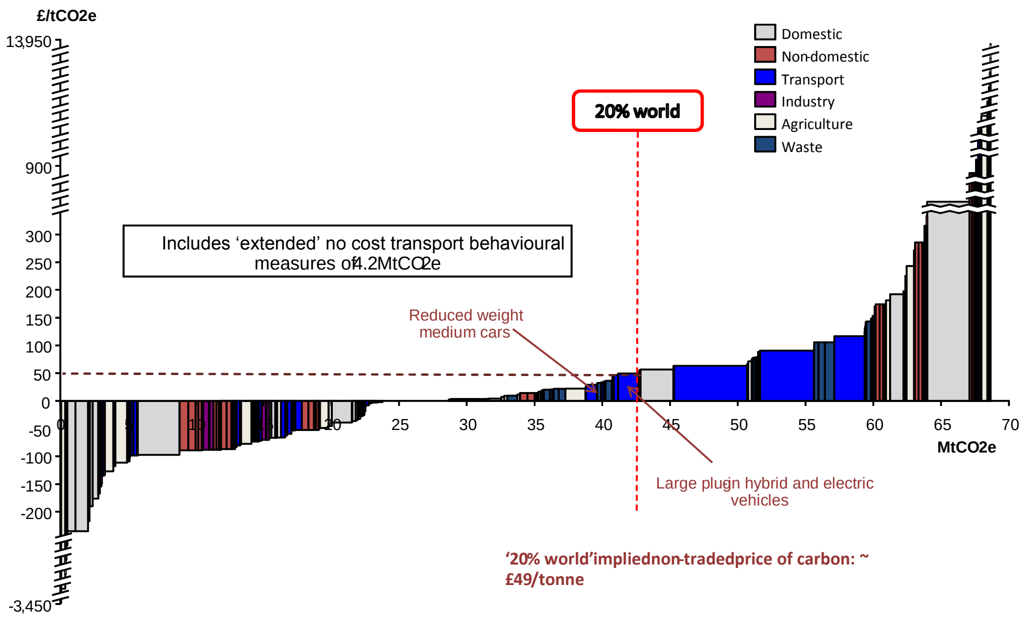
	Lower	Central	Upper
2008	25	50	75
2009	25	51	76
2010	26	52	78
2011	26	52	79
2012	27	53	80
2013	27	54	81
2014	27	55	82
2015	28	56	84
2016	28	57	85
2017	29	57	86
2018	29	58	87
2019	30	59	89
2020	30	60	90

Figure 7.1: Non-traded Carbon Price 2008-2020 period



Figures 7.2 to 7.4 are based on the CCC MAC curves and do not contain policy costs or air quality impacts. Figure 7.2 displays Scenario 1 in which all the 'high- feasible' potential that the CCC judged could be delivered in the UK by 2020, with their assessment of the cost-effectiveness of these potentials. The abatement curve displays the potentials that the CCC identified, ordered from left to right in terms of their cost-effectiveness. This abatement curve includes mitigation of non-CO_2 greenhouse gases. The marginal cost of meeting the target, using a perfectly rational delivery of least cost feasible potentials, would be £49/tCO_2.

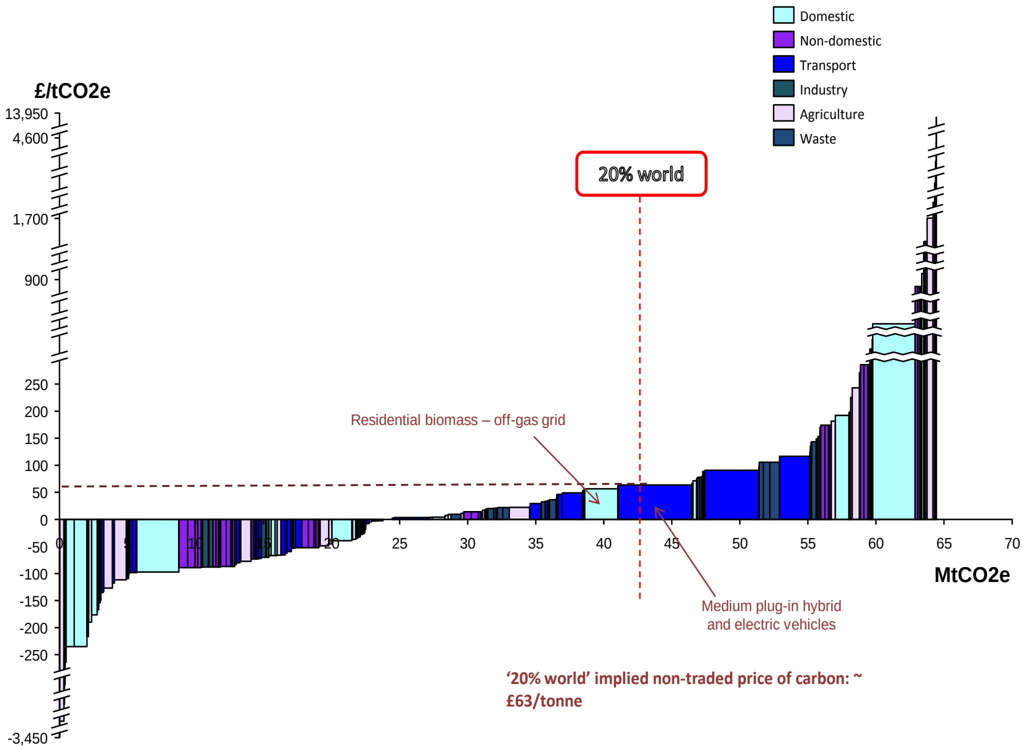
Figure 7.2: Scenario 1 – CCC high feasible all sectors



Source: UK MAC model

The CCC identified just over 4MtCO_2e per year of abatement from behavioural measures in transport. The CCC did not cost these options but stated that they would be expected to be at zero or low cost per tCO_2e. Government analysis of the impacts of policies has found CO_2 lower abatement potential in 2020 than the CCC. Figure 7.3 removes the transport behavioural measures from the abatement curve (but includes non-CO_2). This would increase the implied non-traded price of carbon to £63/tCO_2e from £49/tCO_2e.

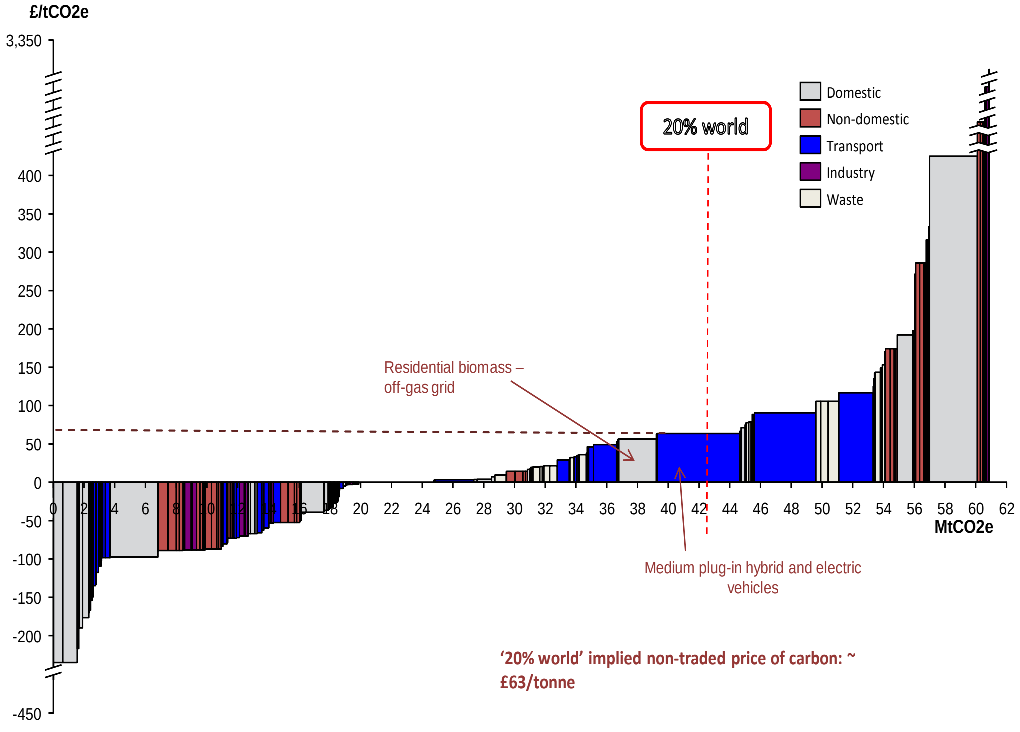
Figure 7.3: Scenario 2 - CCC high feasible excluding behavioural transport measures



Source: UK MAC model

Figure 7.4 shows all the CCC high feasible abatement potential excluding the non-CO_2 abatement potential identified in agriculture. This represents a more conservative view of the deliverability of non-CO_2 abatement to reflect the immaturity of the analysis. The implied value of the non-traded price of carbon is £63/tCO_2e.

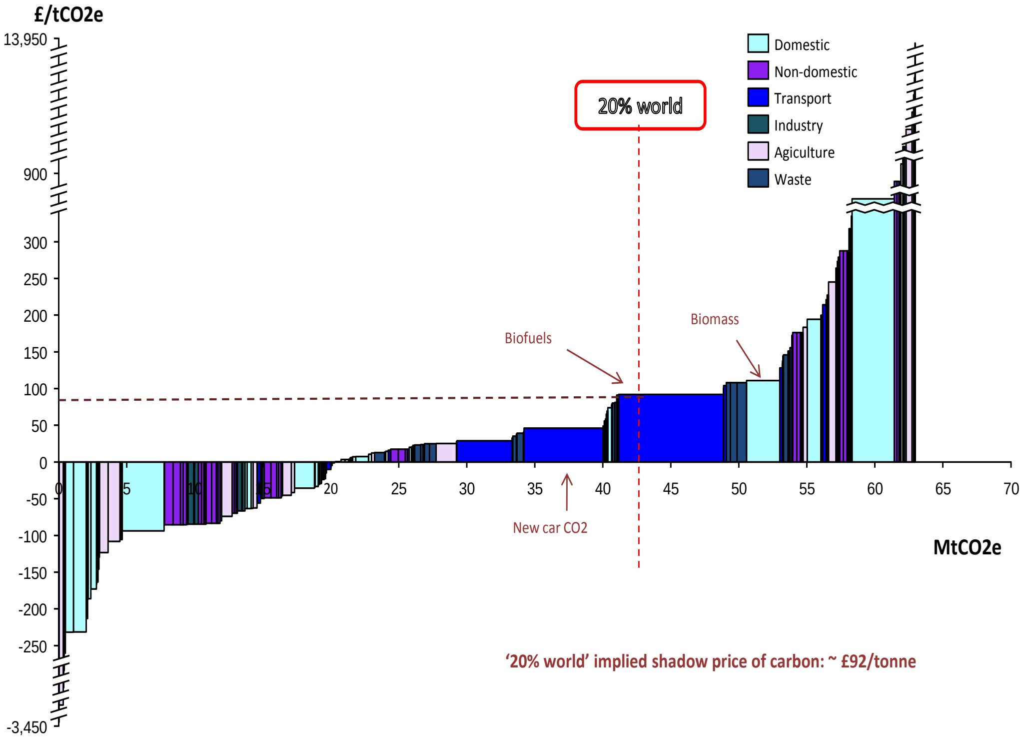
Figure 7.4: Scenario 3 – CCC high feasible with low delivery of non-CO_2 abatement



Source: UK MAC model

Figures 7.5 to 7.7 show high feasible non-traded MAC curves in 2020, relative to UEP29[52] with updated fossil fuel prices. The MACCs include non-CO_2 abatement and adjusted biomass costs to reflect air quality impacts. Policy costs have also been included (based on McKinsey report range), this assumes that higher policy costs are felt for negative cost measures. In Figure 7.5, a Government assessment of transport abatement has been used, which includes a cautious estimate of the savings available from new car CO_2 (115grm of CO_2 per Km in the UK by 2020). The implied value of the non-traded price of carbon is £92/tCO_2e.

Figure 7.5: Scenario 4 – Cautious Government assessment of transport abatement, CCC high feasible in other sectors

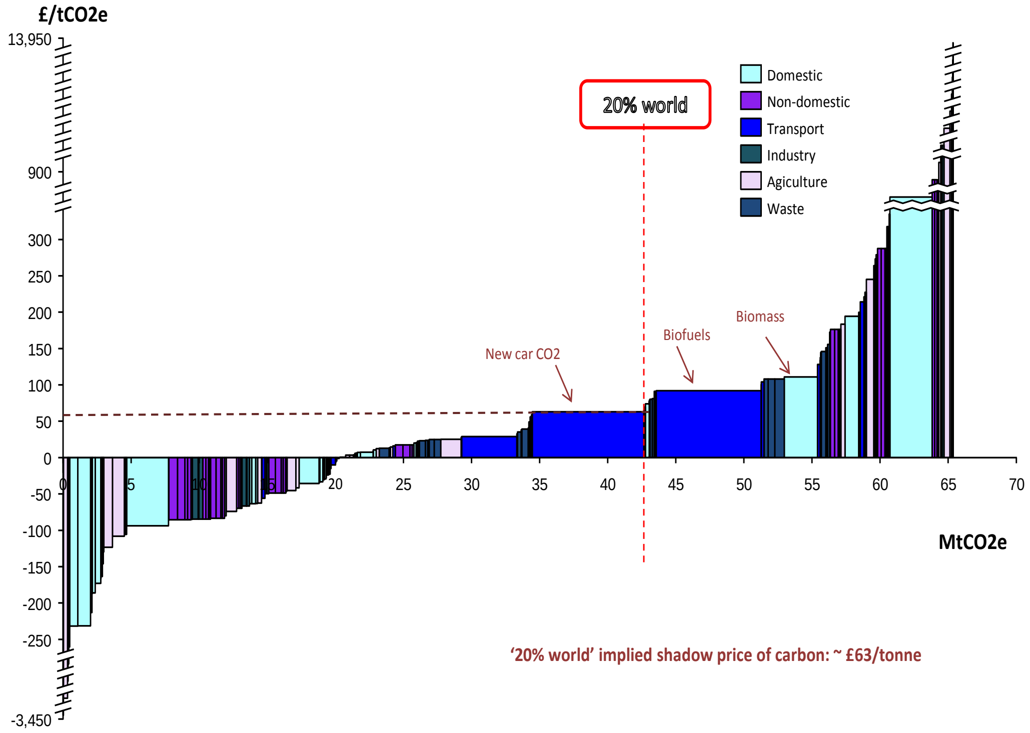


Source: UK MAC model

52 Updated Emissions Projections 29. Consistent with CCC's pre-Energy White Paper baseline (as used in December 2008 report).

In Figure 7.6 Government transport figures are used, which includes optimistic new car CO_2 abatement (95grm of CO_2 per Km in the UK by 2020 scenario). The implied value of the non-traded price of carbon is £63/tCO_2e.

Figure 7.6: Scenario 5 – Government assessment of transport abatement, CCC high feasible in other sectors



Source: UK MAC model

In Figure 7.7 Government transport figures are used, which includes optimistic new car CO_2 abatement (95grm of CO_2 per Km in the UK by 2020 scenario) and measures to counteract the rebound effect. The implied value of the non-traded price of carbon is £33/tCO_2e.

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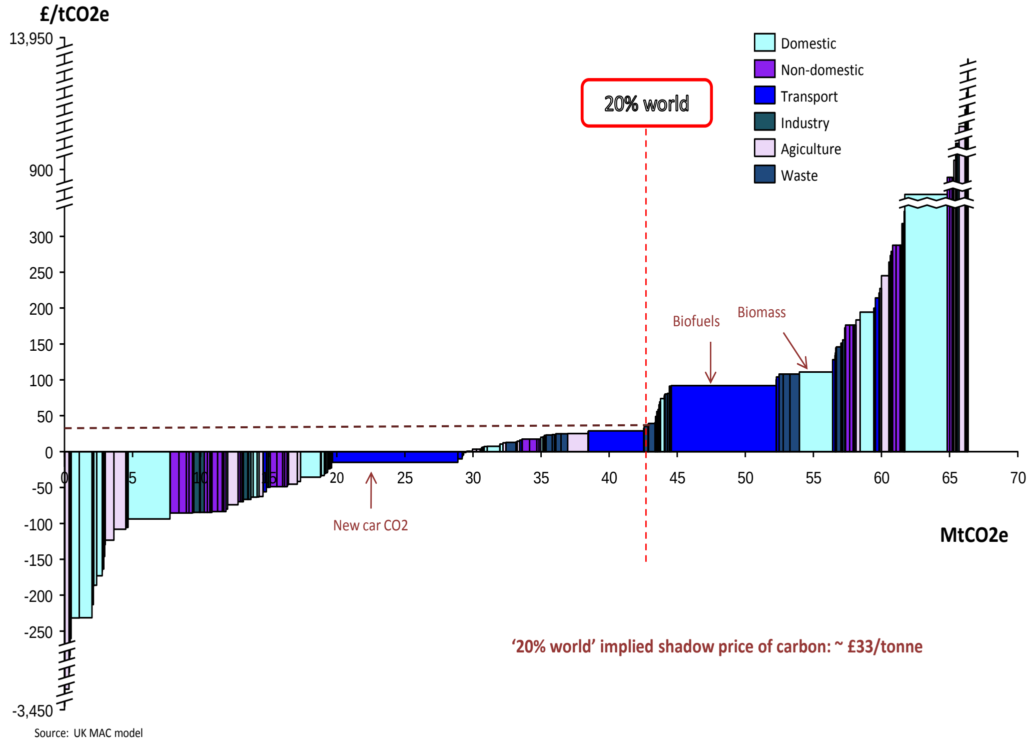
Figure 7.7: Scenario 6 – Government assessment of transport abatement, CCC high feasible in other sectors (measures to counter re-bound)



7.8 Reviewing the Non-traded Values

In theory if a significant number of new policies were introduced that increased emissions then the marginal cost of delivering sufficient compensating reductions in emissions would increase. The marginal non-traded sector measure, identified in the analysis and used to value the target consistent non-traded price of carbon, would not be able to deliver sufficient reductions to offset all the increases in emissions. More expensive options, further up the MAC curve, would have to be implemented to keep emissions within the target.

In practice, it is not thought that this will present a problem. Periodical reviews of the non-traded price of carbon will use updated emissions projections, including the new emissions increasing policies. The reviews will ensure that the non-traded price of carbon continues to be consistent with the marginal price of offsetting policies that increase emissions. Only if policies delivered a sufficiently large jump upwards in emissions in the period between reviews would the non-traded price of carbon become inconsistent with the cost of compensating reductions in emissions.

The frequency of reviews of the non-traded price is set out in Chapter 11.

8. The long run price of carbon

This chapter considers the modelling evidence on long-run carbon prices. Setting the appropriate carbon price for the longer term (post 2020) is more challenging than the short term since it involves modelling global abatement potential and requires assumptions about long term stabilisation goals and the trading regime that will be in place in the long term.

Part 1 of this paper set out the methodology for estimating carbon prices post-2020. Estimates are based on the assumption that there is a functioning global carbon market by 2030, as this is the least cost means of achieving a global stabilisation goal. Therefore, the traded price of carbon post 2030 will be set by the international abatement costs associated with certain stabilisation goals.

The assumption of a functioning global carbon market by 2030 enables the calculation of a global marginal abatement cost that can be applied in UK policy appraisal. This assumption is consistent with the direction set out by the UK Government in The Road to Copenhagen. [53] The Prime Minister has commissioned a report from Mark Lazarowicz – his special representative for carbon trading – on achieving a UK vision for the carbon market. This is expected to be published at the end of July 2009.

This chapter sets out those principles in further detail. The methodology followed consists of:

- adopting an emissions trajectory that most closely reflects the long term climate change objectives of the UK Government and the advice of the Committee on Climate Change in recommending a long term stabilisation goal for the UK;
- assuming a policy regime that will allow us to meet this target at least cost – i.e. a comprehensive, liberal trading regime;.
- modelling the results using Government's Global Carbon Finance (GLOCAF) model, comparing these with the results of other models and evidence.

We conclude that the following values should be used for the long term traded price of carbon:

- **In 2030, a value of £70 per tonne of CO2e should be used, with a range of +/- £35 (i.e. £70 central estimate, £105 high estimate and £35 low estimate).**
- **In 2050, a value of £200 per tonne of CO2e should be used, with a range of + / - £100 (i.e. £200 central estimate, £300 high estimate and £100 low estimate).**

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[53] DECC (2009), http://www.decc.gov.uk/en/content/cms/what_we_do/change_energy/the_issue/copenhagen/copenhagen.aspx

To produce a time series from now to 2050, there would be linear interpolation between the short term traded and non-traded prices of carbon and the 2030 values, and between the 2030 and 2050 values.

The central values are consistent with the aggregate abatement cost figures quoted in the Stern Review. They are drawn from the GLOCAF modelling, adjusted to reflect other available modelling evidence. The high to low ranges of both the 2030 and 2050 values cover most of the available model estimates for relevant emissions trajectories, although in both cases higher plausible estimates are available. **The central values are broadly in line with the values recently adopted by the French Government for valuing carbon in policy appraisal[54] of €100/tCO_2e in 2030 and €200/tCO_2e in 2050 and with work conducted by the CCC as a part of the evidence base considered for recommending the 80% target.**

Since these estimates are based on the assumption of full international trading, they should be regarded as least cost. Evidence suggests that costs may be significantly higher for a non optimal regime.

8.1 Overview of approach to estimating the traded price of carbon in longer term (2020 – 2050)

In the longer term (post 2030), there are several uncertainties to contend with – the relevant emissions trajectory, the reference case (BAU) emissions, the rate of technological progress, as well as the availability of abatement (for example, the availability of emissions reductions from avoided deforestation). There are assumptions to be made regarding both the policy regime and the modelling approach. These issues are explored below.

Policy regime

Emissions Targets/Goals

To estimate carbon prices in the future, it is necessary to specify the relevant emissions reductions goal to be modelled. Our approach is to reflect as closely as possible the long term climate change objectives of the UK Government and the advice of the Committee on Climate Change in recommending a long term stabilisation goal for the UK. In general terms, these goals can be simply expressed – the UK Government has signed into law the Climate Change Act which – following advice from the CCC - commits the UK to 80% emissions reductions by 2050 (relative to a 1990 baseline).

In practice, however, specifying the relevant global emissions reductions goal for modelling purposes involves considering three distinct types of target:

- An outcome from emissions: a target level of probability for not exceeding a given global temperature increase.

[54] http://www.strategie.gouv.fr/article.php3?id_article=830

- A stock of global emissions: a goal for stabilising the stock of emissions in the atmosphere in the long term (typically up to 2200 in most models).
- A flow of global emissions in a particular period time: of particular importance given our focus on the carbon price in 2050 (the furthest point in the future for most abatement cost models) is the target level for global emissions in 2050 and the trajectory of emissions leading up to 2050.

In considering a carbon price for the UK, it would also normally be necessary to identify a goal for emissions reductions in the UK (i.e. the appropriate UK share of an overall global emissions reductions target). However, since, as discussed below, we are assuming a global trading regime from 2030 and beyond, this step is not necessary since such a regime would create a single carbon price – based on global emissions and abatement costs - irrespective of individual country targets.

The UK Government has signed up to a position in relation to the first of the above elements – subscribing to the EU long-term goal of limiting the rise in temperature to no more than an expected 2 degrees centigrade. While it has not publicly stated a view on the appropriate stabilisation goal to target, the UK Government has also adopted a legally binding target to reduce emissions by 80% in 2050, which implies (for a range of burden sharing assumptions) a global level of emissions in 2050 and an emissions trajectory leading up to that level

In its analysis, the CCC[55] approached the setting of an 80% target by working back from a comprehensive global stabilisation agreement, via burden-sharing, to a target for the UK. The CCC's recommendation is to limit emissions in order to aim for a 'central expectation' of global temperature increase of equal, or close to 2°C. It also aims to ensure that a 4°C global temperature increase is reached only with very low probability (less than 1%).

The CCC analysis suggests that in order to achieve such objectives in 2100, it is necessary for emissions to fall to 20-24 billion tonnes CO_2e[56] by 2050 (a 35-45% reduction below 1990 levels), and fall further to 8-10 billion tonnes by the end of the century. Such action would imply CO_2e concentrations of 460-480ppm in 2200. The CCC believes an 80% reduction in UK emissions is consistent with such a goal.[57]

IPCC analysis suggests that a stabilisation target of 450 ppm would result in an increase in global average temperature of between 1.4 – 3.1 degrees, whereas 550 ppm would result in a temperature increase of 1.9 – 4.4 degrees. This would suggest 450ppm is more consistent with the EU goal. The CCC stabilisation range also falls within the range suggested by the Stern Review

[55] Building a low-carbon economy – the UK's contribution to tackling climate change. The First Report of the Committee on Climate Change, December 2008.
[56] 19.5-24.1GtCO_2e to one decimal place.
[57] Building a low-carbon economy – the UK's contribution to tackling climate change. The First Report of the Committee on Climate Change, December 2008.

(450 to 550 ppmCO_2e) as appropriate, and a more recent paper by Stern 'Key elements of a Global Deal' a range of 450-500 ppmCO_2e was recommended.

Estimates of abatement costs should be consistent with the CCC analysis of required emission reductions, as this represents the most recent robust scientific and economic evidence available. Therefore, we have focussed, in our carbon price modelling work, on:

- the range of stabilisation suggested by the CCC analysis – 460 ppm – 480 ppm in 2200
- global emissions in 2050 suggested by the CCC analysis – between 45% and 35% below 1990 levels
- while also noting that some of the scientific evidence suggests that stabilisation at 450 ppm is more likely to achieve a central expectation of not exceeding a 2 degrees C temperature increase.

It is important to stress, as noted above, that stabilisation scenarios do not tell the whole story. It is also necessary to examine the actual trajectories associated with various stabilisation scenarios in different models. Models with identical stabilisation scenarios may have very different emissions trajectories, and in reality it is these emissions reduction trajectories that are the proximate aim of climate change policy. For example, the CCC stabilisation goals above define a trajectory post-2050. The stabilisation trajectories used in GLOCAF also do so, although GLOCAF abatement cost estimates only go to 2050. Similar stabilisation scenarios can be produced from different trajectories, which we explore later on. Another issue explored later on is the business as usual trajectory. As with stabilisation trajectories, BAU trajectories can also differ and this can be a major driver of abatement costs.

Extent and coverage of trading regime

The second policy choice concerns the extent to which we assume there will be a comprehensive, liberal carbon market in place in the future. As noted in the introduction, we believe it is appropriate to assume that there will be a comprehensive global trading regime from 2030 onwards, as this is the most efficient method for tackling climate change. In reality, there are likely to be some sectors of the economy which could not be part of such a regime. However, at the same time these sectors may be able to take part in such a system by having, for example, a buy out from domestic policy to the international market.

As also noted above, estimates that are derived using this assumption necessarily represent the lowest carbon valuation possible in order to reach our goals, which should be kept in mind when considering the modelling outcomes below. If a global carbon market were not to be achieved by 2030, costs would increase considerably. A modelling sensitivity on this is illustrated later on in the paper.

Modelling approach

The third choice to be made concerns the choice of model and modelling approach. Several modelling approaches have been developed to estimate the impact of stabilisation measures on the economy. Some of the major differences in approach are set out below.

There are two broad categories of models – intertemporal optimisation, and ‘recursive dynamic’. The former have the assumption of perfect foresight and find the cheapest manner of meeting goals over the whole time period (often up to 2100). The latter recursive dynamic models (including GLOCAF) are more ‘agent-based’, and do not have perfect foresight – agents act only one time period ahead, where a time period could be, for example, 5 or 10 years. Expectations tend to be adaptive rather than rational. Agent based models are more realistic and often permit inclusion in the analysis a larger number of regions and sectors.

In addition, some models (including GLOCAF) are based on a defined inputted trajectory (that is consistent with reaching certain emissions levels), rather than the model optimising the emissions trajectory. Recursive dynamic models have such a feature. Such a situation is more in line with international agreements – for example the EU ETS sets a trajectory under which borrowing is essentially limited to 1 year ahead. The economy would not be able to define an optimal trajectory for itself under such a regime. International agreements will generally define a form of trajectory (such as targets at milestone years) rather than allowing individual parties to define their own. Reasons for such agreements include upholding the credibility of an international agreement, so as to prevent its collapse (in the case that everyone backloads abatement). There are also genuine difficulties in optimising the trajectory within the model, given the major uncertainties about damage costs discussed in the principles paper.

Another key modelling feature is the treatment of the costs of development of new technologies. Some models assume that the cost of technology fall by an exogenous factor. Despite this approach being relatively simple, it is unlikely to be very realistic - the more a technology is used the cheaper it is likely to become as technology users learn how to use it more efficiently. Other models (including GLOCAF) have attempted to endogenise the treatment of technological change reflecting the learning process in the model. For instance, the cost of technology could decrease following cumulative capacity and the size of R&D spending.

Other models differ in the extent to which they include potential abatement opportunities. Generally, the broadest coverage is to be preferred, unless there are compelling reasons why the abatement in question cannot be unlocked, as this gives an indication of the cheapest feasible means of reaching a given stabilisation goal.

Finally, approaches differ according to the extent to which they endogenise demand responses and other key parameters such as fossil fuel prices. It is important that models have a capability to do this, as:

- demand responses are likely to have an important effect on the cost and volume of abatement (e.g. through the rebound effect); and
- fossil fuel prices will have a significant impact on the cost and volume of abatement and will, in turn be affected by the level of abatement activity that has been undertaken.

On all the above criteria, the GLOCAF model held within Government performs well, as:

- It is a recursive dynamic model, based on a defined inputted trajectory,
- It attempts to model technological change dynamically
- It covers a broad range of abatement options, including notably abatement from avoided deforestation, which certain other models do not include
- It includes data from a partial equilibrium energy model (POLES) which fully endogenises all energy prices, including fossil fuels prices, and demand responses.

Therefore, we have used GLOCAF to model global carbon prices. In a second stage, we compare the results with those of alternative models available, taking into account where possible their performance against the above criteria. Since Government economists have direct access to the GLOCAF model, its assumptions and architecture are more transparent to us, so particular weight is placed on the GLOCAF results.

8.2 Estimating the long term traded price of carbon using the GLOCAF model

DECC has developed a Global Carbon Finance (GLOCAF) model, which uses global abatement cost information to estimate the financial flows that result from various different climate change agreements. The model contains datasets on marginal abatement costs. We can thus use GLOCAF data in order to project carbon prices under various scenarios. GLOCAF currently uses Business as Usual (BAU) data from the POLES energy model for energy CO_2 emissions, the MNP non CO_2 data, and data from afforestation and avoided deforestation from two alternative sources, GCOMAP and DIMA. However, GLOCAF is able to take data from other sources if the data is available at a sufficiently detailed level.

DIMA and GCOMAP are partial equilibrium models of the forest sector that incorporate opportunity costs of abatement from forestry. The main advantage of DIMA is that it captures more than just the opportunity cost of the land in the structure of the model, reflecting the fact that there are likely to be institutional and other factors which limit the effectiveness of compensation at just the opportunity cost. As for GCOMAP, it has reasonably detailed disaggregated data on the alternative usage of the land but it has only 10 world regions. There is potentially a large level of cost effective abatement available for avoiding deforestation but considerable uncertainty about the costs of unlocking it. Therefore it is prudent to consider both datasets in our analysis.

Estimates

The GLOCAF estimate of abatement costs for various stabilisation goals (shown below in ppm CO_2e) are shown in the table below, which also provides an average of the GLOCAF numbers using DIMA and GCOMAP. The table also shows, given the trajectory assumed by GLOCAF, the global emissions reductions in 2050 corresponding to each stabilisation goal (expressed as a percentage reduction relative to 1990 emissions levels).

Table 8.1: GLOCAF estimates of abatement costs (£2008) by stabilisation goal and 2050 emissions reductions

	2030				2050			
Stabilisation goal	**450**	**475**	**500**	**550**	**450**	**475**	**500**	**550**
% reduction in 2050	**-18%**	**-6%**	**-6%**	**16%**	**-50%**	**-50%**	**-41%**	**-14%**
GLOCAF (DIMA)	119.0	77.6	77.6	34.6	317.1	363.1	267.0	101.9
GLOCAF (GCOMAP)	67.7	49.7	49.7	20.4	223.6	238.4	152.8	82.9
GLOCAF (Average)	93.3	**63.7**	**63.7**	27.5	270.4	300.8	209.9	92.4

The 450 and 475ppm scenarios are both overshoot (to 500ppm) scenarios. A 450ppm (no overshoot) scenario is available, but the trajectory taken from SiMCaP (and used in GLOCAF) is not considered feasible (demonstrated by the very high carbon prices that are produced early in the series).

The reader will notice that the carbon price in 2050 under a 475ppm trajectory (with overshoot to 500ppm) is higher than under a 450ppm trajectory. In fact, SiMCaP emission pathways project that in 2050 the emissions produced can be equal between these two scenarios. The difference is that the 450ppm scenario carries out more abatement pre-2050 and post-2050. The prices for 2030 are significantly higher for the 450ppm scenario as more abatement is required; this leads to a lower price in 2050 as the 450ppm scenario sees more investment in earlier years. GLOCAF only runs to 2050, however, it is likely that post-2050 the marginal abatement costs on the 450ppm trajectory would cross over the 475ppm trajectory.

Following on from the policy choices section, where we recommend consistency with the Government-adopted CCC recommendations, we attempt to overlay those recommendations onto the above GLOCAF analysis. This is not straightforward. We have previously noted that it is not only the stabilisation goal which is important (and the CCC recommendation of 460ppm – 480 ppm), but also the emissions trajectory (and the CCC scenarios which produce reductions of between 35-45% by 2050, on 1990 levels). These two pieces of information need to be considered in concert.

The SiMCaP / GLOCAF trajectories differ slightly to the CCC trajectories – GLOCAF takes more action earlier in the period so that in the 450ppm and 475ppm scenarios (both overshoot to 500ppm), global emissions are 50% below 1990 levels by 2050, and in the case of the 475ppm trajectory, they fall to less than 15Gt CO_2e by 2100 (and close to 10GtCO_2e in the 450ppm case). The CCC trajectories have emissions reductions by 2050 of close to 45% on 1990 levels (for those scenarios consistent with central expectation of average temperature rise of close to 2 degrees C), or 35% (for scenarios consistent with around 2.2 degrees C increase in average temperature). These correspond to 2050 emissions levels of approximately 19.5GtCO_2e and 24GtCO_2e respectively.

The CCC 45% reduction scenarios (that have long-run concentrations of around 460ppm, as mentioned in the CCC's letter to Government regarding the appropriate long-term target[58]) have continued emissions reductions post 2050 to 8GtCO_2e. The CCC 35% emission reduction scenarios (that end with stabilisation of 490ppm[59]), have emissions falling to 10-11GtCO_2e by 2100. This compares to GLOCAF's 475ppm trajectory of slightly less than 15GtCO_2e in 2100, and demonstrates that GLOCAF's early action is balanced by less action later on in the period, compared to the CCC analysis.

The GLOCAF 500ppm trajectory produces emission reductions of around 40% on 1990 levels by 2050. This sets it within the range of 2050 emission reductions suggested by the CCC. However, in order to retain consistency with warming of close to 2 degrees C, the trajectory would have to fall much further post-2050 than it actually does. So, although this trajectory is consistent with 2050 emissions reductions scenarios, it is not consistent with the long-run temperature goals.

The issue that this touches upon is that we have only considered prices up to 2050 thus far, whereas ideally – as a result of different assumptions on trajectory and stabilisation – we would need to look beyond this time horizon. However, we recognise that evidence becomes sparser post-2050, and indeed GLOCAF only produces results to 2050. We need to reconcile the fact that there is less evidence post-2050 (and that we have no data from GLOCAF), with the findings above:

- that the 450ppm stabilisation level is more consistent with a central expectation of a temperature increase of 2 degrees Centrigrade;
- that the GLOCAF 475ppm trajectory is consistent with long-run concentration goals (although slightly stricter than CCC recommendations in 2050); and
- that the GLOCAF 500ppm trajectory is consistent with the range of emissions suggested by the CCC for 2050, although not with the scenarios which reach 'close' to 2 degrees C warming (the CCC

[58] Building a low-carbon economy – the UK's contribution to tackling climate change. The First Report of the Committee on Climate Change, December 2008.
[59] As opposed to 480ppm as set out in the CCC letter.

scenarios that reach close to 2 degrees warming have emissions levels in 2050 between the GLOCAF 475 and 500ppm trajectories).

In light of the discussion above, we believe it is prudent to consider both the 475ppm and 500ppm trajectories as relevant for determining 2050 carbon prices. **Averaging the values for 475ppm and 500ppm trajectories (using average GLOCAF values) produces a 2030 carbon price of around £65/t CO_2e, and a 2050 price of around £255/tCO_2e.**

It is clearly of interest to understand the marginal technology driving these price estimates. While are noted, GLOCAF incorporates abatement options from a range of sectors, these estimates heavily influenced by the energy data source – the POLES energy model. Under POLES, there is not one marginal technology. Rather, POLES takes a probabilistic approach (similar to a logit model) to reflect the fact that a diverse mix of technologies are demanded at all carbon prices, although cheaper technologies are preferred, other things being equal. For the trajectories reported on in this paper, by 2050 POLES sees significant uptake of CCS (around one-third of electricity generation involves CCS), a huge increase in wind and solar power (although from a small base, so they still make up only about 15% of all electricity), and a large cut in oil consumption.

Sensitivities

It is also appropriate to explore sensitivities using the GLOCAF model. These are of a higher R&D spend and a relaxation of the assumption of a global trading regime in 2030 and 2050.

The model provides an illustration of the potential impact of increasing research & development spend on the costs of meeting particular targets. In POLES (which provides the energy cost data within GLOCAF), R&D expenditure is exogenous, so a relationship needed to be defined. In this example, R&D spending was quadrupled, with the imposed effect in being to halve technology floor costs (the cost below which technologies cannot fall). There are two outcomes from this: the BAU emissions pathway falls (by around 3 GtCO_2 in 2050), and the marginal cost of abatement increases. The reason for this is that the higher R&D spend causes some of the lower carbon technologies to be taken up in the BAU case. The overall impact is to reduce carbon prices for a given levels of emissions (emissions, rather than abatement, need to be set as the BAU changes) by between 10 - 15%.

For illustrative purposes, we also include a sensitivity on the assumption regarding the trading regime. The table below shows the polar opposite cases of totally free trade vs. no trade (within the set regions – i.e. this would still allow for the EU ETs).

Table 8.2: Trading regime sensitivity (carbon prices under a 475ppm (overshoot) trajectory (in 2008£/tCO_2e)

	2030	2050
Global price under completely free trade	77.6	363.1
Weighted average regional price under no trade	311.7	519.0

As clearly demonstrated, our assumption of a comprehensive and freely-traded global regime significantly decreases the marginal costs of meeting a target (in this case a 475ppm trajectory), especially in 2030. We believe it is reasonable to make the assumption of the most cost-effective solution, however this is a conservative assumption and it is important to note the implication for carbon prices if a comprehensive trading regime is not established.

8.3 Comparison with other model estimates

In looking to assess the reasonableness of the GLOCAF results, we have looked at a broad range of estimates of global marginal abatement costs from various modelling exercises. Annex 3 discusses the models we have reviewed and sets out how we have interpreted the results.

We have adopted the following approach to filtering the results:

- We have focused on results that relate to the relevant stabilisation goals, which, as discussed above, are 475ppm and 500ppm
- We have excluded results that, for a given stabilisation goal, have an emissions reduction profile that is clearly inconsistent with the CCC advice and the 2050 target
- We have excluded results from a model that failed to include abatement from avoided deforestation
- We have excluded results from a range of models that had substantially inaccurate / outdated business as usual BAU assumptions.

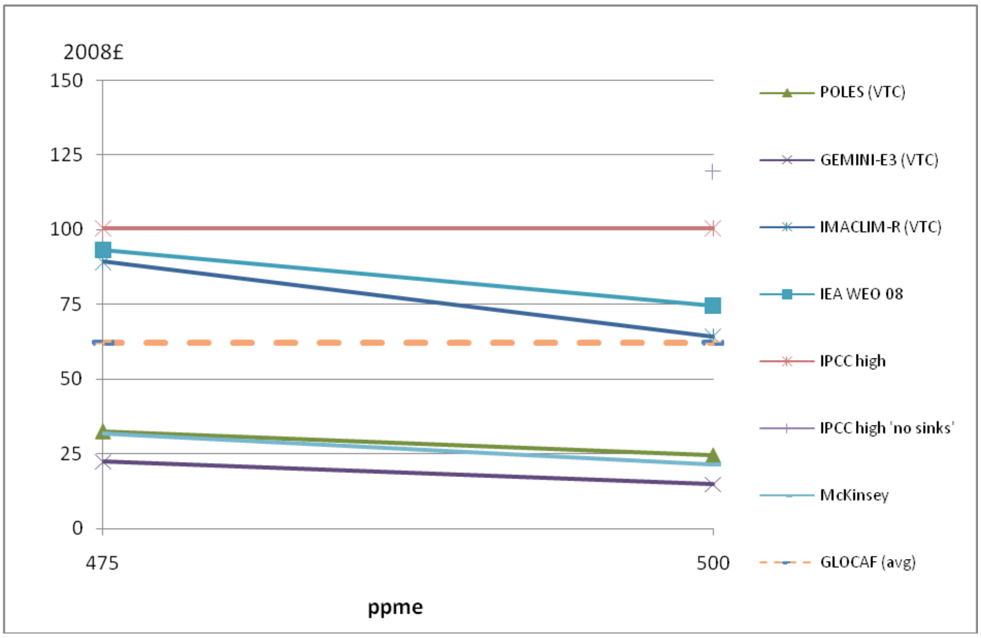
The net effect is to narrow the range of reasonable estimates for 2030 and in particular 2050.

2030 Estimates

The chart below shows the remaining estimates for 2030.

Given the modelling estimates available, **a figure of £70 is a reasonable central estimate – roughly in line with the average GLOCAF estimate of about £65**. Clearly it is a matter of judgement how broad a range of estimates should be covered by upper and lower bound sensitivities. **A range of +/ - £35 (i.e. £105 upper bound, £35 lower bound) covers most of the relevant modelling results.** It is a large range, but this is defensible given the uncertainties involved in projecting a price to 2030 and beyond. It also includes within it the McKinsey estimates at the lower end of the spectrum.

Figure 8.1: Estimates of global abatement costs in 2030



The annexes discuss the range of models and their pros and cons. Of particular interest in relation to the 2030 target is the McKinsey MAC curve, a previous version of which was referenced in the 2007 SPC document. McKinsey have produced a bottom-up marginal abatement cost curve[60] and recently published revised estimates of the costs in 2030 of reducing global emissions. The most notable finding of this study is that achieving a long term stabilisation path of 450ppm (associated with a 40% to 60% probability of maintaining global warning below the 2 degree Celsius threshold) would require about 38 $GtCO_2$ abatement in 2030 and a carbon price of approximately 55€/tCO_2 (Figure 8.2). These estimates are somewhat higher than reported in McKinsey's 2007 paper, which suggested prices of around €40/tCO_2e in 2030, partly because of a higher BAU.

The McKinsey MAC model is a bottom up model that provides a significant degree of technological detail. It covers land use and non CO_2 gases and it has a relatively good degree of regional and sectoral disaggregation (10 sectors and 21 regions). However, this modelling approach is not free of drawbacks. It relies on estimates of technical or potential abatement opportunities that do not account for constraints (e.g. lack of information) and hidden costs that exist in practice. Thus, estimates of abatement potential are likely to overestimate the amount of abatement opportunities that are feasible, and hence underestimate the marginal cost.

The McKinsey approach is a bottom up resource model and, as such, provides neither a partial nor a general representation of how the different sectors of the economy interact and adjust to shocks. This is an important factor in keeping abatement costs low relative to other economic models. For example, when

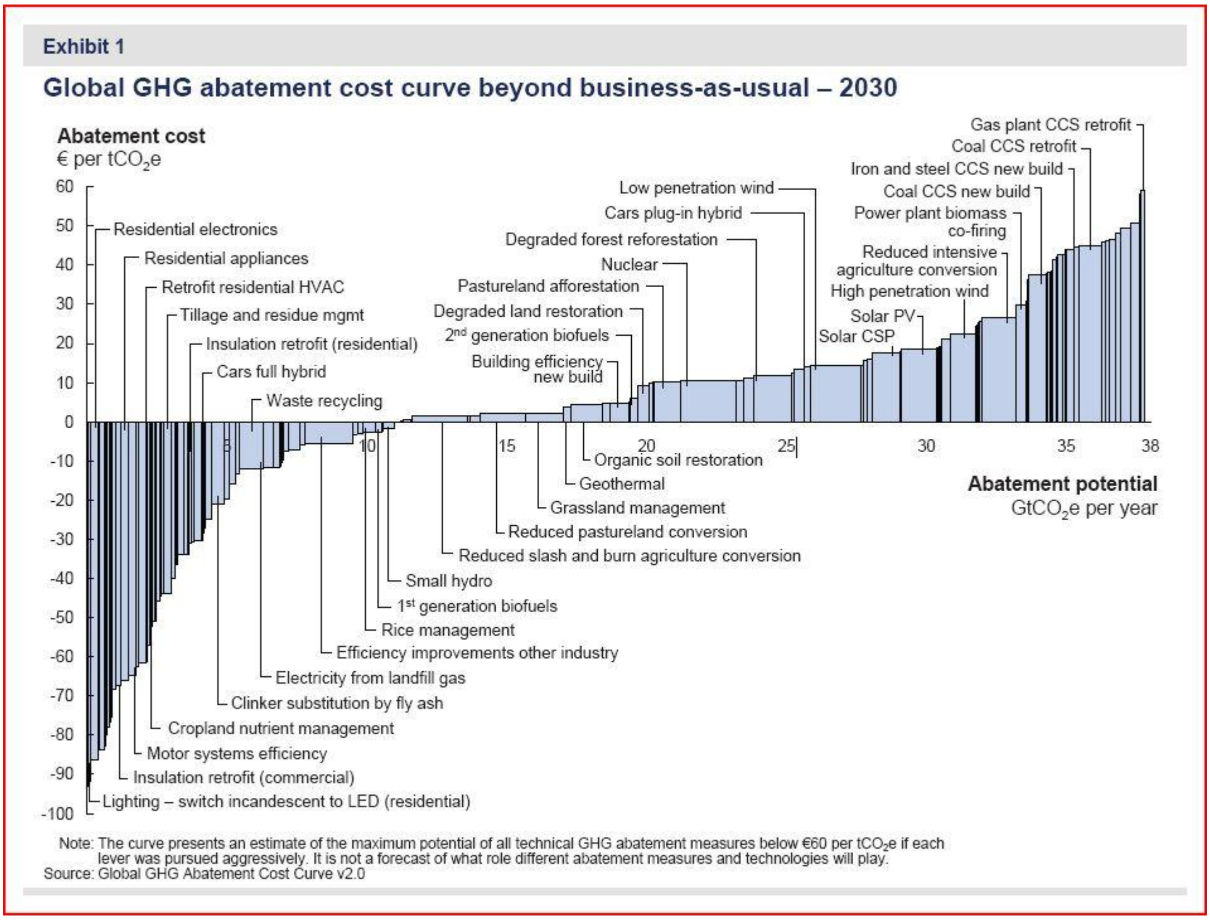
[60] Version 2 of the Global Greenhouse Gas Abatement Cost Curve.

fossil fuel prices are endogenous to the policy environment, they will be lower – ceteris paribus – with than without climate policy. McKinsey's framework cannot take account of this and hence the estimates, particularly towards the upper end of the abatement curve are likely to be underestimates of marginal costs. The McKinsey report notes that policy costs also exist, but these are excluded from their analysis, and hence carbon prices.

Further, and importantly, neither direct rebound effects – e.g. comfort taking due to lower fuel costs from domestic energy efficiency measures – nor macroeconomic rebound effects – in terms of the higher income generated by the significant negative cost abatement potential, leading to more spending on other carbon – non-intensive goods – are taken into account. As this is not endogenised in the curve, baseline emissions essentially adjust in response to climate policy. Overall costs will therefore tend to be understated.

Finally, to derive the cost estimates in 2030, the McKinsey work assumes that the necessary global investment will start in 2010. Any departure from this date – as seems likely given the current state of international negotiations – will result in cost increases in 2030, as available abatement in their model is constrained by a variety of factors such as supply constraints.

Figure 8.2: McKinsey Global GHG abatement cost curve

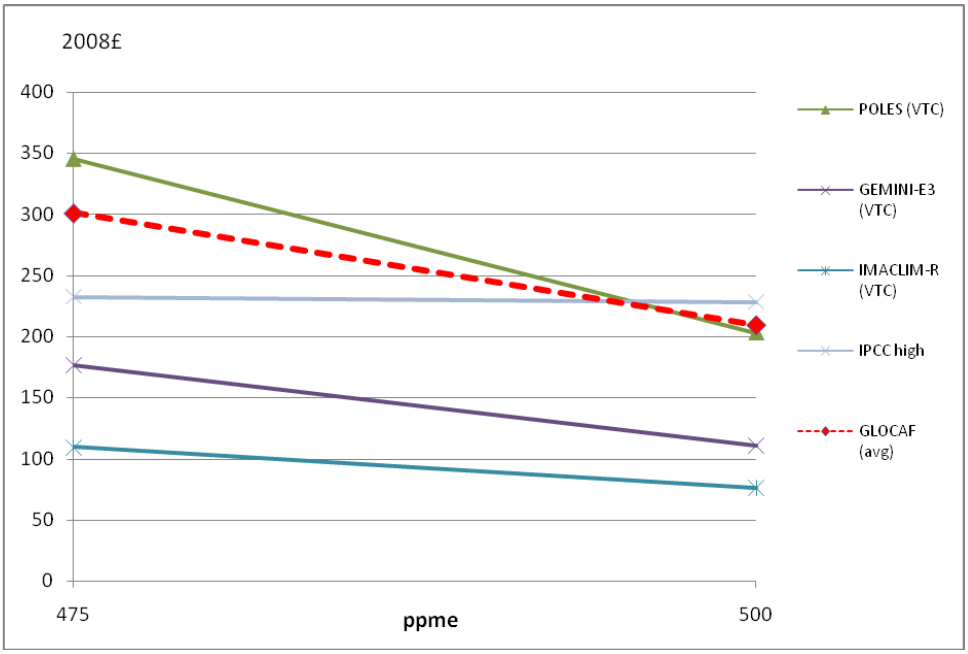


In conclusion, the McKinsey work does not provide an economy-wide 'model' of abatement and hence does not take explicit account of demand responses such as rebound effects. Neither does it model specifically hidden costs and policy costs. For both reasons, cost estimates will tend to be lower than is likely to be deliverable in practice. Indeed, the McKinsey report makes clear "the cost of abatement is calculated from a societal perspective [...] Therefore, the curve cannot be used [...] for forecasting CO_2 prices". Nevertheless it does provide a comprehensive, technology-specific overview of abatement options, and therefore provides a useful sense check on the results of other, more top-down models. For this reason, we think it provides an appropriate lower bound estimate for our carbon price estimates in 2030.

2050 Estimates

The process described above produced the range of estimates for the 2050 price of carbon set out below. Again, annexes to this document provide a detailed description of the relevant models and their characteristics.

Figure 8.3: Estimates of global abatement costs in 2050



The GLOCAF estimates are at the higher end of the range presented and, accordingly, a lower central estimate than £255 may be appropriate. Again the relevant range is a matter of judgement but a broader range than for 2030 is defensible given the greater uncertainties that exist over this longer time period. **On balance, we consider that a central estimate of £200, with an upper estimate of £300 and a lower estimate of £100 is reasonable, as it covers the range of most relevant estimates.**

We do recognise, however, that given all the available evidence this is a conservative valuation, particularly in view of the fact that it is based on the assumption of full international trading. Evidence suggests that costs could be significantly higher for a non optimal regime.

8.4 Estimates and ranges

In summary, the following long term traded prices of carbon will be adopted:

- **In 2030, a value of £70 per tonne of CO_2e will be used, with a range of +/- £35 (i.e. £70 central value, £105 high sensitivity and £35 low sensitivity).**
- **In 2050, a value of £200 per tonne of CO_2e will be used, with a range of + / - £100 (i.e. £200 central value, £300 high sensitivity and £100 low sensitivity).**

To produce a time series from now to 2050, there will be linear interpolation between the short term traded and non-traded prices of carbon and the 2030 values, and between the 2030 and 2050 values. As noted, the high to low ranges of both the 2030 and 2050 values cover most of the available model estimates for relevant emissions trajectories, although in both cases higher plausible estimates are available.

The central values are broadly in line with the values recently adopted by the French Government for valuing carbon in policy appraisal, of €100/tCO2e in 2030 and €200/tCO2e in 2050 and with work conducted by the CCC as a part of the evidence base considered for recommending the 80% target.

The CCC considered a carbon price of £50 in 2030 and £170 in 2050. These estimates were obtained using the UK MARKAL model and assuming a world without carbon trading. The CCC also estimated the carbon price in a world with carbon trading using the GLOCAF model and finding a global carbon price of £150 in 2050. The CCC carbon price estimates are below our central estimates in 2030 (£70/tCO_2) and 2050 (£200/tCO_2) but well within our recommended ranges.[61]

[61] It must be noted that the carbon price estimates without global carbon trading were obtained using the UK MARKAL model that is a least cost optimisation model of energy use and it assumes less realistic perfect foresight out to 2050. These two features of the model could partially explain the relatively low carbon price estimates. The CCC carbon price estimate under a global carbon market diverges from our recommended estimate because it is based on a different exchange rate and a 500ppm trajectory.

9. Carbon price schedules and comparison with the Stern Review

9.1 Synthesis of results: revised carbon price schedule

This chapter of the paper summarises the recommended short (up to 2020) and long term (up to 2050) carbon price estimates while comparing them with the previous approach based on the SPC[62] (Figure 9.1). The full price schedules are reported in Annex 4.

Traded and non-traded carbon prices have been calculated in the short term, converging to a long term traded price of carbon from 2030 onwards. The traded carbon price estimates over the 2008-2020 period were obtained from the internal DECC carbon price model estimate (under central fossil fuel price assumption) adjusted for the opportunity cost of holding allowances (i.e. cost of carry) rather than investing in risk free rate assets. As for the non-traded sector, the recommended carbon price estimates were based on the CCC marginal abatement cost curve for the year 2020 resulting in a central estimate of £60 in 2020. This central estimate was discounted back to 2008 using the cost of carry to determine the yearly price profile.

Values for the non-traded price of carbon are above the traded values up to 2020 suggesting that the marginal cost of abatement is likely to be significantly higher in the non-traded compared to the traded sector (see Figure 9.1). For comparison, the non-traded values are higher than the previous SPC while the traded values are lower than the SPC.

A linear trajectory is used to link the 2020 traded sector estimates to the 2030 recommended central global carbon price estimate of £70 whereas for the non-traded sector of £60 in 2020 is maintained over the 2020-2030 period.

The values for the long term traded price of carbon (over the 2030-2050 period) were obtained assuming that a global carbon market is in place from 2030. The global carbon price over the 2030 - 2050 period was based on GLOCAF estimates adjusted to reflect other available modelling evidence. This approach suggested a central estimate of £70 in 2030 and £200 in 2050. The long term central values are significantly above the previous SPC, based on estimates of damage costs at 550 ppm. Given this, the second half of this chapter assesses the consistency of these results with those of the Stern Review estimates of mitigation costs and damage costs (Figure 9.1).

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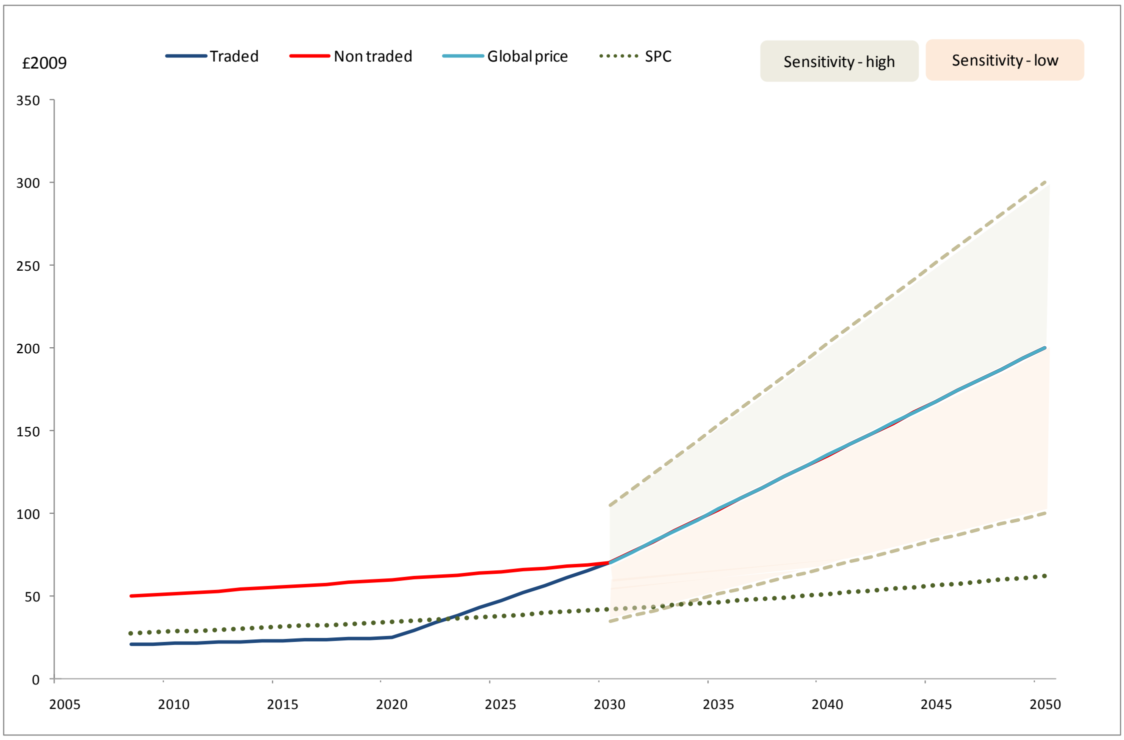
[62] See section 3 for a discussion of the current Shadow Price of Carbon based on the Social Cost of Carbon.

Figure 9.1: Traded, non-traded and previous shadow carbon price (£2009) estimates (2008-50)[63]



These prices represent a view of likely future carbon prices, under a given regime. They are intended to be consistent with the ambitious short-term targets that have been set by Government and the European Commission and with long-term emissions reductions targets, as recommended by the Committee on Climate Change and accepted by Government.

As with any view of the future, there is inherent uncertainty. But, as suggested in the chart above, it is likely that carbon prices will rise in the future given the constraints examined. There are two effects here. Firstly, there is the movement along the abatement curve – given a fixed abatement curve over time, as targets become successively more stringent and the business as usual increases (the demand for abatement rises), the incremental (marginal) cost of reaching these targets increases. The cheapest options will be taken up first, leaving incrementally higher costs per unit abatement. Secondly, the abatement curve shifts out over time as technological improvements lead to lower cost abatement for any given amount of abatement. For the empirical evidence we present to be the case, the former effect must outweigh the latter. This seems a likely outcome of our ultimate goal of globally coordinated action – that when more countries take on more ambitious emissions reductions targets, the demand for - and hence price of - abatement will increase over time.

63 Upper and lower ranges are shown only for the traded price of carbon post 2030.

9.2 Comparison of results with the Stern Review

This section considers the consistency of the above series with Stern estimates of mitigation costs and damage costs.

Are the values adopted consistent with Stern estimates of costs of mitigating climate change?

The Stern Review concluded that mitigation costs would equate to around 1% of GDP in 2050, with a range of -1% to + 3.5% for a 550 ppm. The table below presents the costs of mitigation as a percentage of GDP from the GLOCAF modelling.

It should be recalled that the values that we are suggesting in 2050 are considerably below the GLOCAF estimates and the stabilisation goal more stringent. **Nevertheless, even in the more stringent scenarios, GLOCAF costs in 2050 rise only to around 3% of GDP, which remains within the Stern range for the 550ppm stabilisation scenario.**

Table 9.1: Mitigation costs in GLOCAF (%GDP)

Trajectory	2030	2050
450 overshoot to 500	1.49%	2.95%
475 overshoot to 500	0.84%	3.20%
500	0.84%	2.25%
550	0.27%	0.99%

(With DIMA dataset)

Trajectory	2030	2050
450 overshoot to 500	0.95%	2.33%
475 overshoot to 500	0.58%	2.39%
500	0.58%	1.78%
550	0.22%	0.85%

(With GLOCAF dataset)

Are the values consistent with the Stern appraisal approach?

Clearly, it is also of interest to investigate consistency of the abatement cost estimates with the Stern appraisal approach, and with damage cost estimates themselves, and the conclusions of Stern more generally.

It is useful to start with a description of the methodology of the Stern Review. Rather than undertaking a formal optimisation - estimating the social cost of carbon and the marginal abatement cost, and equalising these across all periods – the Review undertook a less formal CBA. Estimates of the damages on the business-as-usual pathway were compared to estimates of mitigation costs in an ‘action’ scenario (450-550ppmCO_2e). This produced the results of 1-2% costs vs. 5-20% benefits from taking action. Hence, applying the Stern framework involves comparison of the BAU SCC with the marginal abatement cost. In 2050, the **Stern BAU SCC is around £180/tCO_2e**[64], which is broadly in line with 2050 central values we are proposing. However, as noted previously in this document, the uncertainty of the SCC is a major reason for choosing an abatement cost methodology for setting carbon prices. Given the uncertainties, the difficulties in estimating damages and their likely underestimation, any comparison of damage costs and abatement costs on a given pathway should be no more than illustrative.

This informal CBA approach was taken as a result of the large **uncertainty** in outcomes (strictly optimising may not make sense if estimates of the social cost are so uncertain as to make the comparison misleading), and also because of the endogeneity – when both damage costs and abatement costs depend upon the amount of action taken, an optimal trajectory cannot be produced as the trajectory needs to be specified to estimate damage costs. Instead, by fixing an outcome (450-550ppmCO_2e), it is then possible to estimate the damage cost along that pathway. The choice of the 2007 guidance was essentially an outcome of broadly assuming a 450-550ppm stabilisation goal.

Should damage costs constrain our estimates of abatement costs?

There is also a broader question concerning the extent to which damage cost estimates should constrain the values of the traded price of carbon. As already discussed at some length, there is considerable uncertainty surrounding estimates of the social cost of carbon, which is the main motivation for moving to an approach to valuation based on abatement costs.

This uncertainty is reflected in the approaches adopted by both the Stern Review and the CCC. The CCC adopted a similar approach to the Stern Review in setting the long-term target – ensuring that the aggregate costs and benefits stacked up, whilst setting the exact target based more on the science – specifically, staying close to 2 degrees C, and minimising the risks of dangerous climate change (which was taken as exceeding 4 degrees C).

The uncertainty surrounding the SCC must be underlined. Not only is the SCC uncertain, but it is accepted that economic modelling generally provides an incomplete picture of the impacts of climate change. As the Stern Review notes, "*the results presented below should be viewed as indicative only and interpreted with great caution. Given what is excluded, they should be regarded as rather conservative estimates of costs, relative to the ability of these models to produce reliable guidance".* This is inevitable given the estimation of impacts that occur over several hundred years, and with impacts that have not previously been experienced by human civilisation. Lord Stern has recently suggested that estimates of damage costs from the Review are likely to understate true damage costs, by as much as 50%.
Further, as noted previously it is recognised that SCC estimates currently exclude socially contingent impacts – these are the second-round impacts of climate change, such as the cost of mass migrations from inundated countries.

[64] In 2009 prices, which would be the price base year of the new guidance.

Excluding these necessarily underestimates the damages from emissions. Treatment of catastrophic events in integrated assessment modelling is also generally recognised as being incomplete and very stylised. Indeed, it may be difficult to consider any such strong non-linearities within a standard optimisation framework.

A further point regarding SCC estimates is that they do not include ‘equity weights’. These arise from the use of logarithmic utility functions in modelling (a standard assumption in microeconomics that allows for increases in income to have successively lower increases to welfare, consistent with declining marginal utility of income). Incorporating equity weights could increase the social cost of carbon by approximately one-third (the effect of including equity weights at the aggregate level in the Stern Review increases the impacts from 14% to 20% of GDP).

Given these factors, Stern Review estimates of the SCC at 550 ppm should not therefore be seen as an upper bound on the level of the abatement costs. DECC is currently undertaking work to improve the estimates of damage costs, as discussed in the next chapter.

10. Estimating damages to inform target setting

In part 1, the place of damage costs and the SCC in the new appraisal framework was set out: to inform the target-setting process. Given the uncertainties, Integrated Assessment Modelling evidence should be considered as part of the evidence base in targets setting, rather than the only evidence. Judgements regarding the scientific evidence and acceptable levels of risk of certain threshold outcomes are also important factors, as discussed in Chapter 3. Nonetheless, it is necessary to continue improving the evidence base on damage costs, to ensure targets reflect the most robust evidence available.

This chapter first describes how, consistent with the approach set out in part one of this document, the SCC has been used to inform assessments of the climate change impacts of two emissions reductions targets – the 2050 emissions reduction target set out in the Climate Change Act and the emissions reductions targets for 2020 set out in the EU Climate Change and Energy package. It then sets out the work currently underway to improve understanding within Government of damage costs.

10.1 The Use of the SCC in the Climate Change Act Impact Assessment

As discussed, under the revised approach to valuing carbon the SCC will be used only rarely: when helping to appraise overall frameworks for emission reductions. This is likely to be restricted to the Climate Change Act and the European Climate and Energy Package for the foreseeable future. As also noted, evidence from integrated assessment models is only part of evidence required to reach decisions over appropriate target levels. Nonetheless, when assessing overall targets, it is sensible to attempt to value the impacts of particular target regimes, and this should be done using damage cost estimates, whilst recognising that - given all the uncertainties outlined in Section 3 – these are only indicative of the scale of impact.

Results from the Stern review indicated that the social cost of carbon varied by atmospheric concentration, with the Business as Usual social cost of carbon being approximately three times higher. In 2008, the 550ppm SCC is £26/tCO_2 and the BAU SCC is £73.60 (in 2007 prices). This has not always been found in Integrated Assessment Modelling.[65]

Defra's 2007 Shadow Price of Carbon is based on the estimate of the social cost of carbon assuming the world is on a 550ppm CO_2e stabilisation path. As discussed above, it can be argued that under a damage costs approach, the

[65] Indeed the PAGE2002 model (as used in an adjusted form for the Stern Review) in its standard form has not identified such a relationship. One of the reasons underlying this result is that the Stern Review used endogenous discounting which necessarily causes a divergence in social costs on different pathways (as growth is lower on more damaging pathways).

550ppm CO_2e SCC is the appropriate reasonable value to use for actions/measures that induce *marginal* changes in emissions relative to the 550 ppm stabilisation path, and this was the basis for deciding, as part of the previous review of the SPC, that it should be used in policy appraisals.

However, for a commitment such as the 80% target in the Climate Change Act[66] the change in emissions reflects the UK's contribution to global action on climate change. Such global action is non-marginal – without it there is a compelling argument for assuming that the global trajectory of emissions would be on a business as usual path.

It can be argued that UK action is necessary for co-ordinated global action to be achieved, since a global deal with sufficiently ambitious cuts in emissions is highly unlikely to be negotiable without action from developed countries such as the UK. The counterfactual for the Climate Change Act IA, for example, is a world where the UK makes no commitment to reduce greenhouse gas emissions. For the arguments above, absence of UK action is only compatible with the world being on a business as usual trajectory of emissions. In the case of the Climate Change Act, the comparison becomes one of:

- UK reducing emissions by 80% by 2050, and the world being on a 460-480ppm stabilisation target (which is the stabilisation level with which the 80% reduction target is consistent in burden sharing terms);
- UK not reducing emissions relative to business as usual and the world also being on a business as usual trajectory of emissions.

Given the Stern Review result that the social cost of carbon differs for different atmospheric concentrations, the valuation of UK emissions should reflect this logic. In figure 10.1, the benefits of action are represented by boxes A, B and C. The damage costs of the emissions in the counterfactual case should be valued at the BAU SCC and the damage costs of the emissions in the case of taking action should be valued at the 460 ppm SCC.[67] The avoided damage costs are equal to:

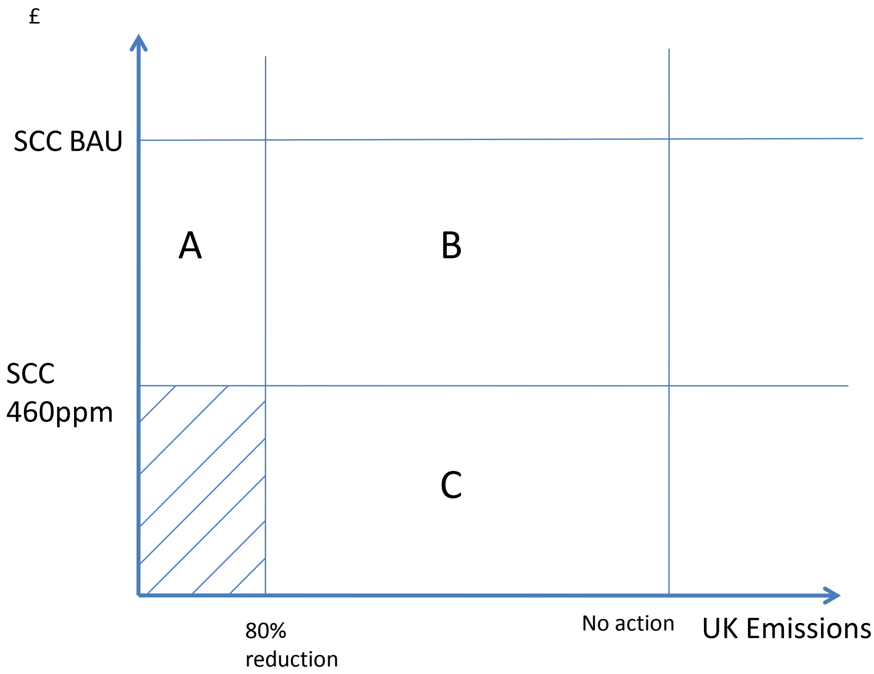
Avoided damages = UK emissions no action * BAU SCC – UK emissions 80% target * 450ppm SCC

Using a social cost of carbon that assumes that a low stabilisation target would be reached with or without action would be equivalent to only capturing the benefit of box C, and would be based on an assumption that the UK can successfully free ride on the efforts of other countries in tackling climate change. Such a strategy is, as discussed above, highly unlikely to be successful and/or realistic.

[66] The Climate Change Act Impact Assessment is available on line at: http://www.defra.gov.uk/ENVIRONMENT/climatechange/uk/legislation/

[67] In the Climate Change Act Impact Assessment we have used the 450 ppm SCC since estimates are not available for scenarios within the 450-550ppm interval. This is expected to have a very minor impact on overall cost estimates as there is not much variation between the 450 and 550 ppm SCC estimates.

Figure 10.1: Illustration of the avoided damages from the Climate Change Act



It is this above approach that has been used in the Climate Change Act Impact Assessment.

Avoided damages = UK emissions no action * BAU SCC – UK emissions 80% target * 450ppm SCC

A similar approach was used for the Impact Assessment for the EU Energy and Climate Change package, due to be published in April 2009.[68]

Under the new arrangements set out in this document, the SCC would be very seldom used beyond appraising significant changes in the emissions reduction regime. It would have no bearing on day to day appraisals valuing carbon emissions from policies once reduction targets have been set - these would be valued at either the traded or non-traded price of carbon, for the traded and non-traded sectors respectively.

The only other use of the SCC would be to value emissions reductions in uncapped economies (essentially only used in estimating embedded carbon in the valuation of the benefits of recycling), where it is reasonable to retain the use of the old SPC values.

[68] www.decc.gov.uk/Media/viewfile.ashx?FilePath=77_20090423091800_e_@@_euclimateenergypackage.pdf&filetype=4

10.2 Improving the evidence base on damage costs

The significant uncertainties in estimating damage costs and the social cost of carbon have led some commentators, including at least one peer reviewer of this revised approach, to suggest that Government should dispense with the whole notion of damage costs in seeking to set targets. While recognising the significant uncertainty surrounding damage cost estimates, Government economists believe that the most robust evidence available from Integrated Assessment Models (IAMs) should be taken into account in the process of target setting. Without any assessment of the damages of climate change, it would not be possible to reach a view on whether overall stabilisation goals and emissions reductions targets are appropriate.

It is therefore vital that damage cost estimates reflect the latest information and modelling of both climatic and economic factors. Work is continuing in government with regard to integrated assessment modelling, where knowledge is constantly evolving in a field where there exist many very long-term, difficult-to-predict and difficult-to-value impacts.

In particular, the PAGE model, upon which the Stern Review damage cost estimates were based, is currently being reviewed to update the treatment of marginal abatement costs and to better model the latest science and economics behind damage cost values, *inter alia*. This review is being undertaken in the course of 2009. Box 10.1 provides a brief overview of the planned development of PAGE (2009).

BOX 10.1: Developing PAGE (2009)

The Policy Analysis of the Greenhouse Effect (PAGE) Integrated Assessment Model (IAM) was created in 1991 (Hope et al, 1993). The current version (PAGE 2002) has been used extensively to study the effects of greenhouse gas emissions under different scenarios. The model estimates market and non-market impacts and those related to abrupt climate catastrophe. The most notable feature of PAGE is the use of Monte Carlo simulations to reflect the risks and uncertainties associated with climate change. PAGE (2002) is internationally recognised as one of the leading IAMs and it has been widely used to model the impacts of climate change, including for the Stern Review (2006). Results from PAGE (2002) have also formed the basis of the damage cost estimates underpinning the previous shadow price of carbon (DEFRA 2007).

Several key updates are currently under way to keep PAGE at the forefront of international excellence. The new PAGE model will improve the current version of the model in four key areas. First, several scientific changes will be undertaken including an explicit modelling of sea level rise, an improved representation of the feedback from climate change to the carbon cycle to simulate more directly the relationship between temperature, CO_2 concentrations, and an adjustment to regional temperatures to take account of higher temperatures at higher latitudes and over land. Second, several changes to impacts will be undertaken including the introduction of a sea level impact, extra flexibility allowing the possibility of initial benefits from small increases in regional temperature and linking impacts explicitly to GDP per capita. Third, the treatment of abatement costs will be improved following the introduction of a new marginal abatement cost curve that allows for negative abatement costs and the impact of learning and technological progress. The fourth change is the introduction of a much simpler representation of adaptation policy where adaptive costs are derived in terms of % of GDP per unit of adaptation bought.

10.3 Next steps

Following the completion of the revision of the PAGE model in 2009, Government economists will review the evidence on damage costs to assess how it should be used to inform decisions on setting emissions reductions targets in the future. The review will be completed in early 2010.

The next occasion at which this evidence will be used is likely to be the review of EU (and UK) emissions reductions targets following a successful global deal on climate change, which, if a deal is secured at Copenhagen at the end of 2009, will take place in 2010.

11. Reviewing carbon values in future

An important question relates to how often the revised values for carbon should be reviewed. The review in 2007 – in moving from the original social cost of carbon to the shadow price – was carried out in order to reflect more recent evidence from the Stern Review. The current review, which changes the approach towards one based on abatement costs rather than damage costs, reflects the significantly improved understanding of abatement costs that has been gained over the last year.

There is a trade-off to be struck between having the most up-to-date carbon valuation figures, and ensuring some consistency in application - a situation where the carbon price used in appraisal changed too often would be undesirable, as this would mean that policy options were being assessed against different criteria. Therefore changes affecting the evidence or policy regime would need to be significant in order to warrant a review.

The new traded and non-traded carbon prices and the damage cost values will therefore be updated according to the following schedule. Such reviews will consider, on the basis of evidence, whether there is a sufficiently strong case to revisit the values.

Schedule for reviewing values

a) The short term traded carbon price will be revised alongside periodic updates to the fossil fuel price assumptions (these usually occur once a year). In addition, if there is a major change in the cap (for instance due to the achievement of a global deal on climate change) a further revision will be undertaken.

b) The non-traded carbon values will be revised after the setting of the fourth carbon budget (by end of June 2011). Further reviews of the non-traded carbon values will occur every five years as successive carbon budgets are set.

c) Revision of the long term traded values will occur on the same timetable as the non-traded carbon values i.e. every five years, beginning in 2011. The first review of the marginal damage cost estimates in 2011 will mean that the outcome of the Copenhagen negotiations to be factored into the review.

   An early review, in 2011, will also allow an evaluation of the application of the target consistent approach in order to ensure that it is acting as intended – i.e. to ensure that the right policies are in place in order to meet our European and Climate Change Act targets cost effectively.

d) Finally, the damage cost estimates will be reviewed following the update of the PAGE model expected for end 2009. Consideration of damage cost estimates will also form part of each five yearly review.

The schedule set out above defines a regular five yearly review at which each set of values will be updated if necessary. Under exceptional circumstances reviews under a different timetable may be necessary if, for example, multilateral negotiations lead to a major change to targets.

Part 3: Application to the policy framework

12. The role of carbon valuation in policy-making

Incorporating a price of carbon into the appraisal of projects and policies ensures proper account of greenhouse gas emissions across Government. By comprehensively and systematically using carbon valuation across appraisal in a consistent manner, it is intended that Government should seek out the most cost-effective opportunities for reducing carbon across policies and projects – not only in areas such as energy and transport policies where emissions reductions are of primary or secondary importance, but also where this is not the case. As a result, we will be able to meet our climate change objectives while minimising burdens on the economy and consumers. For example, an infrastructure project relating to schools or hospitals may well have significant carbon impacts – accounting for these may have the effect of making lower carbon options relatively more attractive in the cost benefit analysis. Having a consistent figure across Government also provides transparency and consistency for business.

Before the change announced in this document, the shadow price of carbon was the methodology for incorporating the cost imposed by greenhouse gases into the appraisal of projects and policies. Any policy or project that increases or decreases GHG emissions relative to a 'business as usual' scenario is required to quantify the change in emissions, and then apply the SPC to value them. This calculation feeds into the overall cost benefit analysis. It is therefore the means by which we assess whether carbon emissions reductions are socially optimal – and in the case of an abatement cost-based value, this means assessing whether policies are cost effective relative to alternative policy options, with the constraint of achieving an overall target.

12.1 Choosing regulatory instruments

Carbon valuation is not a policy instrument in itself. It is a price applied in appraisal in order to guide Government decision-making and signals the level of ambition that should be factored into those policies. Unless it is translated into a tangible incentive (and the incentive may exceed the shadow price in order to overcome barriers), it will not act upon private economic agents, whether individuals or business. Clearly in the traded sector the incentive is tangible – the ETS – up to 2012 at least. Non-traded policy options would be appraised using Non-Traded Price of carbon, but the instrument used to bring about the desired change can be through any number of instruments.

Alongside setting the right carbon appraisal price, the selection of instruments to tap potential emissions reduction is key. A mix of carbon pricing (through taxes/trading), regulatory instruments and information policies are required to address the multiple market failures and barriers which exist. In response to the Better Regulation Commission recommendation, Government has published a report on choosing regulatory instruments to address climate change.[69] This paper contains key principles for instrument design.

Carbon pricing is not the only policy response that is required in order to tackle GHG emissions cost effectively. Other market failures – imperfect information, the public good of innovation – as well as barriers to take-up of cost effective energy efficiency potential exist.

The Stern Review concludes that action to tackle greenhouse gas emissions requires action in three areas, reflecting three separate areas of market failures and barriers. This is because Stern recognises that carbon intensive activity is characterised by, broadly, three different market failures.

(i) The carbon externality. When a polluter makes the decision of whether to emit, s/he does not take into account the cost their actions will have on the environment. The social cost of carbon (SCC) is a monetary estimate of the damage cost imposed upon society by GHG emissions. Here, we reflect the carbon externality through the Traded and Non-Traded Prices of carbon, which are derived from targets which have been set with tackling the externality in mind.

(ii) Innovation market failures. There are a number of reasons why, even with a carbon price, the market may undertake less innovation in low carbon technologies than society would desire. This is because of the presence of a range of innovation market failures and barriers.

- Knowledge spillovers. It is sometimes not possible for an innovator to capture all the returns from innovation. Once new information has been created, it is almost costless to pass on (there is zero/negligible marginal cost). Thus – if mechanisms such as intellectual property rights fail to capture the full benefits of an innovation – individuals and businesses in the market will not be incentivised to innovate at the socially optimal level
- Infrastructure barriers. Clean technologies may require new infrastructure to operate.
- Market structure. Markets occupied by multiple small producers may be ill-equipped to invest in R&D while firms in highly regulated markets may be faced with lower incentives to invest.
- Risk and urgency. The uncertainties and risks of climate change are of a scale and urgency not reflected in the decisions of private investors.

Policies to tackle innovation market failures will help to lower the MAC curve in future, increasing the efficient level of abatement that is associated with a given level of the value of carbon. In the case of a fixed target regime, this would imply a lower 'target consistent' price of carbon associated with given

[69] "Making the right choices for our future: an economic framework for designing policies to reduce carbon emissions." DECC and Defra, 2009.

levels of emissions reductions – i.e. a reduction in the costs of tackling climate change.

(iii) Other market failures and barriers to changing behaviour. Even with a carbon price and technology policy in place, some low cost abatement may not be undertaken because of the existence of other market failures/barriers such as information asymmetry, capital constraints, misaligned incentives, habitual behaviour, etc. Policies to act on such problems should increase the response to carbon pricing, so that a larger proportion of adjustments for which the MAC appears to be below the carbon price occur in practice.

It is important to act on all three market failures, and not on the internalisation of the carbon externality alone. The objective is to ensure the costs of effectively mitigating climate change remain as low as possible.

Assessment of interventions to tackle innovation market failures should take into account the likelihood that (i) the resulting technology will have a MAC below the carbon valuation schedule in future; and (ii) the expected total public and private cost of development and deployment is less than deploying an existing technology to achieve the same reductions. If this is not likely, then the cost-benefit test will not be passed. An intervention under the third leg would be justified where it led to cost-effective abatement opportunities being taken up which would otherwise be missed. In such cases, by definition, the MAC including policy costs (administration, etc) must be less than the value of carbon; if not, the policy should not be pursued on climate change grounds (although other factors, e.g. air quality benefits, need to be taken into account). Ideally, interventions to deal with non-carbon market failures should also be technology-neutral in order to reach a given level of emission reduction at lowest cost.

13. PSA reporting and auditing the use of carbon valuation in appraisal

Making sure that the analytical and empirical basis of carbon valuation is robust is of central importance. However, it is also fundamental to the entire enterprise of carbon valuation to ensure that it is being applied on a consistent basis across Government in policy and project appraisal

13.1 Reporting requirements

In policy and project appraisal all Government departments must carry out carbon impact assessments, as required by the revised BRE Impact Assessment guidelines (the carbon impact assessment must be reported on the 'Summary: Analysis and Evidence' page of the Impact Assessment). This requires analysts to quantify the carbon impacts of their policies, and to value these impacts using the shadow price of carbon. Alongside the PSA on the cost effectiveness of climate change policies, this requirement ensures strong monitoring of the use of the SPC, leading to greater enforceability of its use.

In addition, PSA 27: Indicator 6 requires Government Departments conducting Impact Assessments to report on the proportion of tonnes abated for which the cost falls below the SPC.[70] This is intended to provide an indicator of the cost-effectiveness of emissions reductions policies across Government. Once new values are adopted for the traded- and non-traded prices of carbon, the indicator will use these new values as the barometer of cost effectiveness. Until now, the SPC is the relevant comparator, hence the review discussed below relates to the SPC rather than the guidance that we plan to publish in spring 2009.

Cost-effective emissions reductions are assessed relative to the shadow price of carbon – those emissions reductions that cost less than the SPC are deemed cost effective, whilst those above the SPC are cost ineffective. Each policy will have to report on the proportion of emissions reductions occurring below the SPC (i.e. the proportion of emissions reductions from the policy that are cost effective). For those policies that increase emissions, the cost effectiveness of the emissions increase should exceed the SPC (i.e. the benefit of the additional emissions exceeds the cost of emissions), for those policies to go ahead.

In early 2008, a methodology was developed for reporting against this indicator. Under this methodology, policies that are covered are those that have an impact on emissions that is greater than 0.1tCO_2e per annum, or

[70] Please see http://www.defra.gov.uk/environment/climatechange/ research/ carboncost/pdf/costeffect-psa-indicator6.pdf for further information.

those that have an annual impact of at least 0.05MtCO_2e combined with a cumulative impact of greater than 2MtCO_2e.[71] The cost-effectiveness of emissions reductions is assessed against a 'weighted average discounted' SPC to reflect the fact that future values of the SPC are declining over time when discounted to a common base year (please see above section for this discussion). For example, for a policy that has impacts over two years, the value below which the emissions reductions are cost effective would be an average SPC over those two years, discounted to the year of appraisal, and weighted by emissions reductions. If this weighted average SPC is not used, time-inconsistent policy choices might arise.

13.2 Audit of the use of the SPC

DECC is carrying out an audit of the use of the SPC across Government, for the period 1st April 2008 – 1st April 2009. This has been aided by the publishing, by BRE on its website[72], of all impact assessments from April 1st 2008.

For the purposes of the cost effectiveness indicator the audit is examining the carbon impact assessment of those policies with carbon impacts above the threshold set out in the PSA indicator, in order to determine the cost effectiveness of policies. This will provide a baseline for PSA 27: Indicator 6, in order to compare performance over time. The audit is looking beyond solely reporting against the PSA, and has considered all final IAs published to consider how widely used the SPC guidance has been.

The results of the audit will be reported on in full in spring 2009. The studies have covered about 150 final IAs, published since April 2008. This has covered IAs from central government Departments. Of these IAs, 16 full IAs had quantified an impact on carbon emissions. 10 had reported to indicator 6. This meant that roughly 11% of IAs (of 100) had quantified an impact on GHG emissions and 7% had reported to the indicator.

This does not in itself suggest a low level of compliance with guidance on valuing carbon; it simply reflects the fact that a lot of impact assessments did not have an impact on carbon emissions. Indeed, these results would suggest that there was fairly good compliance with the indicator, despite a restricted evidence base: there were no clear cases in which impact assessments had not quantified carbon impacts but should have done, although there were two impact assessments which had failed to apply the SPC correctly.

Presently 99.6% of emissions are below the SPC in final IAs. The results are summarised in the table below and Annex contains a more detailed summary of the findings is set out in Annex 4.

[71] Which can be accessed via Defra's SPC webpages. See http://www.defra.gov.uk/ENVIRONMENT/climatechange/research/carboncost/
[72] Available at: http://www.ialibrary.berr.gov.uk/

Table 13.1 Cost effectiveness of emissions reductions

	Over SPC (Mt/CO_2e)	Under SPC (Mt/CO_2e)	Percentage of total emissions under SPC
Emissions abated (Final IAs)	1.1	210.4	100%

Partial Impact Assessments are not formally included in the reporting requirements for the indicator. However, given the limited evidence base from full IAs, and given the fact that this is the first year we have also reviewed, on an indicative basis, some 100 partial IAs conducted over the review period. Of these, nine partial impact assessments had quantified an impact on carbon emissions, five of which had reported to the indicator.

When including partial IAs the percentage of emissions abated the cost of which is below the SPC falls to 47.5%. This is mainly due to one large policy, the Renewable Heat Incentive, having all of its emissions costing more than the SPC. The IA did not break down the policy into the cost-effectiveness of the individual measures involved. Work is being undertaken to develop the design of the RHI, which may have an impact on overall cost effectiveness. Nevertheless, it is likely that many of the policies developed to meet the EU renewable target will be expensive in purely carbon abatement terms, because of the stringency of the target. This partly reflects the fact that the rationale for the renewables target was not simply to reduce emissions today but also to bring down the costs of abatement in the future, in part to overcome an innovation externality, the benefits of which have not been quantified.

14. International applications

As climate change rises up the agenda internationally, there is increasing interest in tools to assess the impacts of climate change policies. Clearly, a measure of the benefit (cost) of emissions reduction (increases) is a particularly useful analytical tool.

14.1 Europe

In comparison to international peers, the UK is relatively advanced in terms of its use of carbon valuation. To our knowledge, only the French have conducted a formal assessment of the value that should be attributed to carbon emissions in policy appraisal. The Strategy Unit in the Office of the Prime Minister recently completed an exercise, “La Valeur Tutélaire du Carbon” (see box 14.1), which has essentially modelled the target-consistent price of carbon for France.[73] However, we believe there is as yet no formal requirement to use this value consistently in policy appraisal.

Box 14.1 La Valeur Tutélaire du Carbon

In a recent report on the shadow price of carbon, the French Committee chaired by Alain Quinet recommended the adoption of a target consistent approach to estimate a carbon price profile to be primarily used to evaluate transport infrastructure projects. The approach aimed to determine the carbon price trajectory necessary to achieve the European targets of 20% GHG reduction by 2020 and between 60% and 80% by 2050.

The recommended carbon price profile was based on the key estimate of 100€/tCO_2 in 2030 obtained as a result of a compromise reached in the commission composed of economists and representatives of the economic, social and environmental partners and informed by modelling work done by the Committee - using the general equilibrium model GEM – E3, the partial equilibrium energy model POLES and the hybrid general equilibrium model IMACLIM-R – aimed to identify the trajectory of the carbon prices necessary to achieve the European policy targets.

Over the 2010 - 2030 period, the recommended carbon price profile starts with the previous estimate from the Boiteux report (2001) of the carbon price in 2010 (i.e. 32 €/tCO_2 in 2008 prices) reaching 100€ in 2030 at a rate of 5.8%. After 2030, the carbon price is assumed to increase at the public discount rate of 4% reaching 200€ per ton of CO_2 in 2050. In order to reflect the uncertainties surrounding these estimates, the Committee proposed to include the estimate of 200€ in 2050 within a range between 150€ and 350€. For the same purpose, it was recommended to reassess the carbon prices trajectory required to achieve the EU targets at least every five years to take into account of potentially useful new evidence.

[73] http://www.strategie.gouv.fr/article.php3?id_article=830

Anecdotally, officials from other European countries have suggested that they use the market price of carbon as a proxy of the shadow price in analysis of investments. As outlined in Section 4 of the main part of this paper, we believe this is the correct approach to take when considering emissions in the traded sector only, but is pragmatic in the absence of robust non-traded sector abatement costs.

The European Commission recently consulted on new draft Impact Assessment Guidelines. The UK response identified quantification and monetisation of impacts as an area of the draft Guidelines which could be improved upon and supported efforts to move in this direction. The new guidelines have recently been released, and contain more detailed information on valuing GHG impacts than previously.[74]

14.2 Multilateral Institutions

We also believe that there is a role for pricing of carbon in the investment appraisals carried out by multilateral institutions such as the World Bank. Both World Bank and IFC have indicated that they are considering use of more formal carbon valuation techniques in investment appraisal, as part of the Strategic Framework for Climate Change and Development, which seeks to ensure climate change considerations are mainstream to the Bank's development activities.[75]

There are two ways in which shadow-pricing could in principle be applied – using the social cost of carbon (damage cost) approach as the economies are uncapped, or alternatively using a figure that is consistent with the opportunity cost of emissions that these countries are likely to face in the coming years. This latter approach may be in the context of an international trading some way down the line, or in terms of international credits in the shorter term.

[74] http://ec.europa.eu/governance/impact/docs/key_docs/iag_2009_annex_en.pdf
[75] http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/ENVIRONMENT/EXTCC/0,,contentMDK:21876999~pagePK:210058~piPK:210062~theSitePK:407864,00.html

Annex 1: Further Empirical Analysis on the Non Traded Price of Carbon

Table 1 below summarises the implied non-traded price of carbon for the further MACC scenarios that have been analysed.

Table 1: Further MACC scenarios.

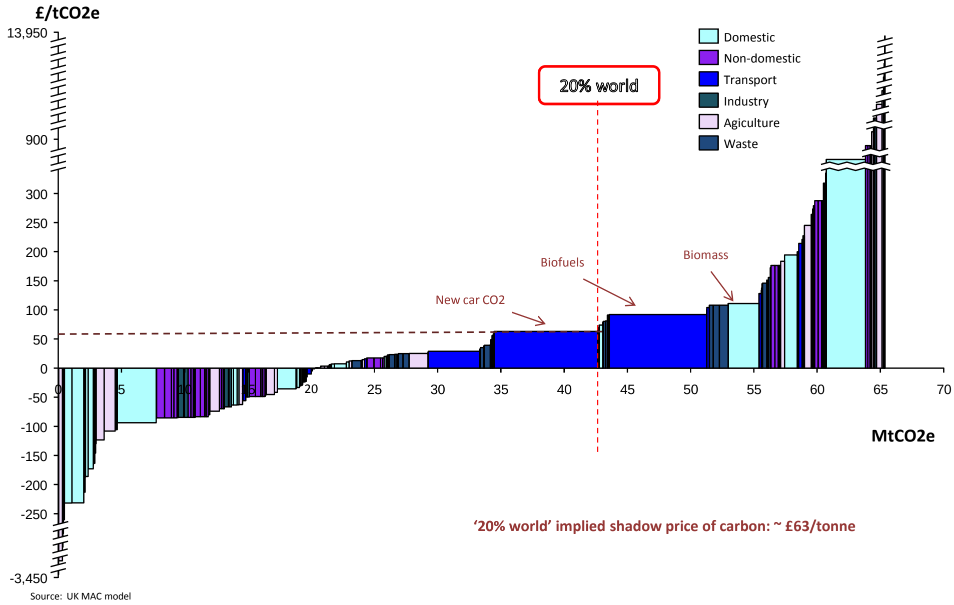
MACC scenario	Non-CO_2 (Waste/ Agriculture)	Other comments	Implied non-traded price of carbon
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	95g/Km of CO_2 in the UK by 2020 (includes re-bound)	£63/tCO_2e
CCC high feasible, CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Excluded	95g/Km of CO_2 in the UK by 2020 (includes re-bound)	£111/tCO_2e
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Low feasible potentials included	95g/Km of CO_2 in the UK by 2020 (includes re-bound)	£92/tCO_2e
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	95g/Km of CO_2 in the UK by 2020 (includes re-bound)	£63/tCO_2e
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	115g/Km of CO_2 in the UK by 2020 (includes re-bound)	£92/tCO_2e

CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	95g/Km of CO_2 in the UK by 2020 (measures to counter re-bound)	£33/tCO_2e
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	99g/Km of CO_2 in the UK by 2020 (includes re-bound, assumes costs decline at a slower rate)	£78/tCO_2e
CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	99g/Km of CO_2 in the UK by 2020 (includes re-bound)	£81/tCO_2e
30% world, including purchasing credits.CCC high feasible for all sectors other than transport. Government transport figures. Including air quality consideration and policy costs.	Included	95g/Km of CO_2 in the UK by 2020 (includes re-bound)	£92/tCO_2e

All MACCs in this annex include air quality impacts, policy costs (based on McKinsey report range and assuming higher policy costs are felt for negative cost measures), and Government estimates for feasible transport abatement. All MACC's are relative to UEP29 with updated fossil fuel prices, without purchasing credits (apart from 30% world MACC which assumes credit purchase). The non-traded price of carbon is sensitive transport abatement assumptions, especially new car CO_2 policy scenarios. This annex uses a new car CO_2 case achieving 95g/Km of CO_2 in the UK by 2020 (including re-bound) as a central estimate of technical feasibility. This central scenario is illustrated in Figures 1 and 4, and sensitivity analysis is comparable to this base case.

The CCC identified approximately 2.44$MtCO_2e$ of abatement potential associated with domestic biomass in 2020. Residential biomass (off gas grid) as a CO_2 abatement technology has the potential to impact significantly on air quality, therefore an adjusted abatement cost has been calculated for this measure using analysis undertaken for the Renewable Heat Incentive (RHI). This analysis, taking in to account the negative impact of domestic biomass on air quality, estimates an increase in the abatement cost of £52.62tCO_2. Adding this to the existing technology cost of abatement (£56.42) results in a total marginal abatement cost for this measure of £109.04tCO_2 (not including policy costs).

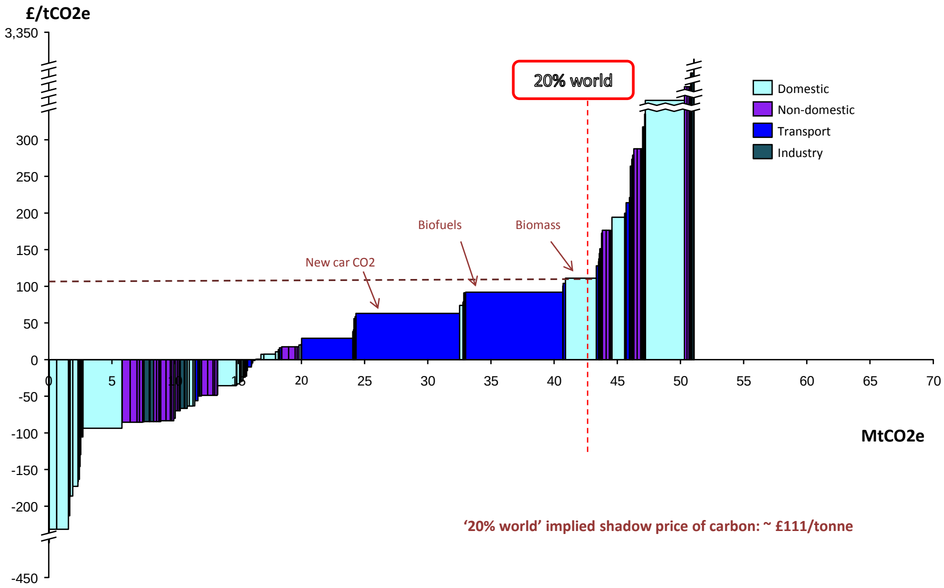
Figure 1: High feasible non-traded MAC curve in 2020, including non-CO_2 abatement. This MACC is the base case from which to compare the sensitivity analysis MACC's in annex 1.



The CCC advice was that the 'interim' budgets should be delivered with no use of project credits but also that abatement from non-CO_2 greenhouse gases should be targeted by policy but not relied on to deliver the budgets. There is both greater uncertainty in non-CO_2 GHG emissions and a less mature policy framework, creating significant uncertainty over the judgements of feasibility. For these reasons, the CCC recommended "that non-CO_2 options should be developed as part of prudent budget management, rather than relied on as firm measures that will deliver budgets."

If this recommendation was accepted, then the target level of abatement would have to be delivered entirely through CO_2 abatement options only. Figure 2 removes the non-CO_2 abatement potential from the abatement cost curve. Removing the non- CO_2 abatement results in the implied non-traded price of carbon increasing to £111/tCO_2e.

Figure 2: High feasible non-traded MAC curve in 2020, excluding non-CO2 measures (agriculture and waste)

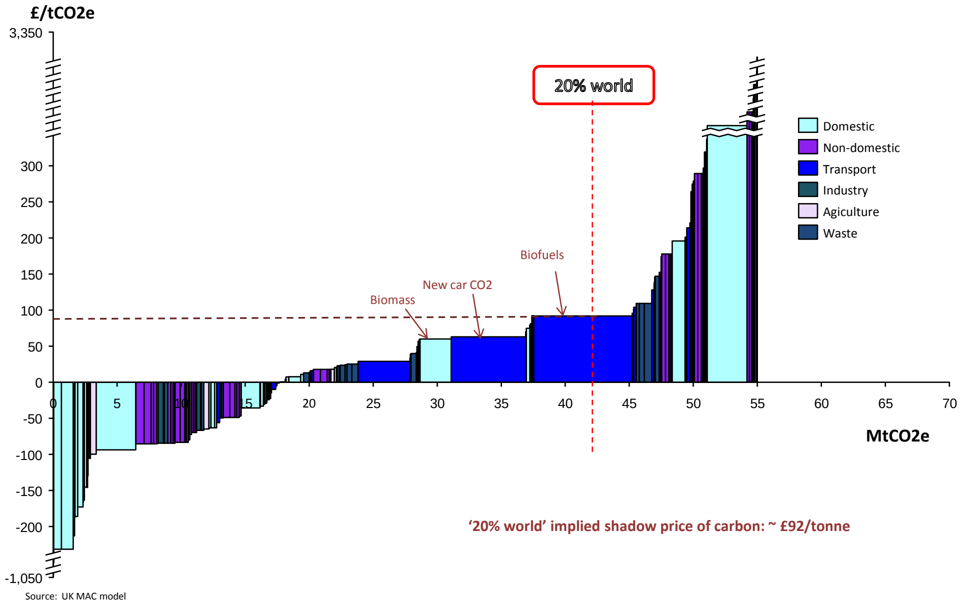


Source: UK MAC model

An alternative to accepting the recommendation from the CCC to not rely on non-CO_2 abatement would be to take a conservative view of the feasible potential. Figure 3 includes the CCC's 'low-feasible' judgement of the potential from non-CO_2. This implies a non-traded price of carbon of £92/tCO_2e.

Government economists have assessed the abatement that it would be feasible to deliver from policies that they have assessed. The potential identified in transport is 21.7MtCO_2e by 2020. This is lower than the potential identified by the CCC. These figures for cost-effectiveness include ancillary costs. For instance new car CO_2 standards reduce the marginal cost of motoring which will result in a rebound effect. Factoring this rebound effect into the cost-effectiveness provides a fuller assessment of the policy. If complementary demand side measures were implemented alongside the new car CO_2 standards then it could be possible to avoid this rebound effect. In this case the volume of abatement will be greater (and cost effectiveness estimates also affected), producing a lower number for the non-traded price of carbon than may be necessary. Work is in hand to consider the scale of these impacts further.

Figure 3: High feasible non-traded MAC curve in 2020, including low feasible non-CO2 abatement potential



Transport policies are one of the main drivers determining the abatement potential in 2020, and the implied non-traded price of carbon. Government analysis has produced several different new car CO_2 policy scenarios, each having different emissions savings and cost effectiveness figures. The following MACC curves (Figures 4 to 8) illustrate the impact of changing the new car CO_2 potential on the non-traded price of carbon, other factors are held constant. Figure 4 shows the new car CO_2 scenario that illustrates (approximately) the central non-traded price of carbon: £63/tCO_2e.

Figure 4: High feasible non-traded MAC curve in 2020. This MACC assumes a new car CO_2 policy scenario that achieves 95g/Km of CO_2 in the UK (includes rebound)

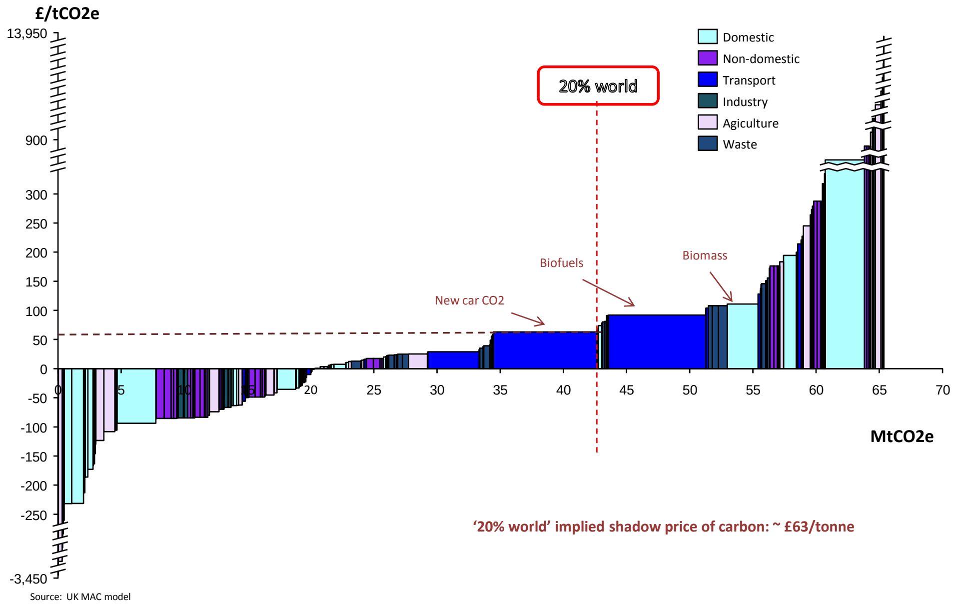


Figure 5: High feasible non-traded MAC curve in 2020. This MACC assumes a new car CO_2 policy scenario that achieves 115g/Km of CO_2 in the UK (includes rebound)

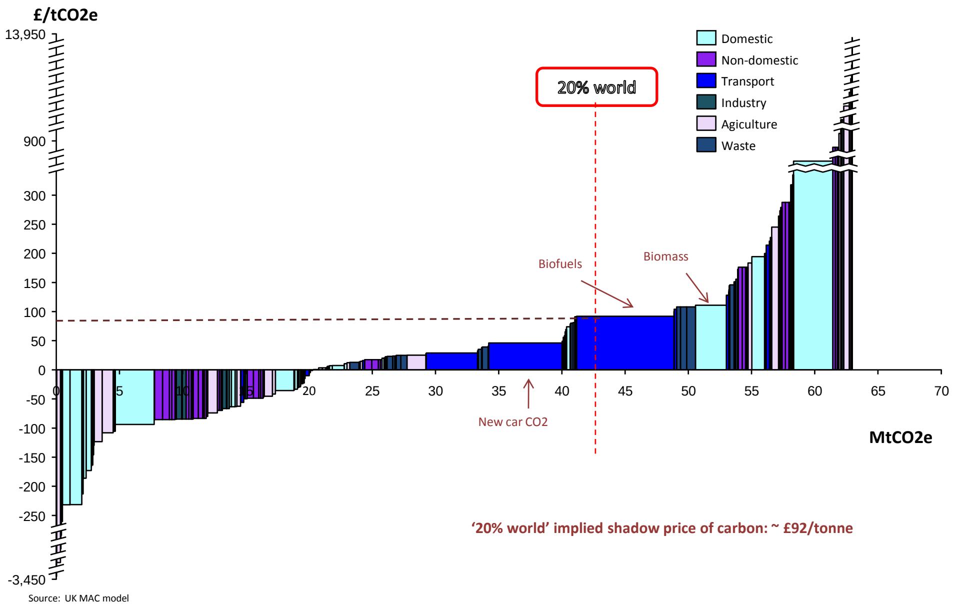


Figure 6: High feasible non-traded MAC curve in 2020.This MACC assumes a new car CO_2 policy scenario that achieves 95g/Km of CO_2 in the UK (measures to counter rebound).

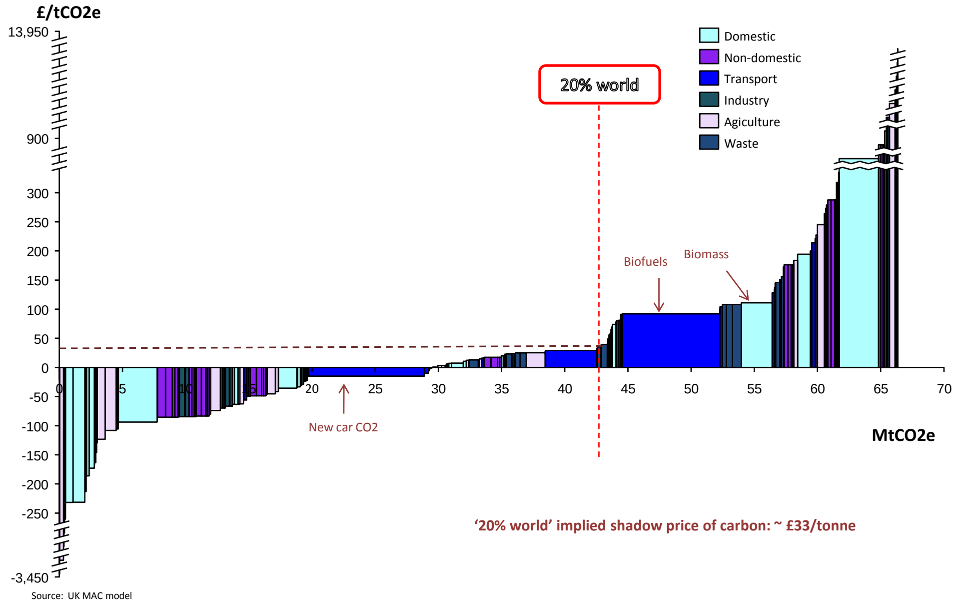


Figure 7: High feasible non-traded MAC curve in 2020.This MACC assumes a new car CO_2 policy scenario that achieves 99g/Km of CO_2 in the UK (includes rebound, and assumes costs decline at a slower rate)

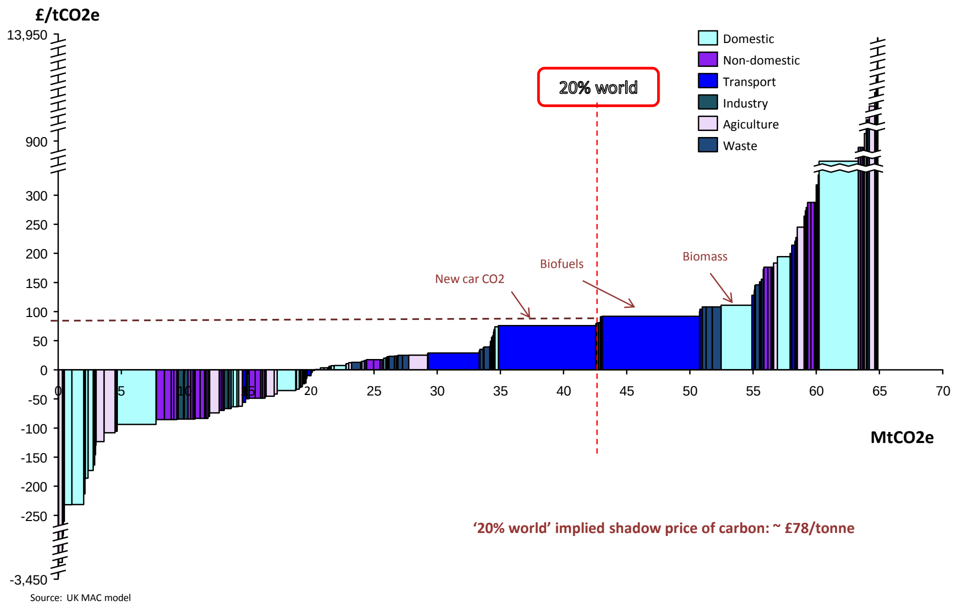
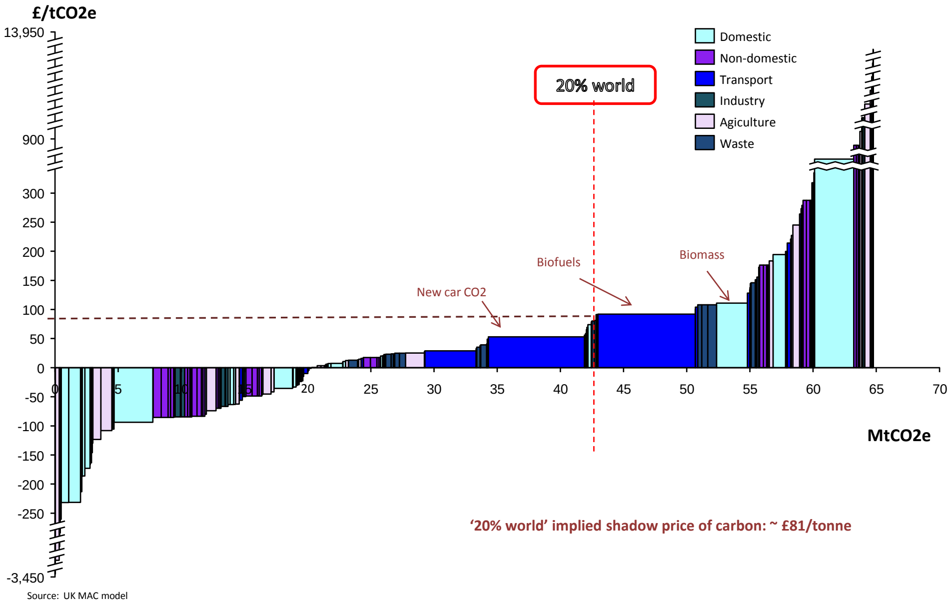


Figure 8: High feasible non-traded MAC curve in 2020.This MACC assumes a new car CO_2 policy scenario that achieves 99g/Km of CO_2 in the UK (includes rebound)



Comparison with Energy White Paper (2007) MAC analysis

The Energy White Paper (EWP) published in 2007 included a marginal abatement cost curve. The analysis indicated that the level of abatement that was then being considered was broadly consistent with the then Shadow Price of Carbon. This raises the question of why the assessment of the marginal abatement cost required to deliver our targets should now be higher.

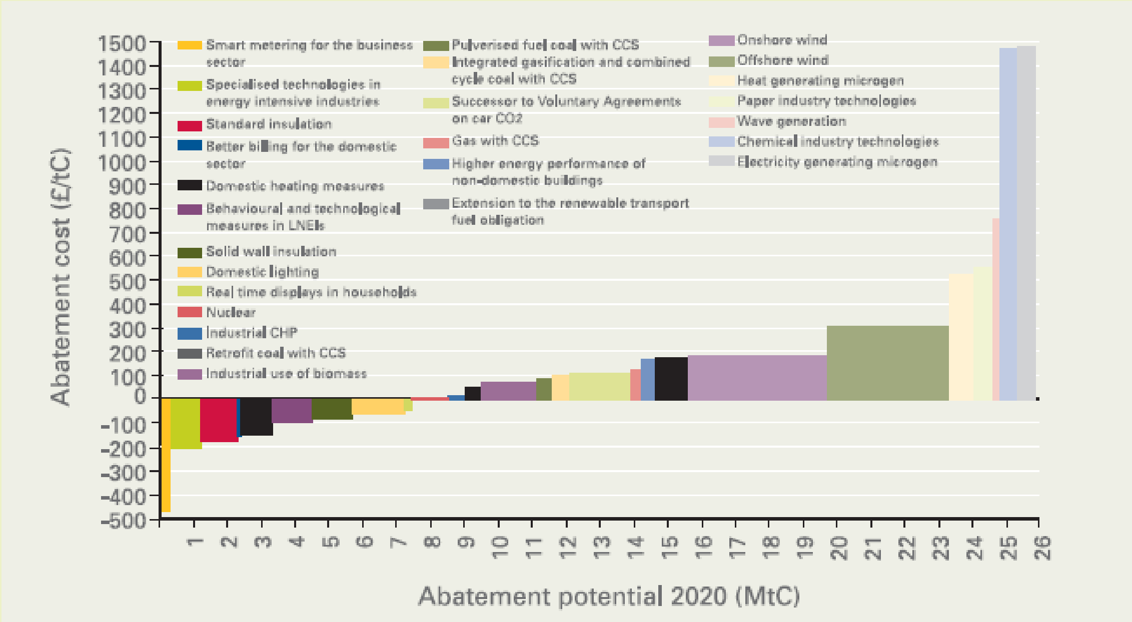
The first explanation is that the ambition of our targets for emission reductions has increased. We are targeting 42.5$MtCO_2$/y of abatement in the non-traded sector, which translates to 11.6MtC/y (the units used in the White Paper). The EWP MAC curve identified up to 26MtC of abatement, but this covered both the traded and non-traded sectors. Large proportions of the abatement relate to decarbonising electricity production or reducing demand for electricity. It is unlikely that there is 42.5$MtCO_2$/y of abatement in this curve in the non-traded sector, and certainly not below a price of £50/tCO_2.

The marginal abatement curve was developed specifically for the EWP pulling together analysis from different government departments. The methodology used was not consistent across the whole MAC curve. Some of the potentials are raw technical potentials (wind generation for instance), and some of the potentials relate to feasible potentials, and some of the potentials are policy options. The CCC MAC curve has made a large step forward in applying a consistent analytical approach across the whole of the UK economy and has assessed a more exhaustive range of options.

BOX 10.1. UK MARGINAL ABATEMENT CURVE.

A marginal abatement curve shows, for a given year, the incremental cost of reducing additional units of carbon, and shows where the most cost-effective abatement opportunities lie. The shape of the curve changes over time, and as part of this White Paper we have constructed a curve for the UK showing the domestic abatement potential of a range of measures and technologies in 2020.

FIGURE 10.2. MARGINAL ABATEMENT COST CURVE 2020

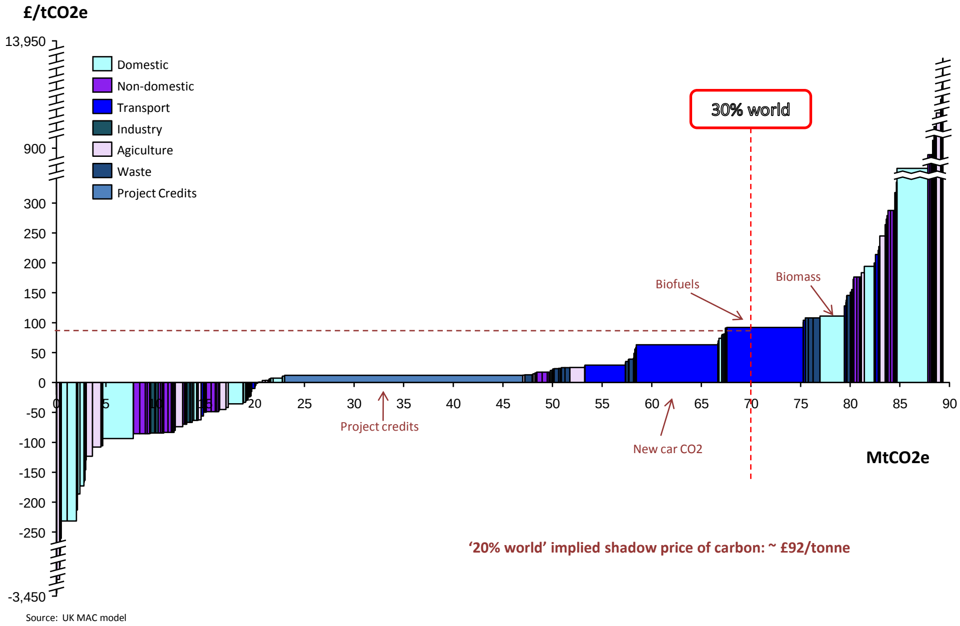


30% world analysis

The EU have committed to adopting a more ambitious climate and energy package following an international climate change deal and have indicated that it would target a 30% reduction in European GHG emissions in 2020 (on a 1990 baseline). The form that this package would take has not been agreed and the UK's burden share has not been negotiated. Any analysis of what a non-traded price of carbon would be in this '30% world' is therefore indicative only.

It is likely that the UK would need to make extensive use of project credits in the 30% world. Abatement curves for the 30% world include the full, estimated, limit on project credit purchase in the non-traded sector (24MtCO_2/y). Figure 10 shows an abatement curve including all high feasible potential, including non-CO_2 abatement potential, and Government estimated transport figures. This implies a non-traded price of carbon of £92/tCO_2e in 2020.

Figure 9: This high feasible non-traded MACC in 2020 includes purchasing credits in a 30% world



Annex 2 Overview of GLOCAF

Introduction

The Global Carbon Finance (GLOCAF) model was developed by the UK Government with the aim of providing estimates of costs and international financial flows that could arise under various post-2012 global deal scenarios. The model allows the user to evaluate the impacts of different global emission reduction targets and burden sharing regimes as well as various specifications of the carbon market design. The model covers the period 2010 to 2050. It also includes functionality to set up funds for abatement outside the carbon market and can evaluate potential market related finance. The model was presented at the UNFCCC COP 13 at Bali.76

Data underpinning GLOCAF

In order to calculate the impacts of a global deal, GLOCAF needs Business As Usual (BAU) emissions as well as Marginal Abatement Cost (MAC) curves for different regions and sectors. This data must cover all the potential GHG emissions which could be included in a global deal. GLOCAF has been set up so that it can use BAU and MAC data from a range of sources. GLOCAF currently contains data from:

- The POLES energy model: this is a partial equilibrium energy model, which takes into account the costs of different technologies as well as the potential demand feedback effects within the energy system.
- Either DIMA or GCOMAP for forestry emissions; these are partial equilibrium models of the forest sector; they incorporate the opportunity costs of abatement from forestry.
- The IMAGE model for non-CO_2 emissions; this is a bottom-up dataset.

All datasets are at a sectoral level, and apply to a number of regions. Currently GLOCAF looks at 15 world regions and 17 sectors although a different level of disaggregation is possible if the data supports it.

[76] http://www.occ.gov.uk/activities/gcf/GLOCAFBaliSideEventPresentation_ac_111207.pdf

The current regions and sectors are shown in the table below.

Table 1: GLOCAF Regions and Sectors

Regions	Sectors
Canada	Steel
USA	Chemistry
Central America	Chemical Feedstocks
South America	Non-metallic minerals
Northern Africa	Other Industry
Sub Saharan Africa	Non-energy uses
Oecd Europe	Road
Eastern Europe	Rail
Former USSR	Air
Middle East	Other transport
South Asia	Residential
East Asia	Services
South East Asia	Agriculture
Oceania	Power (electricity generation)
Japan	Deforestation
	Afforestation
	Non CO2 emissions

GLOCAF functionality around the design of the Global Deal

GLOCAF allows the shape of a potential global deal to be modelled explicitly. The key design elements include how much mitigation must be done domestically and how much can be funded internationally. The internationally funded mitigation can either come through a carbon market, or it can come through specific funds. Therefore the key parameters include

i) The individual region/sector level commitments, this is sometimes known as the burden sharing regime.

ii) The level of supplementarity, i.e. the amount of abatement that can be bought in from overseas. Supplementarity, together with any non market funding effectively sets the size of the carbon market and it is one of the most important drivers of a future traded carbon price.

iii) The participation of regions and sectors in a carbon market over time. For example some sectors may not participate; some sectors may only enter the market gradually; there may be separate carbon markets for different sectors.

iv) The design of the carbon market mechanism. For example, to reflect the CDM, the amount of potential abatement available through the MAC curves can be reduced to reflect the fact that the CDM process limits the amount of potential abatement that can take place by refusing credits from some sectors. GLOCAF can also impose CDM factors for each non annex 1 region and sector which are calibrated to reproduce the observed credit price and supply of credits.

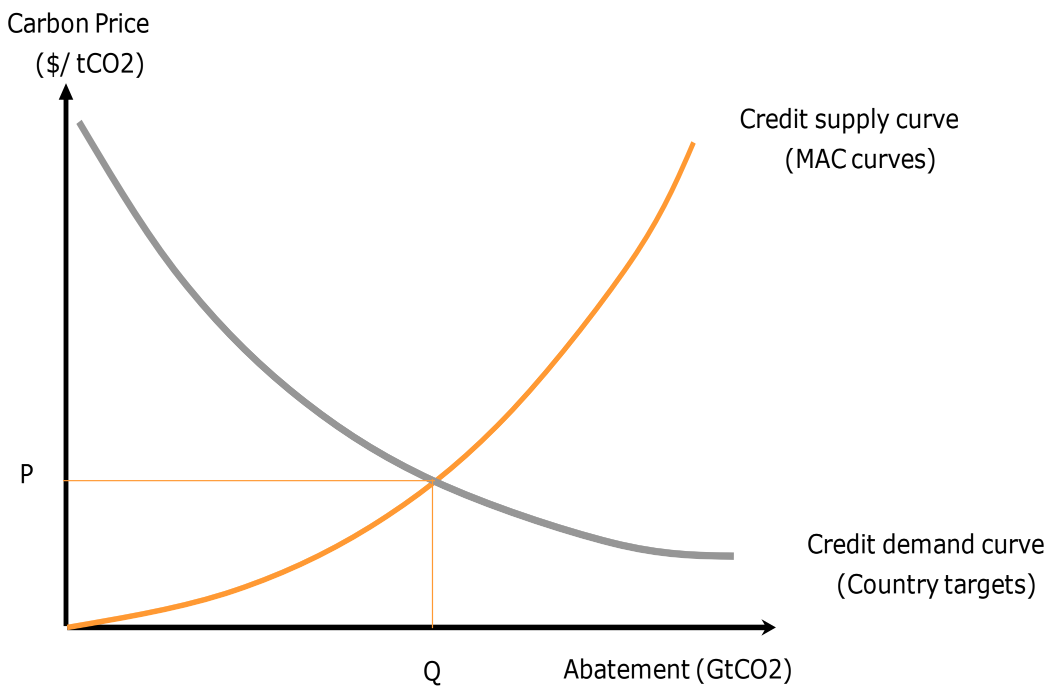
v) GLOCAF has the functionality to model a range of other carbon market rules and non-market financial flows.

Technical Issues

Calculation of the Carbon Prices in different markets

At the heart of GLOCAF is a model of the carbon market(s). By comparing the supply of carbon permits e.g. AAUs or CERs (driven largely by MAC curves) to the demand for such permits, (driven largely by Business As Usual forecasts together with regional commitments). The model finds the market clearing carbon price where the demand for carbon permits matches their supply for each market.

These curves can be constrained by trade restrictions around for example supplementarity and/or participation. This is shown by the chart below.



GLOCAF uses the market clearing carbon price to determine how much abatement each region and sector carries out and the associated incremental cost. Using the carbon price and associated demand for carbon permits GLOCAF also determines the resulting international financial flows.

Path Dependency

A key issue with using MAC curves is that although they are static datasets, in practice abatement costs are dynamic in that they depend on what abatement options have been chosen historically. The timing of action affects the future costs of abatement through three key channels.

i) Induced technological change means that early action leads to lower costs in later years as learning effects lead technologies down their cost curve.
ii) Early action can avoid the lock in of carbon intensive infrastructure
iii) Later action can prevent the scrapping of infrastructure.

GLOCAF deals with this by collecting a library of MAC curves. For the POLES and DIMA models GLOCAF has one set of MAC curves relating to a slowly increasing carbon price (so a relatively high carbon price early); a set relating to a gradual increase in carbon prices; and a set relating to very quickly rising carbon price. These three sets proxy, respectively, lots of early action / investment, medium levels of early action, and late levels of action. GLOCAF then chooses the most appropriate MAC (or interpolates between the available options) depending on the scenario being run.

Annex 3: Comparison of GLOCAF with other model estimates

A reasonable approach to take in considering the modelling evidence is to ask if the GLOCAF estimates presented above are in line with other abatement cost estimates. In essence, the following question is being asked: "where there are exercises with comparable scenarios to GLOCAF, are the model estimates broadly consistent with those produced by GLOCAF?"

In the table and figures below, estimates of marginal abatement costs from various modelling exercises are presented. A broad range of values is produced.

Table 1: Carbon price in 2030 and 2050 (£2008)

Model	**2030**				**2050**			
ppme scenario	**450**	**475**	**500**	**550**	**450**	**475**	**500**	**550**
Glocaf (DIMA)	£119.0	£74.9	£74.9	£34.6	£317.1	£363.1	£267.0	£101.9
Glocaf (GCOMAP)	£67.7	£49.7	£49.7	£20.4	£223.6	£238.4	£152.8	£82.9
POLES (VTC)	£40.7			£16.4	£487.1			£60.7
GEMINI-E3 (VTC)	£30.0			£7.1	£242.1			£44.3
IMACLIM-R (VTC)	£114.3			£39.3	£142.9			£42.9
OECD - Env-linkages				£52.5				£268.8
OECD - WITCH				£60.8				£238.9
IGSM (USCCSP)				£87.0				£190.7
MERGE (USCCSP)				£43.2				£130.0
MiniCAM (USCCSP)				£38.5				£105.5
IEA WEO 08	£112.0			£56.0				
IEA ACTC - average				£112.6				£313.5
IEA ACTC - "best guess"				£62.8				£156.7
IPCC high	£100.5	**£100.5**	£100.5	£65.6	£232.5	**£232.5**	£228.3	£128.7
IPCC low	*£25.7*	***£25.7***	*£25.7*	*£14.9*	*£91.3*	***£91.3***	*£33.2*	*£24.9*
IPCC high 'no sinks'			*£119.4*					
Mc Kinsey & Co	£41.8			£11.4				

Figure 1: Carbon price in 2030 (£2008)

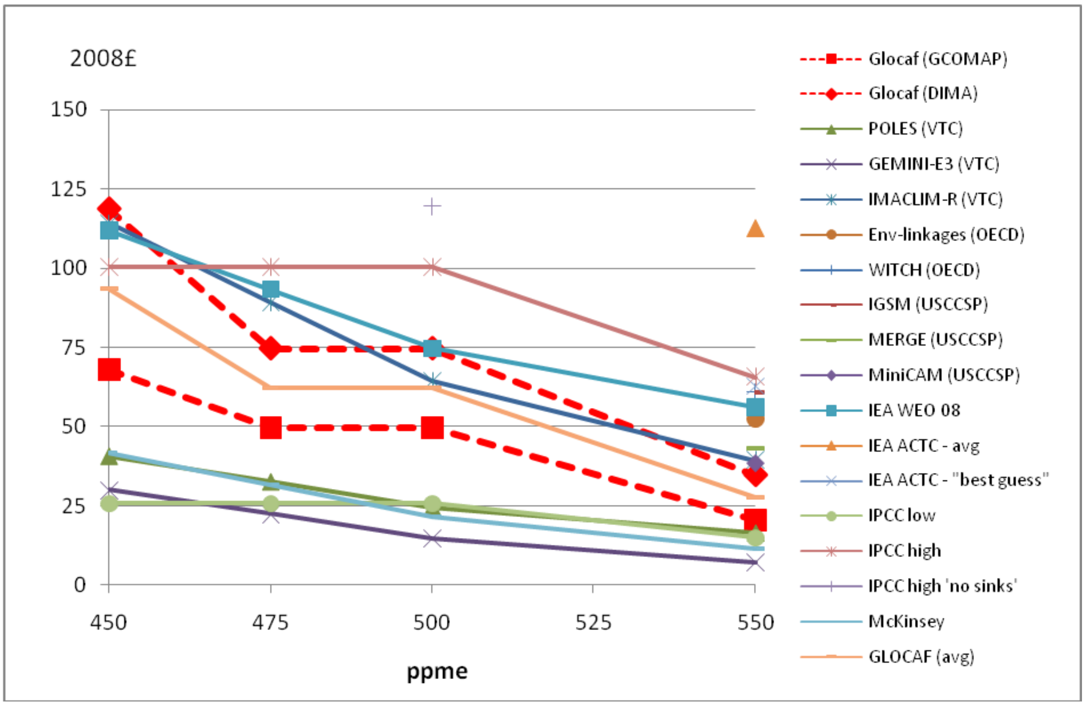
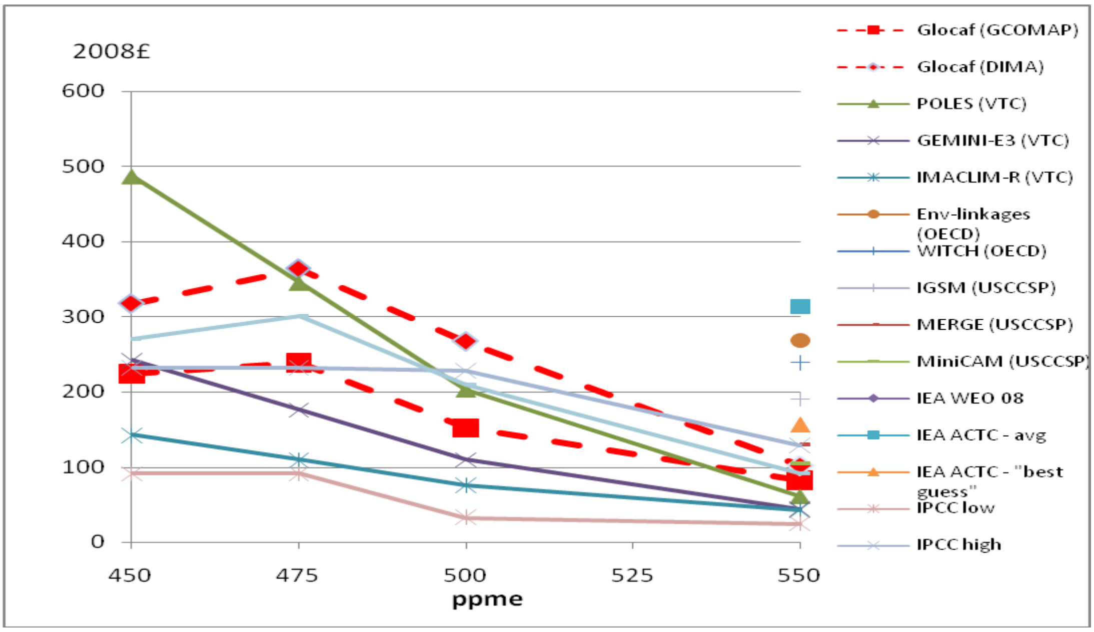


Figure 2: Carbon price in 2050 (£2008)



Refining the estimates

There are inevitable disagreements between modelling outputs regarding the abatement costs associated with any particular stabilisation scenario. However, it is possible to narrow the range by excluding estimates associated with models with unreasonable assumptions. Unlike the GLOCAF model, to which the UK Government has direct access, information regarding alternative models is somewhat limited. However, there are certain pieces of information that can help to narrow the range.

The following approach to filtering the results has been adopted:

- focus on results that relate to the relevant stabilisation goals, which, as discussed above, are 475ppm and 500ppm;
- exclude results that, for a given stabilisation goal, have an emissions reduction profile that is clearly inconsistent with the CCC advice and the 2050 target;
- exclude results from a model that failed to include abatement from avoided deforestation; and
- exclude results from a range of models that had substantially inaccurate / outdated business as usual (BAU) assumptions.

The net effect is to narrow the range of reasonable estimates for 2030 and in particular 2050.

Emissions reduction trajectory

Some of the estimates from the lower end of the IPCC range are likely to be a result of the chosen trajectory. For example, the MESSAGE model is generally at the lower end of the range of the IPCC figures – this model is an inter-temporal optimisation model, and the trajectory is very generous until after 2050 (global emissions in 2050 are only around 10% below 1990 emissions versus approximately 45% - 35% in the CCC work). A similar issue may apply to the USCCSP models - the IGSM model, for example, leads to very high carbon prices in 2100 (over £1000/tCO_2, which are not reported in the table), implying that emissions must decline steeply post-2050 in order to reach stabilisation.

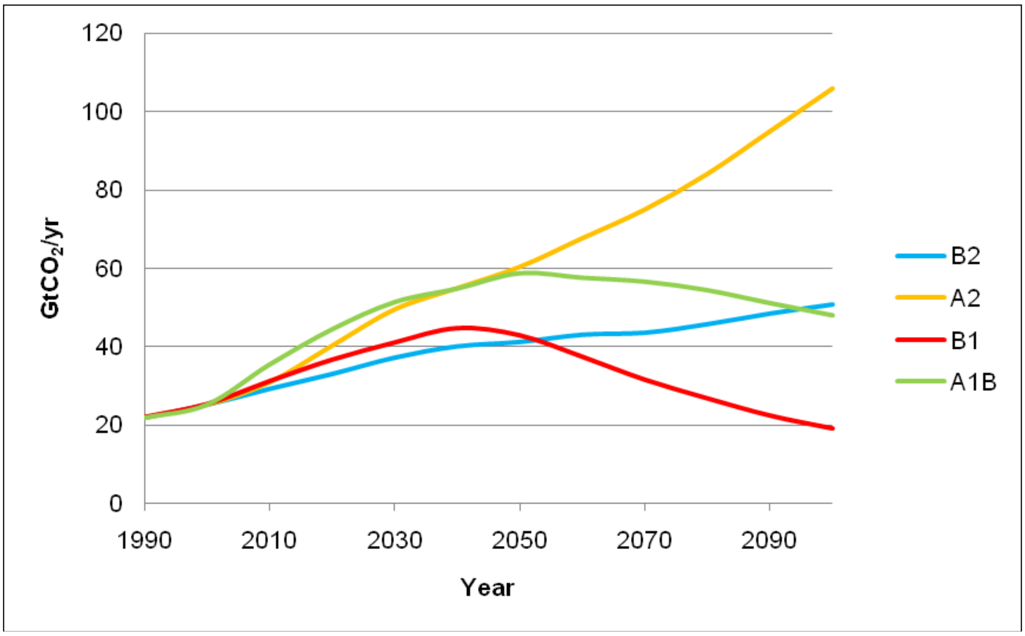
Abatement coverage

The OECD Env-Linkages model produces high abatement costs in 2050, considering it stabilises concentrations at 550ppm. This can be – at least partially – explained by the fact that land-use change mitigation is excluded from the model. As theory suggests, excluding some coverage from mitigation options significantly increases the price.

BAU assumptions

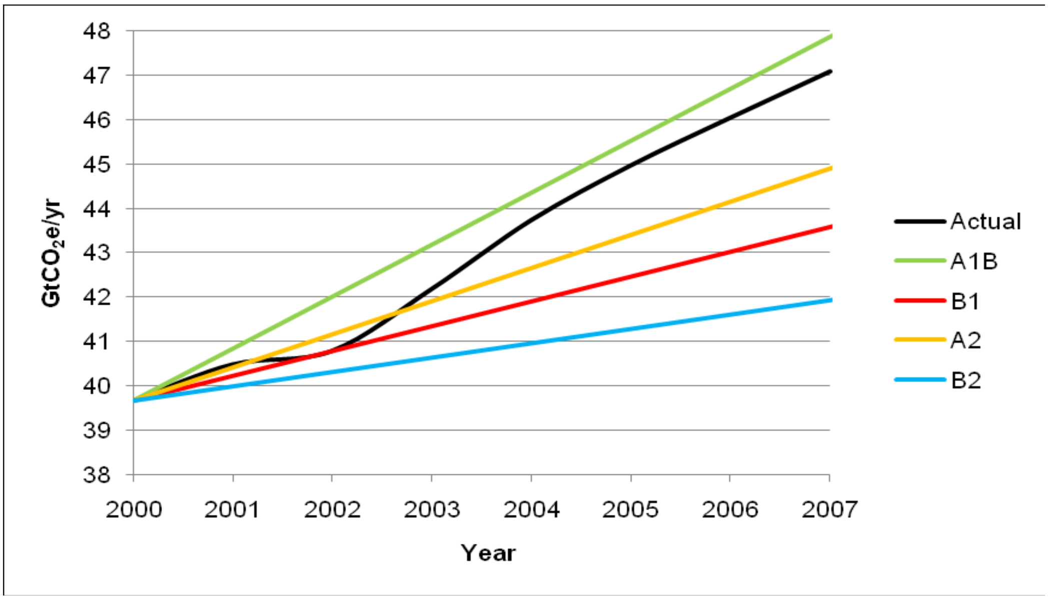
The estimates which drive the bottom end of the IPCC range have baselines which can be considered questionable. The IPCC SRES set out four families of baseline scenario – A1, A2, B1 and B2.

Figure 3: IPCC baseline scenario (1990 – 2100)



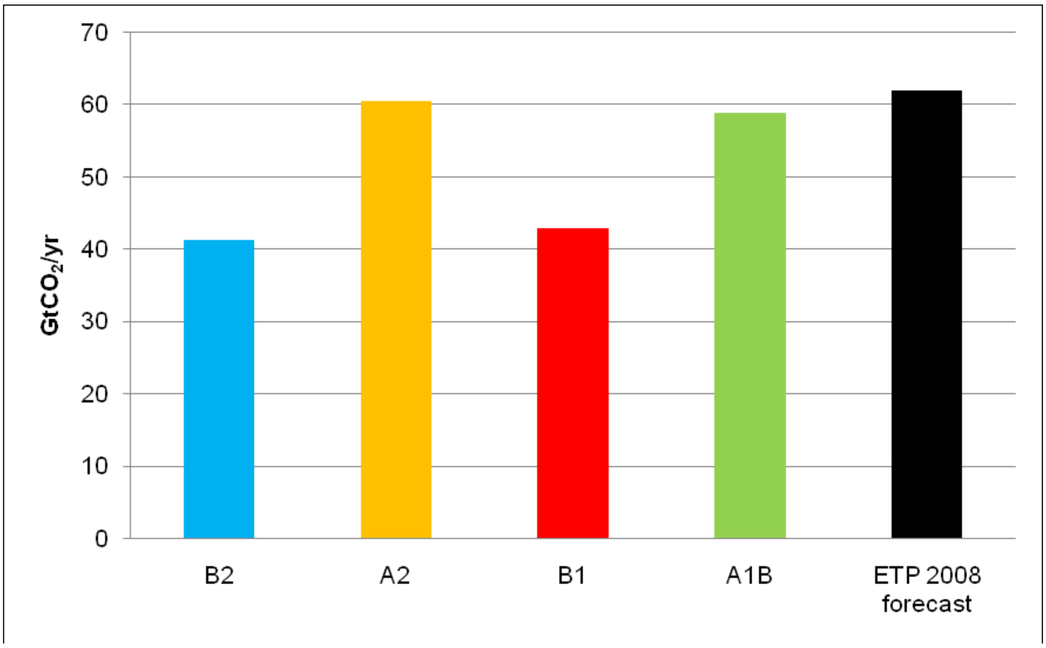
Up until 2050, the ‘A’ scenarios have similar BAUs, as do the ‘B’ scenarios. In 2050, the ‘A’ scenarios are significantly different to the ‘B’ scenarios. Looking at recent data (since 2000), the world is close to an A1 pathway (the A2 pathway re-aligns with A1 by 2030), as shown below.

Figure 4: IPCC scenario and actual (2000-2007)



So, it appears that in the short- and medium-term, the A1 family looks to be a much better description of reality. Does this relationship hold in the longer term? Whilst this is clearly a matter of forecasting, the Stern Review chose the A2 scenario as its baseline, and indeed the IEA predicts emissions that are aligned with A1 and A2 rather than B1 and B2.

Figure 5: IPCC Baseline



Therefore the IPCC ‘low’ estimates are excluded, since they are driven by modelling exercises with ‘B’ baselines, which appear inconsistent with current and projected trends.

Filtered Results

By excluding results that relate to inconsistent stabilisation goals (the OECD estimates, those from the IPCC low scenario and the IGSM model) the range around the model estimates is squeezed significantly. Revised graphs, stripping out these estimates, are shown below.

Figure 6: Estimates of global abatement costs in 2030

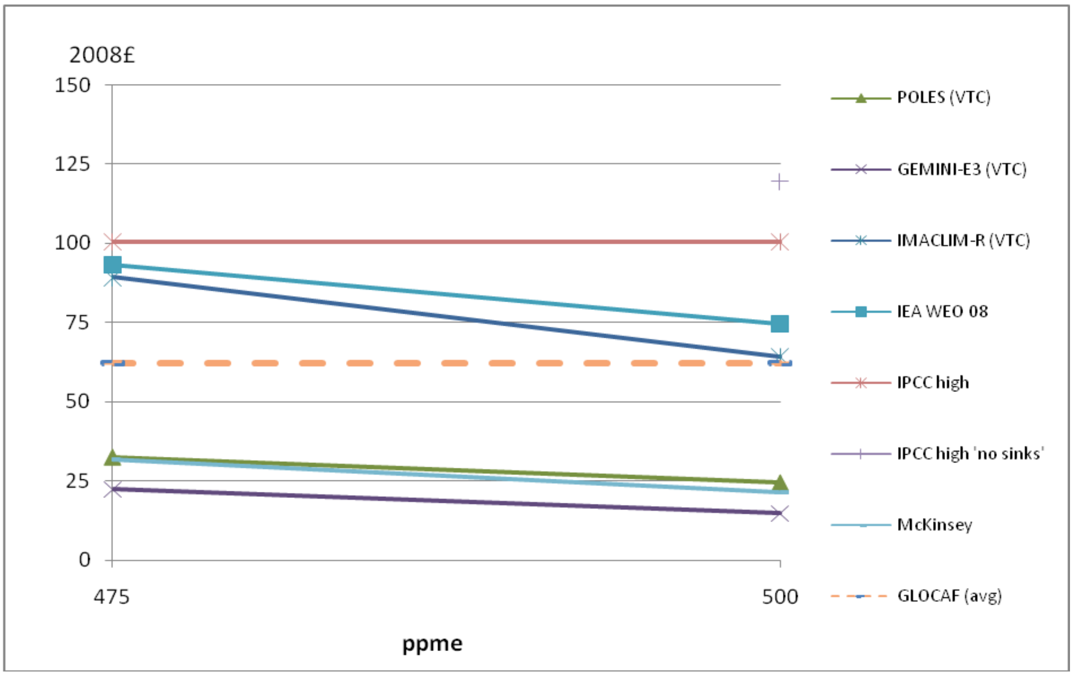
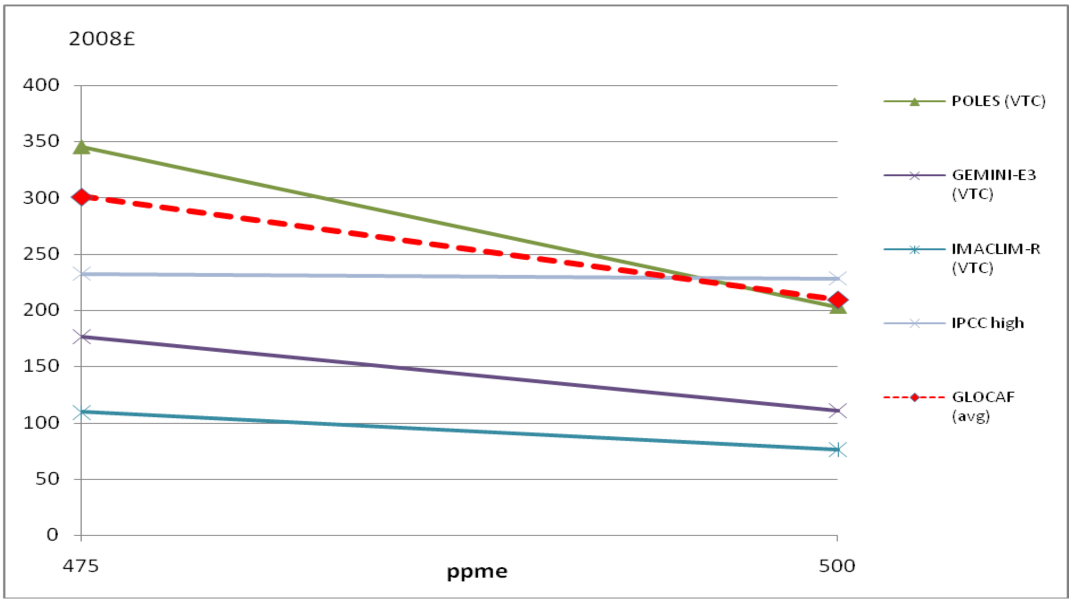


Figure 7: Estimates of global abatement costs in 2050



Annex 4: Traded and non traded carbon values and damage cost estimate (2008-50)

	Traded			Non traded			Damage cost
2009 £	Low	Central	High	Low	Central	High	
2008	12	21	26	25	50	75	27
2009	12	21	27	25	51	76	28
2010	12	22	27	26	52	78	28
2011	12	22	27	26	52	79	29
2012	13	22	28	27	53	80	29
2013	13	23	28	27	54	81	30
2014	13	23	29	27	55	82	31
2015	13	23	29	28	56	84	31
2016	13	24	29	28	57	85	32
2017	14	24	30	29	57	86	32
2018	14	24	30	29	58	87	33
2019	14	25	31	30	59	89	34
2020	14	25	31	30	60	90	34
2021	16	30	39	31	61	92	35
2022	18	34	46	31	62	93	36
2023	20	39	53	32	63	95	36
2024	23	43	61	32	64	96	37
2025	25	48	68	33	65	98	38
2026	27	52	76	33	66	99	39
2027	29	57	83	34	67	101	40
2028	31	61	90	34	68	102	40
2029	33	66	98	35	69	104	41
2030	35	70	105	35	70	105	42
2031	38	77	115	38	77	115	43
2032	42	83	125	42	83	125	44
2033	45	90	134	45	90	134	44
2034	48	96	144	48	96	144	45
2035	51	103	154	51	103	154	46
2036	55	109	164	55	109	164	47
2037	58	116	173	58	116	173	48
2038	61	122	183	61	122	183	49
2039	64	129	193	64	129	193	50
2040	68	135	203	68	135	203	51
2041	71	142	212	71	142	212	52
2042	74	148	222	74	148	222	53
2043	77	155	232	77	155	232	54
2044	81	161	242	81	161	242	55
2045	84	168	251	84	168	251	56
2046	87	174	261	87	174	261	58
2047	90	181	271	90	181	271	59
2048	94	187	281	94	187	281	60
2049	97	194	290	97	194	290	61
2050	100	200	300	100	200	300	62

Annex 5: Results of the Audit of the Use of the Shadow Price of Carbon

Final IAs

Impact Assessment Title	Department	Valuation for GHG emissions	Was the SPC applied correctly	If PSA 27 was carried out what was the threshold
Impact assessment of smart and advance metering for small and medium-sized businesses and public sector sites. Costs and benefits: detailed results	BERR	£94 – £233 million (depending on scenario)	Unclear	Indicator 6 not reported
Impact assessment for the Energy Bill	BERR	Raft of IAs	Yes	Indicator 6 not reported
Provision of historic consumption on Energy Bills	BERR	£100 million	Unclear	0.09 mt CO_2e p.a. Indicator 6 not reported though.
Impact Assessment - The Next Steps: EPCs and the establishment of the Green Homes Service	CLG	Not quantified but stated that there would be an impact on emissions		Indicator 6 not reported
Changes to Permitted Development Rights for Householder Microgeneration: Impact Assessment	CLG	Should have been £0.2 - £0.9 million. Was stated as £0.02 - £0.09 million	Yes	Indicator 6 not reported
Mandatory rating against the code	CLG	£72 million	Unclear	Indicator 6 not reported
Impact Assessment of the Carbon Reduction Commitment	DECC	£1.761 billion	Yes	1.8 mt/CO_2e p.a 100% of emissions under the SPC and EU A
Measures to protect marine biodiversity in Lyme Bay	Defra	Stated as “minimal”		Indicator 6 not reported
Implementation of F Gas Regulation EC 842/2006 and 10 associated European Commission Regulations	Defra	£1.04 billion	Yes	2.0 mt/CO_2e p.a 98.4% of emissions under the SPC 1.6% of emissions over.

Impact Assessment of EuP Implementing Measures for Standby and Off-Mode Losses	Defra	£242-304million	Yes	0.16 mt/CO_2e p.a. 100% of emissions under the SPC and EU A
Impact Assessment of EuP Implementing Measures for Simple Set Top Boxes	Defra	£77,710,000 net	Yes	0.46 mt/CO_2e p.a. 100% of emissions under the SPC and EU A
Impact Assessment of EuP Implementing Measure for External Power Supplies	Defra	£ 4.5m net increase in emissions through HRE. £ 16.2m in EUA savings through realisation of traded sector emission reductions.	Yes	0.11 mt/CO_2e p.a. 100% of emissions under the SPC and EU A
Impact Assessment of Implementing Measures for ecodesign requirements and energy labelling of Televisions (TVs)	Defra	£160 million	Yes	0.48 mt/CO_2e p.a. 100% of emissions under SPC and EU A
Impact Assessment of EuP Implementing Measure for Motors	Defra	£366 million	Yes	1.42 Mt/CO_2e p.a. 100% of emissions under SPC and EU A
Impact Assessment of EuP Implementing Measures for cold domestic appliances	Defra	£282 million	Yes	1.00 Mt/CO_2e p.a. 100% of emissions under SPC and EU A
Impact Assessment of EuP Implementing Measures for non-directional household lamps	Defra	£89-141 million	Yes	0.85 Mt/CO_2e p.a. 100% of emissions under SPC and EU A
Impact Assessment of EuP Implementing Measures for Tertiary Lighting	Defra	£245 million	Yes	0.92 Mt/CO_2e p.a. 100% of emissions under SPC and EU A
NHS Next Stage Review proposals for primary and community care	Department of Health	In IA written as "little/reduction"		Indicator 6 not reported

Partial IAs

Impact Assessment Title	Department	Valuation for GHG emissions	Was the SPC applied correctly	If PSA 27 was carried out what was the threshold
Impact assessment of smart metering roll out for domestic consumers and for small businesses	BERR	£104 - £646 million (depending on scenario)	Yes	Indicator 6 not reported
Offshore electricity transmission: a joint Ofgem/BERR policy statement. Updated impact assessment	BERR	Total costs are £830million not £720million (according to their calculations). 2013 is not calculated on the table	No SPC is £25 for every year and this is even the wrong base year	Indicator 6 not reported
Impact Assessment of proposals for a UK Heat and Energy Savings Strategy	DECC	£3.3 bn – £4.8 bn	Yes	10.7 mt/CO_2e p.a 0% of emissions under the SPC and EU A
CERT	DECC	48 Million	Yes	1.1 mt/CO_2e p.a. 0% emissions under SPC and EU A
Community Energy Saving Programme	DECC	£67 – 251 million	Yes	0.093 mt/CO_2e p.a. 100% of emissions under the SPC and EU A
Impact Assessment of Proposed Euro VI Heavy Duty Vehicle Emission Standard	DfT	£126 million	Unclear	Indicator 6 not reported
Impact Assessment of EU Proposals on New Car CO_2 targets	DfT	£5 million to £192 million	Unclear	Indicator 6 not reported

Miscalculations of carbon values

In the “Changes to Permitted Development Rights for Householder Microgeneration: Impact Assessment”, the value was incorrectly estimated in the summary sheet. The values should be £0.2million – £0.9million not £0.02million - £0.09million.

The impact assessment on offshore electricity transmission also has errors and omissions. It miscalculates the SPC using the wrong base year – 2007 – not 2008 as it should do and then keeps the SPC constant at its 2007 level throughout the calculations. This is further exacerbated by the fact there are no figures for 2013, which makes calculating the overall figures difficult. The IA has total carbon benefits at £720million, whereas, using the correct SPC, the figure would be closer to £830million (still with the omission of 2013 figures).

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