The Social Cost of Carbon

The Social Costs of Carbon (SCC) Review –

Methodological Approaches for Using SCC Estimates in Policy Assessment

Final Report

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Executive Summary

The effects of global climate change from greenhouse gas emissions (GHGs) are diverse and potentially very large. Traditionally the policy debate on climate change has tended to focus on the costs of mitigation, i.e. how much it will cost to reduce greenhouse gas emissions. This study focuses on the economic costs to society from climate change actually occurring, known as the **Social Cost of Carbon (SCC)**. The SCC is usually estimated as the net present value of climate change impacts over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. It is the marginal global damage costs of carbon emissions.

In 2002, the UK Government Economic Service (GES) recommended an illustrative estimate for the SCC of £70/tonne of carbon (tC), within a range of £35 to £140/tC, for use in policy appraisal across Government. The GES paper also recommended that this should be subject to periodic review. The current project, *The Social Costs of Carbon (SCC) Review - Methodological Approaches for Using SCC Estimates in Policy Assessment*, was commissioned by Defra as part of such a review.

The aim of the project has been to inform Government on how best to incorporate SCC values in decision-making, given the uncertainty which will continue to surround monetisation of global climate change. Defra also commissioned a parallel project from the Oxford Office of the Stockholm Environment Institute. This second project, *The Social Cost of Carbon (SCC) review – A Closer Look at Uncertainty,* undertook a survey of expert opinion and new modelling work relevant to estimates of the SCC.

Both projects will input to the review. The specific objectives of this policy project were to:

- Review the previous use of the SCC values in policy assessment, and the possible approaches for future assessment, taking into account the factors that influence the values;
- Undertake expert stakeholder consultation, to obtain their views on how such analysis should be undertaken, and on the uses of SCC estimates in policy assessment in the face of uncertainty;
- Develop a series of case studies to demonstrate the various approaches for including SCC estimates in policy decision-making; and
- Make recommendations.

The study findings are set out below.

Review of SCC use

We found four potential applications for the use of the SCC across Government. These concern:

- Project appraisal (project cost-benefit analysis);
- Regulatory Impact Assessment (policy cost-benefit analysis);
- Setting of economic instrument (input to the setting of taxes, charges, or subsidies);
- Long-term (sustainability) objectives or targets.

There has been widespread use of the current SCC estimates across Government for the first three of these applications, though the exact approach used has varied. For example, some applications have used the central illustrative value of £70/tC only, whilst some have used the full range £35 to £140/tC. Some applications have used one end of the range only. The review has also found a number of relevant policy appraisals or policy areas across Government where the SCC was not used at all, even though the policies involved changes in greenhouse gas emissions.

The study also reviewed the use of SCC estimates in policy applications in other countries and organisations. We have found a general trend towards the use of marginal abatement cost estimates as a 'shadow price' of carbon emissions in project and policy appraisal, rather than a marginal damage cost estimate represented by the SCC. The UK government appears unique in its widespread adoption and implementation of a SCC estimate in policy assessment. However, we have also found a recent rise in interest in the economic benefits of climate change policy, as part of wider post-Kyoto considerations.

Review of SCC Estimates

The two projects have reviewed the SCC literature estimates. The review indicates that with typical assumptions about discounting and aggregation, some central estimates of the marginal damage cost of carbon dioxide emissions are lower than the current GES illustrative value of £70/tC. This reflects a trend in the literature towards lower SCC values in recent years. However, the literature studies do not cover all the impact categories of climate change, and most researchers consider the possibility of negative surprises to be more likely than positive ones. We have therefore assessed the coverage of the valuation studies to investigate the extent to which they may under-estimate the total SCC.

The studies have been compared against a risk matrix, in relation to the uncertainty of climate change impacts and the uncertainty in valuation. Mapping the literature studies onto this matrix, we have found that very few studies cover any non-market damages, or the risk of potential extreme weather (floods, storms, etc). None cover socially contingent effects, or the potential for longer-term effects and catastrophic events. Therefore the uncertainty in the SCC value concerns not only the 'true' value of impacts that are covered by the models, but also uncertainty about impacts that have not yet been quantified and valued. Perhaps most importantly, it indicates that values in the literature are a sub-total of the full SCC, though we do not know by how much.

We have also reviewed the key policy choices on parameters that affect the SCC. We have found that much of the variation in SCC estimates (for the sub-totals assessed so far) arise from a few key parameters in the choice of decision perspectives, most importantly:

- Discount rate used;
- Approach to weighting impacts in different regions (called equity weighting);

The study has also reviewed potential approaches for using the SCC values in policy applications that take risk and uncertainty into account. The study has identified a number of options, including:

- Use of an illustrative central value;
- Use of a range;
- Switching values;
- Sequential sensitivity analysis;
- Different values for different applications;
- Marginal abatement costs
- Multi-criteria analysis.
- Other risk analysis techniques.

We have assessed the advantages and disadvantages of each of these approaches. These findings above were used as the starting point for a stakeholder consultation.

Stakeholder consultation

The stakeholder consultation process focused on experts and users. The consultation process:

- Identified stakeholders and provided a briefing paper on the review findings;
- Undertook direct interviews with relevant experts and users;
- Organised a follow-up seminar to the international social costs of carbon workshop, to present the initial findings from the study and obtain wider views.

The consultation aimed to elicit views on the SCC, assess preferred approaches to deal with risk and uncertainty, and reveal views on the key parameters (discount rate, equity etc) appropriate for policy applications. Over 20 interviews were carried out. When views were collated, there were a number of key messages emerging:

- All stakeholders saw the need for a shadow price of carbon in detailed appraisal. (i.e. for project appraisal and regulatory impact assessment). This involves appraisal at lower levels compared to strategic long-term objectives.
- Nearly all stakeholders recognised the need for some form of benefits analysis for setting long-term targets, though views varied on the form this analysis should take;
- All stakeholders agreed that once a long-term goal had been set, detailed (lower level) policy appraisal should be consistent with it;
- All stakeholders agreed the need for concise guidance for day-to-day appraisal, which is implemented consistently across applications;
- All stakeholders agreed that there was a need for further research to progress the analysis of costs and benefits, and in particular, more work on the disaggregation of impacts and values.

This suggests that a shadow price of carbon emissions should be maintained for project and policy appraisal across Government, that it should be consistent with longer-term policy goals, and that it should be implemented consistently across applications. However, there were three key areas where the respondents had differing views. These were:

- *Whether these shadow prices should be based on estimates of marginal abatement costs (MAC) consistent with the existing UK long-term target (a 60% reduction in CO_2 emissions by 2050), or should use the estimate of the marginal damage costs of carbon emissions (SCC).* These views reflect different methodological viewpoints amongst stakeholders and are discussed further below.
- *Whether to adopt a central value or a range for the value in appraisal*. Whichever approach is adopted (SCC or a MAC), there were different views on whether day-to-day appraisal is best served by the use of single, central value or by a range. In theory a range of uncertainty could be used consistently in different applications. However in practice in several contexts users are likely to prefer to work with a single value. Several stakeholders (specifically from the users group) have expressed concerns that the indication of a range is more open to the risk that practitioners may tend to emphasise the single value within the range that better suits them. Therefore, most interviewees recognised that there was a trade-off between 1) consistency across applications, which would be achieved through the indication of a single value, and 2) consideration of uncertainty, which would be achieved through the indication of a range.
- *Whether to use Green Book guidance or to use an alternative scheme for discounting – and on the appropriateness of equity weighting*. There were different views on whether it was appropriate to use the Green Book guidance (for example with declining discount rates), or to introduce schemes that would recognise that climate change was a special application. There were also different views on whether equity weighting should be included, on the exact equity weights that should be adopted, and over consistency with using equity weights for climate change vs. other policy areas. While there was considerable support for the use of the Green Book declining scheme, there was a wide and divergent set of views on equity weighting.

The first bullet point above reflects the different individual perspectives on policy appraisal in general (and particularly on the appraisal of climate change policy). There were three broad groups of stakeholders.

- A first group believes that cost-effectiveness should be the primary consideration when appraising lower-level policies, given that the UK Government has already set a long-term (2050) target for reducing emissions of CO_2. Such an approach should lead to the achievement of this goal at least cost. Within this group there were two related lines of argument. There are those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy and targets. They believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle. Some respondents in this group also raised the issue of the duty of care and human rights. There are also those that believe that when policy is not easily based on an objective assessment of the costs and benefits (as with climate change), the process of target setting helps to reveal the weight which society puts on costs and benefits. They implicitly believe that policy makers use the available information to make the most efficient decisions possible with the knowledge available. Independently of the underlying interpretation of the process of target setting, the policy recommendation from this group is that for day-to-day project and policy appraisal, it would be relevant to use marginal abatement cost (MAC) estimates that are consistent with the existing overall policy goal (the 60% target) as a shadow price for carbon emissions.
- A second group starts from the position that unless policy makers have a good understanding of the costs and benefits, targets may be set at an inefficient level. They believe that formal cost-benefit analysis leads to better policy making, through its transparency and consistency, and its explicit attempt to assess the optimal policy outcome. The policy recommendation from this group isto use the SCC estimates across all levels of policy appraisal, including for the setting of long-term targets as well as detailed, day-to-day project and policy appraisal.
- A third group accepts that cost-benefit analysis is a useful input to policy decision-making, but highlighted concerns over what they see as simplistic application of SCC values for longer-term climate change policy. This group also drew attention to the considerable uncertainty in both MAC estimates and SCC estimates and recommended a pragmatic approach that would consider and compare both sets of estimates to derive a shadow price for detailed, day-to-day project and policy appraisal.

Based on reflection by the study team and input from the steering group, we make the following recommendations on a way forward.

Recommendations

1. Benefits of climate change policy should be considered when setting long-term targets and goals. Some benefits can be directly estimated as monetary values, but a wider framework is needed to take all relevant effects into account. Single monetary estimates of the SCC should be avoided for such policy decisions. The framework should include a disaggregated analysis of economic winners and losers by region and sector, and a disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems. The full risk matrix identified in the study (including risk of major change) should be considered, and the analysis should include extensive uncertainty analysis. Green Book recommendations should be used for assumptions on discounting, but with sensitivity analysis. The uncertainty analysis should also consider equity assumptions. Benefits analysis should consider ancillary effects, but the analysis of these should be kept separate in the assessment. This is an informed process leading to a long-term goal.
2. Detailed policies follow from, and should be consistent with the long-term goal, once set. The aim should be to ensure the target is achieved in the most cost-effective way, and there is a need for consistency in appraisal across policy areas to achieve this.

3. To this end, it is useful to examine the current MAC estimates towards the current 2050 target over future decades. For any revision of long-term goals, it would also be useful to examine MAC estimates under different emission reductions targets. At the same time, it is still useful and instructive to compare pathways of MAC estimates with pathways of SCC estimates although both set of estimates are highly uncertain.
4. The SCC estimates generated in this study would provide useful information for the analysis of costs and benefits of policy steps to put the UK on a path towards the 60% 2050 target. However, we highlight that any such application of these estimates should recognise the limitations in the SCC values (the omission of major categories of impacts) and be consistent with recommendation 1 above – notably that when setting long-term climate change targets and goals, a wider framework (the full risk matrix) is needed for considering benefits, to take all relevant effects into account, complemented with consideration of the disaggregated SCC values, and uncertainty and sensitivity analysis.
5. We believe that a pragmatic way forward to the choice of shadow prices for use in (day-to-day) appraisal is to examine the marginal abatement cost curve towards the existing 2050 target, and to compare against the SCC estimates over time. These values should be used consistently across all applications.
6. The values derived could be presented as a single illustrative value or a range. In theory a range of uncertainty could be used consistently in different applications. However in practice in several contexts users are likely to prefer to work with a single value, particularly in lower-level appraisals. Hence presenting a single value would ensure consistency across all areas of appraisal. On the other hand a central value does not properly take into account all the inherent uncertainties. While a single value would be preferable for areas where GHG reductions are not the primary concern, a range would be preferable for cases where major greenhouse gas emissions reductions or policies were being considered.. However, the use of a range may lead to inconsistencies between applications (as with the current guidance).
7. To address this, we recommend a multi-level (stepped) approach, which varies with application.
   - For project appraisal, a single central illustrative value (rising over time) could be used.
   - For policy appraisal affecting greenhouse gas emissions, a central range (rising over time) could be used, allowing some consideration of uncertainty.
   - For major long-term policies, e.g. for climate change policy, or for a revised Energy White Paper, a full range and additional sensitivity analysis could be used, within the wider framework proposed in 1. above.
8. Ancillary effects (e.g. air pollution benefits, energy security) are important but should not be combined within the shadow price, as they will be specific to particular technologies and circumstances. They should therefore be assessed separately.

Consistent with these recommendations, we have assessed the MAC implied by the 2050 target and compared this to the marginal SCC values derived as part of the two SCC projects. This has shown that there is considerable uncertainty in using such an approach to derive shadow prices for appraisal:

- There is no agreement on the relevant marginal abatement costs to use, and the published values in the supporting analysis for the Energy White Paper are now controversial (though these values were part of the decision framework that led to the acceptance of the RCEP recommendation to put the UK on a path towards the 60% target). A review of the wider abatement costs of long-term CO_2 reductions shows that estimates differ by over an order of magnitude, and some studies even vary in sign. Indeed recent debate on the likely costs of the 60% target appears to have led to a greater divergence of views rather than a consensus. There is ongoing work in the current climate change review (in Defra) that will update the marginal abatement costs to 2010 and 2020. This should provide a valuable input for reconciling short-term estimates. However, further work is needed to investigate, and reach consensus on, the costs of abatement towards mitigation towards the long-term – if these values are to be used for input into shadow prices. This will require the use of a wide range of methods and models. This is highlighted as a priority for future research.

- The modelling report reveals that estimates of the social cost of carbon span at least three orders of magnitude, from about zero to more than 1000 £/tC, reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables. Moreover, the models do not fully capture the full risk matrix (and the full SCC). The report concluded that it was not possible to provide an illustrative central, or an upper benchmark of the SCC for global policy contexts, though the risk of higher values for the social cost of carbon is significant. The modelling study did, however, provide a lower benchmark of 35 £/tC as reasonable for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting.

Nonetheless, policy appraisal requires a value.

We believe the issues raised above lend greater weight to the recommended pragmatic approach, which also has some theoretical basis. If the MAC and SCC values are derived based upon the same set of underlying assumptions, then any divergence between these two values reflects a divergence from the optimal level of carbon emissions. The optimal carbon price is simply a weighted average of the MAC and SCC values, depending on the respective elasticities of the two curves. Some stakeholders question, however, whether the MAC and SCC curves are derived with a reasonably consistent set of assumptions.

We have used the information from a number of data sets – as an **example** on how to progress the recommendations here:

- The MAC implied by the Energy White Paper analysis of the 2050 target and other literature estimates of the costs of long-term targets (recognising the issues raised above);
- The conclusions from the modelling study (see above), including the results of the SCC review;
- A number of additional modelling runs with PAGE and FUND, undertaken as part of policy project – specifically looking at the profile of SCC values over future years, recognising these models do not fully capture the full risk matrix (and the full SCC).

The additional analysis on the SCC undertaken for the policy study is summarised below:

- The literature review (undertaken by Richard Tol) shows that the mean of the SCC values is £80/tC (with 5% and 95% values of £-9/tC and £300/tC), or £111/tC as a mean value based on author weights (with 5% and 95% values of £-10/tC and £550/tC). This falls to £43/tC when only peer-reviewed studies are included (with 5% and 95% values of £86/tC and £210/tC)). These values only provide current SCC estimates – they do not indicate how the SCC will change in future years. They also include the use of different discount rates and equity weighting schemes.
- The mean estimate from the PAGE model, run with Green Book discounting scheme, is a SCC value (£46/tC in 2000) that is lower than the existing illustrative central value (the £70/tC). However, PAGE shows a much sharper rise in the SCC estimate in future years (i.e. above the recommended increase of £1/tC per year), so that PAGE estimates are higher than the existing illustrative SCC value after 2030. The PAGE results show a wide distribution of values, with a 5% and 95% value of £9/tC and £130/tC for current emissions (year 2000).
- The mean estimate from the FUND model (a 1% trimmed mean), run with Green Book discounting scheme, is SCC values that are very close to the existing Defra illustrative central value, and has a similar rate of increase in later years. The full range of results from FUND still covers an extremely large range, with a range in 2050 that spans from -£40/tC to £500/tC (5% and 95% values).

The values are summarised below.

	SCC Estimates - Year of Emission						
£/tC	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**
Existing SCC central	70	80	90	100	110	120	130
Lit. Rev Mean	80 / 111 /43						
Lit. Rev 5%	-9/ -10 / -8						
Lit. Rev 95%	300/ 550 / 210						
FUND Mean (1%)	65	75	85	95	97	129	
FUND 5%	-53	-46	-46	-41	-47	-40	
FUND 95%	309	378	482	458	498	575	
PAGE CC Mean	46	61	77	102	127	157	187
PAGE 5%	9	12	14	20	27	30	34
PAGE 95%	130	159	215	270	324	418	513
	Energy White Paper MAC estimates – Year of Emission						
EWP MAC central				0	13	242	
Low MAC				93	193	351	
High MAC				143	229	538	

Three literature review values are shown – based on those reported by Tol in his analysis: the mean of all studies, the mean of author weights, and the mean of peer reviewed studies (using weights assigned by the literature paper author). Note values for FUND and PAGE are based on declining discount scheme in the Green Book and assume equity weighting. The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.. The MAC estimates are based on the MARKAL model estimates (the Low Carbon Futures work).

The analysis with both models uses the parameters agreed for UK policy analysis with the steering group, i.e. it applies Green Book declining discount rates and equity weighting (the use of these parameters explains the choice of only using these two models to derive the value).

In interpreting the values (and underlying models), it is essential to note that these SCC estimates still do not include consideration of the full risk matrix – they exclude socially contingent effects and major events, and (in particular in the case of FUND) only have a partial coverage of bounded risks and non-market impacts.

From the analysis of the MAC estimates, and the above SCC values, we have derived **example** shadow prices, consistent with the above recommendations. This includes an illustrative central value, a lower and upper central value, and a wider range as follows:

- To derive the example central illustrative value, we have taken values from 2000 to 2020 using the average of the SCC modelling values – specifically the average of the FUND model mean (1% trimmed mean of £65/tC) and the PAGE model mean (£46/tC) - which provides an estimate of £56/tC (for year 2000). The mean values from these models sit within the range from the wider SCC literature review. The two models have also been used to investigate SCC estimates in later years. The mean value from FUND rises at a very similar level to the existing SCC guidance. The mean value from PAGE rises at a higher rate post 2030. The SCC estimates have been compared to the central MAC in the Energy White Paper supporting analysis (towards the 2050 target 60% goal, based on the MARKAL model). Interestingly these estimates show a similar value in 2030 to the SCC values, at around £100/tC. The MAC estimates do, however, increase more sharply than the SCC values in 2040 and 2050. The MARKAL estimates have been compared against other abatement cost estimates in the literature, which shows they are broadly in line with other studies (see next bullet). Taking this information, we believe that a value of £55/tC in 2000, but rising more sharply than the current guidance (i.e. at a higher rate than the current £1/tC per year), would seem to capture the evidence using a pragmatic approach. This example of the illustrative central shadow price would be used at simple project level appraisal as outlined in the multi-level approach.

- To derive the example central illustrative range, we have adopted the conclusions of the parallel modelling study. This proposed a lower benchmark of 35 £/tC as reasonable for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting. The modelling study did not make any recommendations on an upper benchmark, but reported that the risk of higher values for the social cost of carbon is significant. To try and capture this upper benchmark, we have based the upper central estimate on the PAGE 95% values, and its path over future years (the PAGE 95% values start at £130/tC in 2000 and rise to £400/tC by 2050). The lower and upper central values are also consistent with the central range of abatement costs in the literature – from MARKAL and the wider literature (the MARKAL costs to achieve the 2050 60% target report represent 0.5 to 2% of GDP –most other studies fall in the range 0.5 to 3.5% (with a mean estimate of 2.5%)). The wider literature has marginal costs in 2030 that are much lower, typically between £25 and £150/tC.
- To derive an example of a more complete range of values, we have considered the wider SCC estimates and the wider abatement cost literature. The lower value is based on the 5% values from PAGE. The upper values are based on the wider literature on abatement cost (note more than 50% of 2050 abatement cost studies have MAC less than £500/tC) and the 95% values from FUND and PAGE. We highlight that even this range does not fully capture all estimates in the literature. For example, the range of values for the long-term abatement costs (2050) spans from less than 0% of GDP (which would imply an increase of economic output) to over 4.5% - at the top end this implies MAC of £900/tC. The full range of modelled SCC values includes negative SCC values (i.e. implying climate change will have net benefits), right through to values in excess of £1000/tC. Even the range we propose is extremely large. This type of value would be intended for use in major long-term analysis for uncertainty analysis, as outlined in the multi-level approach. Note our recommendation for such appraisal (see recommendation 1 above) is that it should be considered as part of a wider framework including analysis of disaggregated physical impacts and values by sector and region.

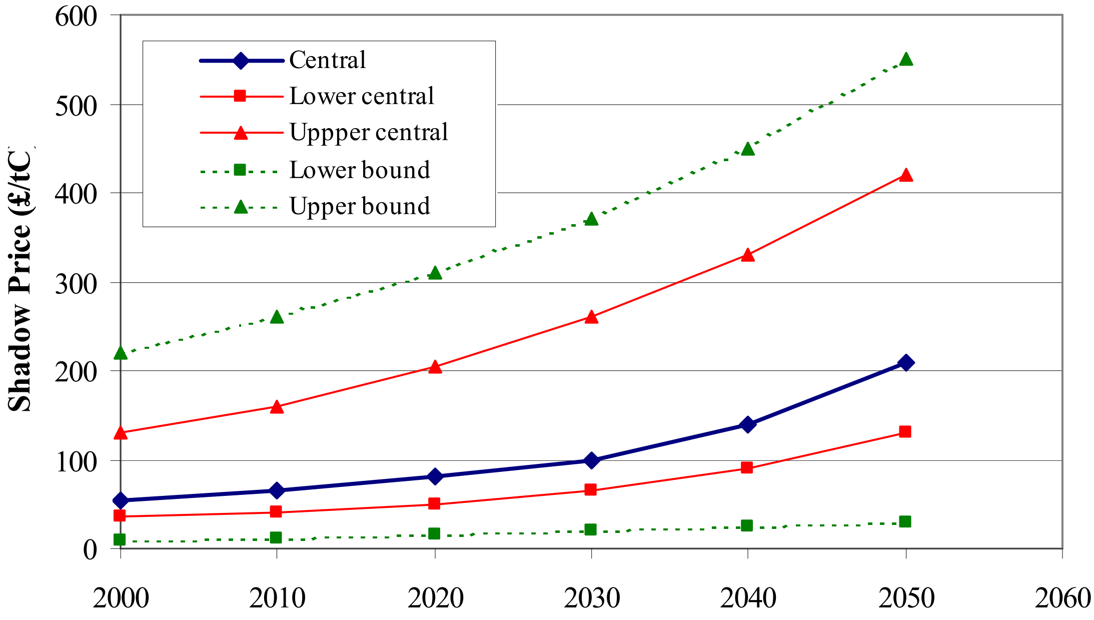
The example estimates are shown below[1].

Example Shadow Price Values from the Study, consistent with study Recommendations

Year of emission	Central guidance *	Lower central estimate	Upper central estimate	Lower bound	Upper bound
2000	55	35	130	10	220
2010	65	40	160	12	260
2020	80	50	205	15	310
2030	100	65	260	20	370
2040	140	90	330	25	450
2050	210	130	420	30	550

See notes under the figure below

[1] The values have been rounded and fitted to a distribution based on the overall trends shown for each set of estimates. This ensures that the values can be applied in appraisal, using standard rates of increase (£/tC per year) for each decade.



Example Shadow Price Estimates (£/tC), consistent with study recommendations

Notes
The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.The consideration of the SCC as part of these numbers is dependent on the assumed low discount rates (specifically declining discount rates), and includes equity weighting from a global policy perspective. The issue of equity weighting is the subject of continued debate, both in relation to the approach, and the consistency with other policy areas. At the present time, we have not recommended adjustments between the SCC and the MAC.
The consideration of the MAC is based primarily on the full range from the Government analysis (the White Paper analysis), though we also benchmark these values against the wider literature. We highlight the current debate on the accuracy of these values and the need for further modelling work.
The SCC from PAGE and FUND are global estimates (i.e. global social costs). The MAC in terms of the 60% UK target is in relation to UK marginal abatement costs, though these values have also been compared against the wider literature.
Successful mitigation policy will reduce the SCC estimates, as progress is made towards the 2050 target, and some of the major effects from climate change are avoided (i.e. we move below a threshold of effects for some impacts). Therefore in looking at long-term policies, further work is needed to look at the potential effect of different policies on the SCC over time.

As recommended above, we propose that such values are used in a multi-stage approach. To illustrate this, the study has applied the values to four case studies: a project based example (transport appraisal) using the central value; a regulatory impact assessment (F-gases) which uses the central range; a potential aviation tax; and the Energy White Paper analysis (long-term strategy). The case studies clearly suggest that the full range is not appropriate for day-to-day appraisal, because the range is so large it makes the use of the shadow price meaningless. This strengthens our recommendation to use the narrower central range in most policy appraisal. The use of the full range is, however, useful for the high level strategic examples.

It is also possible to use the information above to present a separate SCC estimate over time, rather than the combination of the SCC and MAC as recommended here. This does provide useful information for the analysis of costs and benefits of policy steps to put the UK on a path towards the 60% 2050 target. However, we highlight that any such application of these estimates should recognise the limitations in the SCC values (the omission of major categories of impacts) and be consistent with recommendation 1 above – notably that when setting long-term climate change targets and goals, a wider framework (the full risk matrix) is needed for considering benefits, to take all relevant effects into account, complemented with consideration of the disaggregated SCC values, and uncertainty and sensitivity analysis. The average of the FUND and PAGE values have been used to derive this SCC profile (note the lower bound profile is based on the same relative increases starting at £35/tC, consistent with the modelling study recommendations).

Example SCC Values from the Study.
Note these should only be used as part of a wider framework that considers additional effects of non-quantifiable impacts across the full risk matrix (including major change).

Year of emission	Central guidance	Lower central estimate	Upper central estimate
2000	56	35	220
2010	68	43	270
2020	81	51	350
2030	99	62	365
2040	112	71	410
2050	143	90	500

The use of these SCC values for CBA of future climate change policy objectives and measures should be consistent with recommendation 1 above, i.e. undertaken within a wider framework that considers all the impacts of climate change, using disaggregated information, considering uncertainty, and ensuring that additional effects of non-quantifiable impacts in the full risk matrix (including risk of major change) are included.

The study has identified research priorities. The most immediate priority is to assess the disaggregated effects of the SCC value, by sector and region, and work to establish estimates of the physical impacts for consideration of different long-term policies. This could be demonstrated with a case study on long-term CO_2 reduction goals. Other research priorities include specific consideration of the approach for equity weighing, including issues of policy consistency with other areas. An appropriate expert group could take this area forward. There is also a need to improve the MAC estimates. It is likely that the costs of short-term measures will emerge from the current Defra review of the climate change programme, but further work is needed to investigate, and reach consensus on, the costs of post 2020 abatement - it is clear that will require the use of a wide range of methods and models. Finally, there is a need to review and update the analysis here, as the evidence on the SCC, the MAC, and future policy emerges.

As a concluding note, we highlight that to derive a new set of shadow prices for appraisal of greenhouse gas emissions across Government (consistent with the study aims and consistent with the study recommendations above[2]), either:

- The example values above should be accepted as the best currently available, whilst recognising the limitations associated with the estimates of both MAC and SCC, or
- Further work should be taken to progress the marginal abatement costs, and/or further work to progress the analysis of the full risk matrix for SCC values. This will significantly delay the derivation of a new set of values.

Unfortunately it has not been possible within the current project time-scale to reach agreement on the first of proposed way forward. We highlight that there is some ongoing analysis (summer 2005) as part of the climate change review in Defra that will provide agreed short-term marginal costs to 2020. This is a positive step forward towards improving the evidence base. However, there is still a need for further work to progress post 2020 MAC values, and to capture the full estimates of the SCC (as highlighted in the modelling study).

[2] Or for that matter for use of either the MAC or SCC values individually to set a new set of shadow prices.

Contents

1 Introduction

The effects of global climate change from greenhouse gas emissions (GHGs) are diverse and potentially very large.

Traditionally the policy debate on climate change has focused on the costs of emissions reductions, i.e. the mitigation of greenhouse gas emissions. This study focuses on the cost of climate change impacts (the social costs from climate change actually occurring), known as the **Social Cost of Carbon (SCC),** to examine the scope for using the SCC as a measure of the benefits of greenhouse gas mitigation.

The SCC is the marginal global damage cost of carbon emissions. It is usually estimated as the net present value of the impact over the next 100 years (or longer) of one additional tonne of carbon emitted to the atmosphere today. This should not be confused with the total impact of climate change or the average impact (the total divided by the total emissions of carbon). The SCC is expressed as the economic value (in US$, € or GB£) per tonne of carbon (tC). In this assessment, the baseline is the year 2000 for the emissions and for the net present value. In some literature, marginal damages are related to 1 tonne of carbon dioxide (but not in this report)[3].

The SCC value is potentially relevant in many decision making processes, from project appraisal, through to regulatory impact assessment. It is relevant for wider energy and transport policy, project appraisal, and regulatory impact assessment, as well as greenhouse gas mitigation policy.

The objective of the study is to assess how best to incorporate social cost of carbon values in relevant decision making contexts, given the uncertainties over monetisation of global damage from greenhouse gas emissions. The work was undertaken in parallel to a more technical modelling analysis, which aimed to improve the valuation by including some of the more difficult areas of quantification. The results from both will be used to reflect upon and make recommendations on how SCC estimates could best be incorporated in policy decision-making and assessment.

The report has been prepared for Defra as the final report to the study on 'The Social Costs of Carbon (SCC) Review - Methodological Approaches for Using SCC Estimates in Policy Assessment'.

1.1 Existing Guidance

In 1996 IPCC Working Group III published a range of $5 - $125 per tonne of carbon as SCC estimate. A number of studies have emerged subsequently, and in early 2002 the UK Government Economic Service (GES) paper *Estimating the Social Cost of Carbon Emissions*[4] presented a review of the available literature on the social cost of carbon (SCC).

The GES paper suggested a value of £70/tC (within a range of £35 to £140/tC) as an illustrative estimate for the global damage cost of carbon emissions. It also suggested that since the costs of climate change are likely to increase over time, the estimates should rise in real terms by £1/tC per year.

The GES paper recommended periodic reviews of these illustrative figures as new evidence became available. With this in mind, Defra organised an International Seminar on the Social Cost of Carbon[5] in July 2003 to provide an opportunity for leading environmental economists, modellers and analysts to contribute to the debate on the SCC and its application to policy assessment.

[3] 1t C = 3.664t CO_2. So, a value of £100/tC would be equivalent to £ 27/t CO_2.
[4] http://www.hm-treasury.gov.uk/documents/taxation_work_and_welfare/taxation_and_the_environment/tax_env_GESWP140.cfm
[5] http://www.defra.gov.uk/environment/climatechange/carbonseminar/index.htm

Subsequently, in October 2003, Defra established an Inter-departmental Group on the Social Cost of Carbon (IGSCC)[6] in October 2003 to take forward a review.

In January 2004 the group commissioned two research projects aimed at improving the available SCC estimates, and to explore how they could be applied to policy assessment.

This paper is an output of the first of these projects:

'*The Social Cost of Carbon (SCC) Review - Methodological Approaches for Using SCC Estimates in Policy Assessment*' led by AEA Technology Environment.

The second project, '*The Social Cost of Carbon (SCC) review – A closer look at the models, the estimates and the uncertainty'*, was led by the Oxford Office of the Stockholm Environment Institute. It undertook a survey of experts and new modelling to revisit estimates of the SCC, i.e. to review the £70/tC central value and the £35 to £140/tC range.

Details of both these projects are available on the project web site:
http://socialcostofcarbon.aeat.com

1.2 Project Objectives

The policy assessment project undertook the following tasks:

- To review the previous use of the social cost of carbon values in policy assessment.
- To review the possible approaches for using the SCC values in policy assessment, taking into account the key factors that influence the values (choice of discount rate, equity weighting, substitutability, time frame, uncertainty, etc).
- To undertake stakeholder consultation with experts to obtain their views on how such analysis should be undertaken, and on the appropriate uses of SCC estimates in policy assessment in the face of uncertainty.
- To develop a series of case studies to demonstrate the various approaches for including SCC estimates in policy decision-making, including dealing with uncertainty.

[6] http://www.defra.gov.uk/environment/climatechange/carbon-cost/igscc/index.htm

2 Review of Current and Potential Uses

2.1 Introduction

There are a number of potential uses for a social cost of carbon (SCC) in policy making. These mostly relate to the existing framework of cost-benefit analysis used in government departments.

This report does not address the question of whether cost-benefit analysis is the most appropriate tool or technique as a general policy tool. The starting point for this study has been the existing guidance and recommendations in this area[7]. The aim of the study has been to assess the potential application of an SCC value within the existing frameworks, and in particular, how to deal with the high uncertainty surrounding the SCC value.

Generically, the SCC seems relevant to projects and policies directed at:

1) Greenhouse gas mitigation, or towards adaptation.
2) Other policy objectives, such as improvements for air quality, transport congestion, energy policy, which also have some effects (positive or negative) on greenhouse gas emissions.

Different approaches may be needed for these two applications. There are also four specific policy issues, where the SCC value could be used. These are:

- Project appraisal (project cost-benefit analysis).
- Regulatory Impact Assessment (policy cost-benefit analysis).
- Setting of economic instrument (taxes, charges, or subsidies).
- Long-term (sustainability) objectives or targets.

The report provides further discussion and some examples of these applications below

2.1.1 Project appraisal

Project appraisal is intended to produce an **indication** of the degree to which a proposed project or scheme is justified. It can also be used to rank or prioritise alternative schemes or options.

The Treasury Green Book provides guidance on the appraisal of government action. It requires that appraisal be based on an assessment of how any proposed policy, programme or project can best promote the public interest. The Green Book identifies two key questions:

- Is the rationale for intervention clear?
- Are the benefits of intervention expected to exceed the costs?

The technique recommended to address the latter question is cost-benefit analysis (CBA), whereby all relevant costs and benefits to government and society of all options are valued, and the net benefits or costs calculated (though note we are unlikely ever to be able to value all the important costs and benefits of a particular project). In the subsequent discussion, we refer to project appraisal interchangeably with project cost-benefit analysis[8]. This approach differs from cost-effectiveness

[7] Better Policy Making A Guide to Regulatory Impact Assessment'. Cabinet Office, January 2003. http://www.cabinet-office.gov.uk/regulation/ria-guidance/intro.asp
Green Book, Appraisal and Evaluation in Central Government. HMT, 2004. http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm

[8] Appraisal is an input into decision-making, but not a substitute for it. Project or policy appraisal is one strand of information that informs whether to proceed with a particular course of action. As with any approach, it will inevitably entail some judgements in areas such as distribution, risks and uncertainties.

analysis, where a goal is set and the most cost-effective way to meet it is determined, or other approaches such as multi-criteria analysis, where benefits are not (solely) expressed in monetary terms.

The SCC may be used to assess the benefits that directly relate to projects intended to reduce greenhouse gas emissions, and it may also be used in appraising projects that are not primarily driven by greenhouse gas mitigation, but which have a knock-on effect (positive or negative) on greenhouse emissions (e.g. air quality projects, transport projects).

An example of the potential use of the SCC in project appraisal is with the existing road transport scheme appraisals (see box), where it is planned to include the SCC values alongside other benefits in transport appraisal. Examples in other areas include the use of project cost-benefit analysis in infrastructure investment schemes in the power sector.

The Treasury Green Book states 'all new policies, programmes and projects, whether revenue, capital or regulatory, should be subject to comprehensive but proportionate assessment, wherever it is practicable, so as best to promote the public interest'.

The Green Book presents appraisal as a process, starting with the identification of the rationale for intervention, proceeding through the development of outcomes to be achieved and appraisal of a range of solutions to implementation. It also recommends that options should be appraised using cost benefit analysis ('analysis which quantifies in monetary terms as many of the costs and benefits of a proposal as feasible, including items for which the market does not provide a satisfactory measure of economic value').

This process is well established for transport investment. It has long been common practice to use benefit to cost ratios to choose between options for a transport proposal. A cost-benefit framework (COBA) has been in place for transport investment for many years. This has included the valuation of prevention of road casualties and road accidents, and the valuation of the travel time benefits, in the appraisal of road schemes, alongside the appraisal of scheme costs. This has now been updated with the New Approach To Appraisal (NATA) and *Guidance on the Methodology for Multi-Modal Studies* (GOMMMS). The Department is now committed to extending valuation to a wider range of the impacts of transport investment. Valuation is planned for impacts such as noise, local air quality and greenhouse gas emissions. Summary statistics, such as net present value (NPV) and benefit to cost ratio (BCR), are presented.

Source: Green Book/DfT Guidance on the New Approach to Appraisal.

2.1.2 Policy Appraisal (Regulatory Impact Assessment)

The general approach and techniques for policy appraisal are the same as described above for project appraisal. The recommended approach is built around cost-benefit analysis. The box below summarises some key points from the Cabinet Office's existing policy appraisal guidance, known as Regulatory Impact Assessment (RIA).

The SCC is already in use in RIAs of greenhouse gas mitigation policies, including:

- The cost-benefit analysis of the UK Emissions Trading Scheme;
- Proposed regulation for greenhouse gas emission abatement with the Regulation on Certain Fluorinated Gases.

It has also been used in RIAs that do not primarily relate to greenhouse gas policy, but which have a knock-on effect (positive or negative) on GHG emissions. Examples include:

- Use of the SCC values in air quality policy appraisal in Defra. In many cases this will be positive (e.g. reductions in GHG from fuel switching) – in some cases this will be negative (e.g. increases in GHG from certain abatement equipment due to loss of efficiency).

- Use of the SCC values in transport policy appraisal. The SCC estimates have been incorporated in DfT's National Transport Model and marginal social cost pricing models, which look at national transport policy.
- Use of the SCC values in energy policy. The SCC was referred to in DTI's Energy White Paper[9] in that 'most of the carbon savings in the Energy White Paper ….can, we believe, be delivered at costs lower than, or in line with, the illustrative range for [SCC] damage costs.'

The issues highlighted for project appraisal above, with respect to the use of appraisal in decision-making, and the consideration of distribution, risk and uncertainty, also relate to policy appraisal.

'A **Regulatory Impact Assessment** (RIA) is a tool that informs policy decisions. It is an assessment of the impact of policy options in terms of the costs, benefits and risks of a proposal'…..'RIA are required for all proposals (legislative and non-legislative) which are likely to have a direct or indirect impact (whether benefit or cost) on business, charities or the voluntary sector and could have a regulatory solution.' 'This applies to UK policy, but also for legislative or non-legislative proposals which originate outside the UK, notably EU proposals'

'An assessment of the benefits and costs of a proposal is the central analytical component of the RIA. It is the anticipated stream of benefits that flow from regulation or other policy measures that may justify the costs that are imposed on business or other sectors of the economy and society. The purpose of the analysis of benefits and costs is to determine whether these costs are proportionate to the expected benefits.'

'An assessment of the expected benefits is therefore one of the most essential aspects of an RIA. But it is also one of the areas, which receives least attention. It cannot be automatically assumed that the benefits outweigh the costs and thus do not need to be valued.'

For a partial RIA. 'If placing a monetary value of the impact is not possible then try to quantify the main impacts'. For a full RIA. 'By now it should be possible to quantify and place a monetary value on all impacts'. 'In the few cases where this is not possible then quantify what you can and provide detailed qualitative analysis where you cannot'. 'Where there are uncertainties about the impacts, use ranges rather than being spuriously accurate'.

The RIA guidance recommends that estimates of costs and benefits should be on a per annum basis and, where necessary, discounted (using Green Book guidance).

Source: Better Policy Making A Guide to Regulatory Impact Assessment'. Cabinet Office, January 2003

2.1.3 Economic Instruments

Economic instruments include environmental taxes, charges and subsidies, as well as market-based instruments. There is a potential role for SCC estimates to help inform the design of economic instruments.

Environmental taxes, emissions trading schemes and other economic instruments can play an important role in ensuring that prices reflect environmental costs. In theory one would look at SCC estimates as guidance for setting carbon taxes or emissions caps (under emissions trading schemes) that deliver an efficient amount of carbon emissions.

In practice the application of these theoretical concepts is often not straightforward. Scientific, technological and economic uncertainties make it difficult to exactly estimate marginal damage curves as well as marginal abatement cost curves. In turn, this tends to limit the scope for fine-tuning economic instruments at the theoretical optimal level. The picture is further complicated when considering potential overlaps between different instruments and policy measures, an issue which is

[9] Our Energy Future – Creating a Low Carbon Economy. DTI, 2003.

particularly relevant to the UK energy context. On the other hand economic instruments can be fine-tuned after implementation on the basis of observed behavioral responses.

The Government commitment towards Tax and the Environment is summarised in the box.

The Green Book advises that 'First, the Government will identify the environmental policy objective. Second, the Government will assess the rationale for becoming involved. Third, the Government will evaluate the benefits and costs of intervention. The potential environmental benefits need to be considered in relation to the costs of achieving them. Fourth, the Government will determine the most efficient instruments for achieving the objectives. The most efficient approach will be the one that provides the greatest overall economic benefits'. It also states that 'cost-benefit analysis should be used to appraise individual measures and also to inform high level target setting.' The statement of intent also deals with potential limitations of CBA in relation to target-driven environmental policies.

The current and potential use of the SCC in this context include:

- Use of the SCC values in a number of DfT assessments to look at road user charging, vehicle excise duty and fuel duty levels. The SCC values were also presented for consideration in the DfT consultation paper on economic instruments for aviation;
- Similarly, SCC values have been used by Defra in consideration of taxes and charges in the waste sector.
- The SCC values were considered for costing of carbon emissions for standards in Part L (energy performance) of the Building Regulations.
- An SCC value was used in setting allowable subsidies for renewables (on the basis of the external costs avoided), as part of the EC's guidelines on state aid for environmental protection;

'In 1997 the Treasury published a Statement of Intent on **environmental taxation** which set out the role that the tax system can play in delivering environmental objectives. Well designed environmental taxes and other economic instruments can play an important role in ensuring that prices reflect environmental cost – in line with the "polluter pays" principle – and discouraging behaviour that damages the environment. The climate change and aggregates levies, for example, have sent strong environmental signals'.

'For both consumers and business alike, economic instruments such as tax can enable environmental goals to be achieved at the lowest cost and in the most efficient way. By internalising environmental costs into prices, they help to signal the structural economic changes needed to move to a more sustainable economy'.

'Since 1997 the Government has implemented a range of tax measures such as the climate change levy and the aggregates levy, made changes to existing taxes such as the landfill tax, and used fuel duty differentials to favour cleaner fuels and graduated vehicle excise duty (VED) to favour less polluting cars'.

'Judgements need to be made about how to balance uncertain environmental costs against the costs of taking action, and about how to offset the various constraints on policy options. Economic analysis offers a framework to help determine how best to reconcile these factors, taking account of the long time horizons which may be involved. Economic tools can be used to appraise the costs and benefits of actions, and to identify the most efficient methods of government intervention. The Government aims to use these techniques as effectively as possible to ensure that intervention is effective and efficient, and proportionate to the problem being addressed.'

Source: Tax and the Environment: Using Economic Instruments. HM Treasury. 2002.

2.1.4 Longer Term (Sustainability) Objectives

The SCC is also relevant for the consideration of longer-term sustainability objectives, either related to climate change policy or for other long-term policy goals. This involves the same techniques as for other policy appraisal, but with longer-time frames.

For these types of longer-term goals, cost-benefit analysis is rarely used, and in the context of climate change, the approach has been the subject of considerable debate[11]. Instead, policies tend to be set on the basis of scientific and political negotiations, and are driven by an underlying focus on scientific evidence, the precautionary principle (see box), and (sometimes) consideration of cost-effectiveness or economy-wide costs.

There are a number of ways the SCC values could be used in this context. This could be via cost-benefit analysis (CBA) as part of formalised policy appraisal. It could also be through the use of the SCC to provide additional information in some form of multi-criteria or other target setting discussion.

In the UK, extensive analytical work was undertaken to look at the costs and the implications of meeting the Government long-term goal before the commitment was made in the energy White Paper *(see box)*. In particular, the technological feasibility and the costs implications of reaching such a target were analysed through a major modelling exercise involving the calibration of the MARKAL model to the UK. The Energy White Paper also referred to the Government estimates of SCC, and observed that until 2020 most of the carbon savings required to put the country on a path towards the 60% reduction can be achieved at a cost that is lower than the estimated range for the SCC.

The Energy White Paper and the Government long-term (2050) Goal

The Energy White Paper, published in 2003, sets out the longer term framework for the UK's energy policy and accepted that the UK should put itself on a path to reducing carbon dioxide emissions by some 60% (from 1990 levels) by 2050. The Energy White Paper goes on to set out the first steps to achieving this goal and sets as a key objective of the UK's foreign policy securing international commitment to this ambition. This target follows the Royal Commission on Environmental Pollution's recommendation. 'A reduction in carbon dioxide emissions of 60% by 2050 is consistent with the level of reduction likely to be needed by developed countries in order to move towards stabilisation of carbon dioxide concentrations in the atmosphere at no more than 550 ppm, taking account of a realistic assessment of emissions growth in developing countries.' The 550 ppm value is set on the current scientific knowledge about human impact on climate, and that this is an upper limit that should not be exceeded, see *The scientific case for setting a long term emission reduction target*, available at http://www.defra.gov.uk/environment/climatechange/ewpscience/index.htm

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

Scientific evidence

'Decisions should be made on the basis of good scientific evidence. However, there are often limitations or uncertainties in the science. For example, the impacts of climate change may have very significant consequences for the environment in the longer term which are impossible to predict with any degree of certainty. As a result, the costs of not acting are not always clear, nor are the potential risks involved. The Government is working to understand the impacts of climate change more fully through a major research programme managed by Defra.'

'….there are some policy areas where target setting is not easily based on an objective assessment of the costs and benefits. For example, it may be difficult to establish the costs of action or the benefits of avoided environmental damage. If there is significant uncertainty then judgements will need to be made on the relative importance of the factors involved. In some instances targets will be set through a process of negotiation, such as for the climate change targets agreed under the Kyoto Protocol. In these cases the process of target setting will help to reveal the weight which society puts on the costs and benefits, but unless all those involved have a good understanding of these, there remains a danger that targets will be set at an inefficient level.'

The precautionary principle

'Where there are significant uncertainties surrounding the scientific case, policy decisions should take account of the precautionary principle. The Rio declaration defines the precautionary principle as: 'where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation'. This encompasses the concept that precautionary action may be justified to mitigate a perceived risk or uncertainty, even if the probability of environmental damage is low, but where if it did happen the outcome would be very adverse.'

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

2.2 Existing examples of the Use of the SCC in UK Government

As part of the review, and stakeholder interviews, a list was made of the existing policy applications of the SCC across UK Departments and Agencies. Some of these were discussed above. The full list we have found is provided below.

Table 1. Applications of the SCC across UK Government and Agencies.

Organisation	Application	Notes
Defra	F Gas Regulatory Impact Assessment	Use of £35 - £140/tC. Number makes large difference to RIA of specific options
	Cost-benefit analysis of UK ETS	
	Used in consideration of waste tax charges as part of the review and consultation	Use of £35 - £140/tC.
DfT	Preliminary use in New Approach to Appraisal for Road Transport infrastructure appraisal	Use of £35 - £140/tC. The SCC is very low in relation to other cost or benefit streams in the appraisal results
	Incorporation into National Transport Model/Social Pricing Model	Use of £35 - £140/tC, with central £70/tC.
	Used in Aviation White Paper, for possible aviation tax	Use of £70/tC, rising by £1/tC by year to give £100/tC for 2030
	Considered in analysis on road user charging and consultation paper	
DTI	Energy White Paper	Use of £70/tC as a benchmark for costs of options to 2020
	Use in current RIA for Renewables Obligation II	
ODPM	Social cost of carbon is factored into ODPM proposals for amendment to Part L (energy efficiency provisions) of the Building Regulations.	Use of 0, £70 and £140/tC
Ofgem	Energy investment, notably gas network extension, some consideration of electricity transmission infrastructure (e.g. distribution losses under the distribution price control)	Use of 0 - £35/tC
EA	Asset Management Programme 4 (AMP4)	

Defra = Department for Environment, Food and Rural Affairs.
DfT = Department for Transport
DTI = Department for Trade and Industry.
Ofgem = Office of Gas and Electricity Markets.
OPDM = Office of the Deputy Prime Minister.
EA = Environment Agency.

Whilst there has been widespread use of the value, we have found that the application approach has varied. For example, some of the analysis has used the central illustrative value of £70/tC, whereas some has used the full range £35 to £140/tC. Moreover, there are examples where a single value at the upper or lower end of the range has been used. During the interviews, the reason for the variations in application was investigated: in some cases this was due to view that the analyst held on the robustness of the SCC (leading to the use of the low value).

The study has also found that the SCC values have not always been applied. We have found a number of relevant policy appraisals or policy areas across Government organisations (including the organisations listed above) where the SCC was not used at all, even though the policies involved changes in greenhouse gas emissions. This issue was also highlighted in the stakeholder consultation (see later section) and raises a broader issue of consistency in policy applications in relation to the use of the SCC.

2.3 Use of the SCC in other Countries

The study has also reviewed the use of SCC values, or alternatives, in policy applications in other countries and organisations. The examples found are:

- Previous use by the European Commission and the European Investment Bank of the original ExternE value of Euro 70 - 170/tC (1995) for project or policy cost-benefit. This is approximately £60/tC to £145/tC (2000). Note both organisations have now moved away from this value.
- Previous use by the World Bank of $20/tC with a range of $5/tC and $40/tC for optional project appraisal of energy projects. This is approximately £14/tC, with a range of £4/tC to £28/tC.
- Use by the Netherlands government of the 2001 ExternE value of Euro 8.8/tC. This is approximately £6/tC.
- Use of switching values in the European Investment Bank, particularly for energy appraisal, using values of 5 Euro and 125 Euro/tC. This is approximately £4/tC to £87/tC. These values were based on a review of the SCC values in the literature, and an informal poll of experts. The low value was based on market-based damages only. The high value also included longer-term impacts[12].

We have found no specific use of SCC values in setting carbon taxes or economic instrument design in other countries (at least that have been explicitly stated in national communications or other published material). This is perhaps surprising given number of carbon taxes in Europe, and the level of taxes in some areas such as Scandinavia. What is also interesting is that very few countries set equal or consistent charges on the basis of emitted carbon, and many taxes (per tonne of CO_2 emitted) vary between fuels even within the same country, including the UK.

We have also reviewed the discussion of uncertainty in cases where the SCC is used. Beyond a simple analysis with a low and high value, and the switching values used in the EIB application above, there are almost no practical examples of uncertainty being considered in policy applications. Therefore the UK appears unique in widespread use of a SCC value in appraisal.

Instead, we have found a general pattern is to use marginal abatement costs in project and policy appraisal. This is because:

- Firstly, at the project level, many analysts are using predicted estimates of permit prices, due to the forthcoming introduction of the European Union Emission Trading Scheme (although this is not necessarily consistent with achieving any long term goal);
- Secondly, climate change policy setting is considering longer-term CO_2 stabilisation targets, or maximum temperature changes. These are being set on the basis of a precautionary principle, and are focused on the analysis of the cost-effectiveness of achieving certain CO_2 concentration levels, and the implied emission reduction targets.

The EC appeared to have dropped the SCC approach it was using in environmental policy cost-benefit analysis, and switched to the use of marginal abatement cost values in many policy assessments. It assumes that any CO_2 reductions that arise (as a co-benefit) from policies are valued using the costs of greenhouse gas reduction policies (climate change policies). These have been calculated at €12/tCO_2 in 2010, €16/tCO_2 in 2015 and €20/tCO_2 in 2020. This is approximately £30/tC in 2010, £40/tC in 2015, and £50/tC in 2020. These costs are from the report of the European Climate Change Programme (ECCP, 2001). The report identified 42 possible measures, which could lead to some 664-765 MtCO_2 equivalent emissions reductions that could be achieved against a cost lower than 20€/tonne CO_2eq (~£50/tC). This is about double the emissions reduction required for the EU in the first commitment period of the Kyoto Protocol with respect to 1990. These values were used to provide

[12] The low value was consistent with the current traded price for carbon (at the time of the study) – the high value with marginal abatement costs for longer-term GHG reductions.

approximate costs for future policy (i.e. post the first commitment period under the Kyoto Protocol (KP)) for a 2020 scenario, and the likely costs for 2010 of meeting current commitments under the KP.

However, there has been some recent re-consideration of SCC values. This may well be linked to the forthcoming discussion in 2005 of post-1st commitment period Kyoto Protocol policies. For example, the European Parliament recently asked the European Commission to consider the costs and benefits of post-1st commitment period KP policies, and also to investigate these in light of long-term stabilisation targets. This follows earlier policy statements by the Council (see box below). Such analysis explicitly considers the social costs of carbon, though it is clear that any stabilisation target will not be set on the basis of a calculated economic optimum (i.e. the analysis of costs and benefits will not be used explicitly to set the optimal stabilisation target).

The Costs and Benefits of EU Post 1st Commitment Period Kyoto Policy

A key priority of the EU is contributing to global climate stabilisation efforts beyond 2012. As part of this priority, the EU needs to identify an emission reduction target up to 2030 and indicative targets beyond. The Council has made a statement on the likely indicative long-term targets:

'*Council believes that global average temperatures should not exceed 2 degrees above pre-industrial level and therefore concentrations lower than 550 ppm CO_2 should guide global limitation and reduction effort*'. 1996.

'*Council…acknowledges that to meet the ultimate objective of the UNFCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2˚C above pre-industrial levels'*. Spring Council meeting of 2004

Different emission reduction strategies and/or different post-Kyoto targets are being evaluated in order to prepare for:

- The Commission Report to the Spring Council 2005;
- Negotiations on future commitments at international level.

In order to balance the climate policy debate, the Commission requires the benefits of climate change mitigation policies to be evaluated. It has recognised that monetised avoided impact benefits, estimated globally, but with a focus also on the European scale, will enable fully informed policy making.

The Commission has recently published its findings in relation to the costs and benefits of climate change mitigation in a recent communication (European Commission (2005).[13]

[13] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions 'Winning the Battle Against Climate Change (SEC(2005)180. Published at *http://europa.eu.int/comm/environment/climat/pdf/staff_work_paper_sec_2005_180_3.pdf*

3 The Social Cost of Carbon

The parallel SCC study on modelling of the social cost of carbon has progressed the analysis of the values. However, there are a number of key issues that affect the SCC value, all of which have a strong policy dimension and are discussed below.

The IPCC Third Assessment Report (IPCC, 2001) outlines the potential effects of climate change. It presents an increasing body of observations that give the picture of a warming world and changes in global and regional climate systems. Taking 1990 as the baseline, models assessed in the Third Assessment Report (TAR) of the IPCC project the following key climate change impacts by 2100[14].

- Global average temperature is predicted to rises by 1.4 to 5.8°C over the period to 2100 (temperatures rose by +0.6 °C in the 20th Century);
- Global precipitation increases, but with regional increases and decreases of typically 5 to 20% in annual average rainfall;
- Sea levels rise by 0.09 to 0.88 m;
- Extreme events such as drought and severe storms are more likely;
- Beyond 2100 major changes in the climate system (e.g. alteration of ocean currents especially North Atlantic Circulation, collapse of West Antarctic Ice Sheet, release of methane hydrates) become more likely if climate change is not stabilised.

Evidence since the TAR suggests that the climate sensitivity may need revising upward and in many cases the risks appear more serious than previously. Ocean acidification is now recognised as a major impact[15].

All of the above changes will lead to major impacts on biodiversity and ecosystem services, on economic activities, on human health and welfare (including the loss of life and forced migration) with associated implications for international equity.

With the upper range of IPCC projections of climate change, the impacts are likely to adversely affect achievement of the Millennium Development Goals (as agreed at the World Summit of Sustainable Development (WSSD) at Johannesburg). With the low projections of climate change, impacts will be more mixed in terms of positive and negative effects.

Impact studies begin with an inventory of the effects on multiple criteria - typically lives lost, the burden of disease on humans, species lost and economic impacts. Negotiating global climate change targets has tended to recognise such multiple effects, in effect corresponding to an informal multi-criteria approach. Multi-Criteria Analysis (MCA[16]) has been recommended - for instance in the development of National Adaptation Programmes of Action (NAPA). Nevertheless, a common metric is desirable, if possible, for consistency in a wider range of project level analyses and policy appraisal. The most common metric is money. A monetary metric is particularly well suited to measure market impacts. For example: the costs of sea level rise could be expressed as the capital cost of protection and the economic value of land and structures lost in the absence of protection; agricultural impact can be expressed as costs or benefits to producers and consumers; and changes in water runoff might be expressed in new flood damage estimates. Using a monetary metric to express non-market impacts, such as effects on ecosystems or human health, is more difficult, though it is sometimes possible. There is a broad and established literature on valuation theory and its application, including studies on the monetary value of lower mortality risk, ecosystems, quality of life, etc. However, economic

[14] The IPCC Third Assessment Report (IPCC, 2001). Climate Change 2001: Synthesis Report. Summary for Policymakers.

[15] See for example the Report of the Steering Committee, International Symposium on the Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, UK, 3-5 Feb 2005

[16] Multi-criteria analysis (MCA) is a structured approach used to determine overall preferences among alternative options, where options accomplish several objectives.

valuation, especially in the area of climate change, is often controversial, because of ecosystem and socially contingent effects[17], the potential magnitude of some of the impacts, non-linearities and irreversibility of impacts, and because of issues with intergenerational and international equity. There is also an incomplete understanding of climate change itself.

The box summarises the areas of key impacts, and the coverage of the valuation models for each:

The Social Costs of Climate Change: Key Areas of Assessment in the Literature and the Models

Sea level rise leads to costs of additional protection, or otherwise loss of dry land and wetland loss. The balance will depend upon future decisions about what protection is justified. Costs of protection are relatively well known and included in nearly all models, but other costs (rising sea levels increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands) are more uncertain and often excluded (or only partially captured in terms of valuation). Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges. This raises the issue of migration (e.g. for those living on small island states), the costs of which depend on diverse social and political factors (so called socially contingent effects) but these are not captured in the current valuation models.

Energy use impacts will depend on average temperatures and range, but there will be a combination of increases and decreases in demand for heating (both in terms of overall energy supplied, and to meet peak demands). Benefits from increased winter temperatures that reduce heating needs may be offset by increases in demand for summer air conditioning, as average summer temperatures increase. The models capture these effects, although the reference scenario is difficult to project.

Agricultural impacts depend upon regional changes in temperature and rainfall, as well as atmospheric carbon dioxide levels (and fertilisation). The key impacts will be to crops and changes in the cultivated area and yields. These effects depend on many factors and in some areas, the area suitable for cultivation and potential yields will increase. Climate variability, as well as mean climate change, is an important consideration. Adaptive responses will be important - choice of crop, development of new cultivars and other technical changes, especially irrigation (see also water supply below). Most valuation studies capture the direct impacts, but it is important to note these do not fully determine damages - these will also depend on changes in demand and trade patterns driven by socio-economic factors – but also complex responses to climate variability, pests and diseases, etc.

Water supply impacts depend on changes in rates of precipitation and evapo-transpiration and demand changes – including those driven by climate change. The water demand of biological systems is affected by various climatic factors, including temperature and humidity. Water supply systems are usually optimised to meet (currently) extreme supply/demand conditions and the costs of shortage can be very high. Climatic variability is therefore important in determining damages. Climate change will exacerbate water shortages in many water-scarce areas of the world. There is the potential for water scarcity and severe socially contingent damages, which are not quantified at present. Water supply is included in some models, though coverage is often partial.

Health impacts include both an increase in (summer) heat stress and a reduction in (winter) cold stress, though as these are in opposite directions the net mortality impact (global) of direct temperature changes may be quite small. Direct health impacts from temperature changes are included and valued in many studies. The area amenable to parasitic and vector borne diseases, such as malaria, will expand and impacts could be large. The inclusion of disease burdens has been advanced through specific studies, and some models include partial coverage of such effects. Socially contingent damages to health (via other impacts such as food production, water resources and sea level rise) in vulnerable communities are difficult to estimate but could be very large, and these are not included in any of the valuation modelling frameworks. Overall, climate change is projected to increase threats to human health, particularly in lower income populations, predominantly within tropical/subtropical countries.

[17] We use the classification of socially contingent damages to describe those large scale dynamics related to human values and equity that are poorly represented in damage estimates based on marginal cost values, e.g. regional conflict, poverty.

Ecosystems and biodiversity impacts are amongst the most complex and difficult to evaluate. Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species. Most of the major ecosystem types are likely to be affected, at least in parts of their range. Some isolated systems are particularly at risk, including unique and valuable systems (e.g. coral reefs). Recent evidence has also identified acidification of the oceans, which is an observable consequence of rising CO_2 levels in the atmosphere, with potentially large impacts on marine ecosystems and fluxes of greenhouse gases between the ocean and the atmosphere. The analysis of ecosystems effects is one of the most problematic areas, in terms of a comprehensive or reliable assessment of the impacts of climate change on ecosystems, and on valuations of ecosystems. Most studies do not capture ecosystems effects fully – with valuations relying on *ad hoc* estimates of species loss and contentious valuation studies. The value of ecosystem function may also be important, but has received even less attention, and is not included in valuation modelling.

Extreme weather events are also likely to increase, with heat waves, drought, floods, and potentially storms, tropical cyclones and even super-typhoons. However, the frequency and severity of extreme events may not be linearly dependent on average climate. Climate variability will also be important and there is no consensus on how this will change. Impacts and damages will also depend on the location and timing of the hazard and adaptive responses. For example, cyclone damage to property will tend to rise with wealth, but mortality effects may fall considerably. Extreme events are excluded from all but a few studies in relation to valuation.

Major Events, i.e. the risk of major effects - potentially catastrophic effects or major climate discontinuities are the most uncertain category. They include (Schellnhuber, 2004: Pachuari 2005) such potential events as loss of the West Antarctic ice sheet; loss of the Greenland ice sheet; methane outbursts (including runaway methane hydrates); instability or collapse of the Amazon Forest; changes in the thermo-haline circulation (loss or reversal of the gulf stream, changes in Atlantic deep water formation, changes in southern ocean upwelling/circumpolar deep water formation); Indian monsoon transformation; Change in stability of Saharan vegetation; Tibetan albedo change; ENSO triggering; reduced carbon sink capacity, and other events. Many have previously been thought to be longer-term events (i.e. that would occur at temperature changes >2˚C), though recent evidence (presented at The International Symposium on the Stabilisation of Greenhouse Gases, held in February – Stabilisation 2005) indicates that in many cases the risks from major climate change impacts are greater than originally thought at the time of the Third Assessment Report 2001, and may actually occur at lower temperature thresholds. Major events are not captured in the models.

The existing SCC range of £35 to $140/C (with an illustrative central value of £70/t/C) is based on models that set out to assess and value the above categories, though many only cover a relatively small subset of impacts, see below. More details of the modelling approaches, and the detailed issues on quantification and valuation are being considered in the parallel modelling project. This paper concentrates on the use of the values from these studies, and on the key issues in a policy context.

3.1.1 The IPCC view

Overall, the IPCC (2001) concluded that ‘Projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger the changes and rate of change in climate, the more the adverse effects predominate’. Essentially, the severity of the adverse impacts will be larger for greater cumulative emissions of greenhouse gases and associated changes in climate.

The IPCC also states ‘overall, the aggregated market sector effects, measured as changes in gross domestic product (GDP), are estimated to be negative for many developing countries for all magnitudes of global mean temperature increases studied, and are estimated to be mixed for developed countries for up to a few °C warming and negative for warming beyond a few degrees. The estimates generally exclude the effects of changes in climate variability and extremes, do not account for the effects of different rates of climate change, only partially account for impacts on goods and services that are not traded in markets, and treat gains for some as canceling out losses for others.’

The IPCC's next Assessment Report, due to be published in 2007, will contain a much more extensive assessment of physical impacts. Meanwhile it seems that, since the TAR was published the likelihood of greater climate sensitivity, and the likelihood of associated negative impacts (including non-linear shifts in the climate system and previously unforeseen or underemphasized effects such as ocean acidification) have increased.

3.2 Review of the Valuation Literature

The study has reviewed the literature estimates of the social cost of carbon. Full details are presented in the parallel modelling study (Downing *et al*, 2005). In summary, marginal social cost values from 28 studies in the literature[18] (including peer reviewed studies and the grey literature) were reviewed, which provide 103 estimates (when the best estimate and range is taken into account). The analysis has combined the studies to form a probability density function. The review has shown that uncertainty is strongly right-skewed. If all studies are combined, the mode is \$2/tC (£1/tC in year 2000 values), the median \$14/tC (£12/tC), the mean \$93/tC (£80/tC), and the 95 percentile \$350/tC (£300/tC)[19]. For this review, we consider the mean is the appropriate estimator of central tendency; given the right-skewed distribution the mode and the median will both be biased towards low valuations, and neither should be regarded as representative. Using the weights favoured by authors, the mean is \$129/tC (£111/tC) and the 95 percentile \$635/tC (£547/tC). The explanation of this increase is that some studies (Azar and Sterner, 1996; Tol, 1999) deliberately reproduce the low estimates of Nordhaus (1994) and then argue that his assumptions are biased downwards. Excluding the studies that were not reviewed, the mean is \$50/tC (£43/tC). The highest estimates are in the grey literature.

Table 2. The probability characteristics of the marginal costs of carbon dioxide emissions

\$/tC (\$1995)	Mode	Mean	5%	10%	Median	90%	95%
Base	1.5	93	-10	-2	14	165	350
Author-weights	1.5	129	-11	-2	16	220	635
Peer-reviewed only	5.0	50	-9	-2	14	125	245
No equity weights	1.5	90	-8	-2	10	119	300
Equity weights	-0.5	101	-20	-2	54	250	395
PRTP=3% only	1.5	16	-6	-2	7	35	62
PRTP=1% only	4.7	51	-14	-2	33	125	165
PRTP≤ 0% only	6.9	261	-24	-2	39	755	1610

£/tC (£2000)	Mode	Mean	5%	10%	Median	90%	95%
Base	1.3	80.2	-8.6	-1.7	12.1	142.3	301.9
Author-weights	1.3	111.3	-9.5	-1.7	13.8	189.8	547.8
Peer-reviewed only	4.3	43.1	-7.8	-1.7	12.1	107.8	211.4
No equity weights	1.3	77.6	-6.9	-1.7	8.6	102.7	258.8
Equity weights	-0.4	87.1	-17.3	-1.7	46.6	215.7	340.8
PRTP=3% only	1.3	13.8	-5.2	-1.7	6.0	30.2	53.5
PRTP=1% only	4.1	44.0	-12.1	-1.7	28.5	107.8	142.3
PRTP≤ 0% only	6.0	225.2	-20.7	-1.7	33.6	651.3	1388.9

Source: Tol (2004). The values are in \$1995 and £2000.

[18] This work was undertaken by Richard Tol, and updated his meta-analysis of published studies. It has been published in Energy Policy, The Marginal Damage Costs Of Carbon Dioxide Emissions: An Assessment Of The Uncertainties. *Richard S.J. Tol. April 2004* Energy Policy 33 (2005) 2064–2074.

[19] The conversion of the estimates cited in the literature review to GBP is based on \$1.42 = £1.00, and we have inflated the 1995 results to USD2000 by using the average U.K. Retail Price Index over the period from 1995 to 2000, an increase of 22.5%. This is consistent with later modelling analysis.

Studies with a lower discount rate have higher estimates and much greater range. Similarly, studies that use equity weighting have higher estimates and a larger range. Studies that are peer-reviewed have lower estimates and smaller uncertainty ranges. The author (Richard Tol) also expresses his personal view on the values in the conclusions of the paper: 'using standard assumptions about discounting and aggregation, the marginal damage costs of carbon dioxide emissions are unlikely to exceed \$50/tC (approximately £43/tC in 2000 values), and probably much smaller'.

The trend in the data is towards lower values over time, as shown in the figure above. The reason for the drop in the estimated values over the past decade is because of more recent climate scenarios, consideration of explicit socio-economic reference scenarios (generally of wealthier futures), inclusion of benefits as well as impacts, and notably due to autonomous adaptation (which allows economic costs to be off-set in anticipation of climate change). It should be noted that such trends may change in future analysis. Two emerging findings are that climate sensitivity and likelihood of severe impacts increases at lower temperature thresholds maybe higher than previously expected[20].

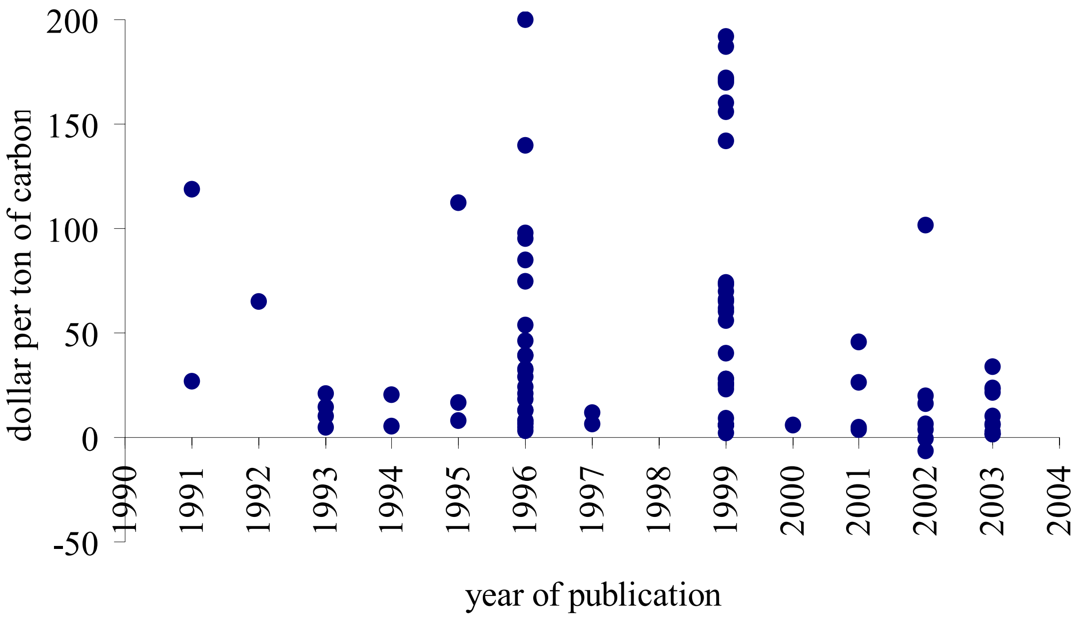


Figure 1. Estimates of the Social Cost of Carbon

Source: Tol (2004). Note, one study from the early 1990s is excluded which has very high values (1800\$/tC)

The review shows that some literature values are lower than the current GES illustrative value of £70/tC[21]. It also indicates that that there is a significantly greater range around the central value, than the current GES range of £35 to £140/tC. However, while the literature (and especially more recent studies) indicates lower central values, there are a number of important caveats to take into account. Most importantly, the studies do not cover all of the potential impact categories set out in the box above, and most researchers (and indeed the IPCC) consider the possibility of adverse surprises are more likely than beneficial ones. We have therefore assessed the coverage of the valuation studies to investigate the extent to which they may under-estimate the total SCC.

[20] See the Report of the Steering Committee from the International Symposium on the Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, Exeter UK, Feb 2005.

[21] Indeed, some literature values are lower than the marginal abatement costs for post-Kyoto scenarios, i.e. below the estimated marginal abatement costs of Euro 20/tCO_2 (approximately £50/tC) and some below the estimated marginal abatement cost to Europe of meeting Kyoto, i.e. below Euro 12/tCO_2 (approximately £30/tC). See earlier section for the discussion of these MAC estimates.

3.2.1 SCC Values: Coverage of the Studies

SCC studies include estimates for different categories of impacts from climate change – some are only focused on market damages in areas where we are more certain of effects - whilst others include analysis of wider social, environmental, and economic effects. It is important to take account of these differences in reviewing the SCC values.

We have reviewed the studies against a risk matrix presented at the International Social Cost of Carbon Seminar (Downing and Watkiss, 2003)[22]. This matrix separates climate change impacts, and valuation of those impacts, into nine individual categories, described below:

Categories of impacts

The IPCC TAR shows three main categories of climate change, with different confidence levels, which are:

- ***Projections***. For example, with respect to (relatively) predictable trends such as sea level rise or average global temperature rises.
- ***Bounded risks***. Other elements are less clear, but fall within a range that can be assigned approximate probabilities, for example, the change in the probability of summer drought.
- ***System change and surprises***. For example, the impacts related to large scale dynamics and regional feedbacks that are currently beyond our ability to predict with much confidence, such as alterations of North Atlantic Circulation, collapse of the West Antarctic Ice Sheet, release of methane hydrates, reversal of the terrestrial carbon sink, etc.

Valuation of impacts

There is a similar range of confidence in our ability to provide robust estimates of economic damages. The categories can be split into:

- ***Market damages,*** where we have relatively high confidence, for example with respect to traded goods such as for agriculture;
- ***Non-market damage,*** *which is further split into*
    - ***Non-market goods where valuation is undertaken***, for example with valuation of health or ecosystems; and
    - ***Socially contingent effects***, such as regional conflict or poverty, where we are trying to capture large-scale dynamics related to human values and equity that are poorly represented in valuation estimates.

The risk-based approach combines both of the above aspects, i.e. the nature of uncertainty in climate change with the elements of economic valuation. Such a risk matrix shown provides some structure to the search for more robust estimates of the costs of climate change, and helps inform what is covered in the current economic values, and what is not. It provides a holistic approach for addressing categories not covered by integrated assessment models and not likely to be covered in the foreseeable future.

[22] Downing, T., and Watkiss, P. (2003). The Marginal Social Costs of Carbon in Policy Making: Applications, Uncertainty and a Possible Risk Based Approach. Paper presented at the DEFRA International Seminar on the Social Costs of Carbon.

Uncertainty in Predicting Climate Change	Uncertainty in Valuation		
	Market	**Non Market**	**(Socially Contingent)**
Projection (e,g, sea level Rise)	Coastal protection Loss of dryland Energy (heating/cooling)	Heat stress Loss of wetland	Regional costs Investment
Bounded Risks (e.g. droughts, floods, storms)	Agriculture Water Variability (drought, flood, storms)	Ecosystem change Biodiversity Loss of life Secondary social effects	Comparative advantage & market structures
System change & surprises (e.g. major events)	Above, plus Significant loss of land and resources Non- marginal effects	Higher order social effects Regional collapse Irreversible losses	Regional collapse

Figure 2. The SCC Risk Matrix (Source: Downing and Watkiss, 2003)

We stress that the risk matrix des not fully capture all dimensions of the SCC. It is clear that there will be different time dimensions associated with the different categories of impacts – to illustrate system change and surprises at the bottom are likely to be longer-term effects. There is also no evidence on the relative importance or probability of the various grid cells. For simplicity, all nine boxes above have been drawn of equal size – we simply do not know how important relative categories of impacts (or even benefits) will be in reality, nor the probability of the occurrence of different impacts. Nonetheless, the matrix provides a useful tool to start to interrogate the coverage of the literature estimates.

The 28 studies identified in the literature review have been mapped against the matrix, and the coverage is shown below. Very few studies extend beyond the top left hand corner of the matrix and none even has a full coverage of the four boxes that represent market and non-market impacts for the projected and bounded risks of climate change. There are only limited studies that have considered any socially contingent effects, or the potential for longer-term effects.

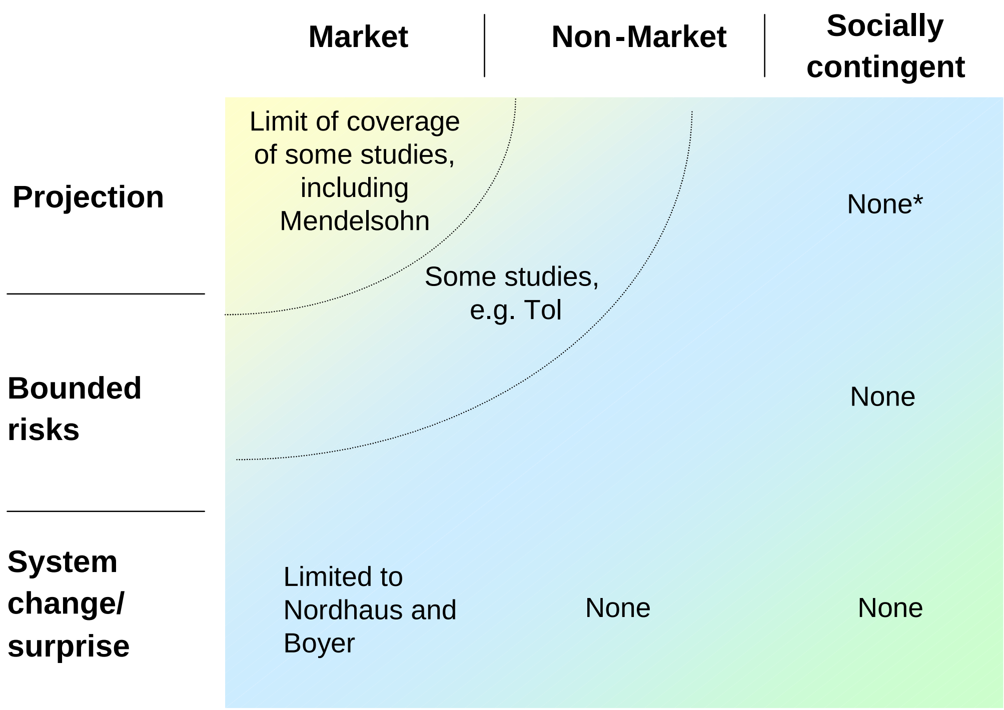


Figure 3. Coverage of Existing Studies Against the Matrix

* Some sectoral and/or regional studies exist for socially contingent effects for 'projections' (and limited analysis of 'bounded risk'), but they are limited to impacts, and do not extend to economic costs.

This shows that the uncertainty in the SCC value concerns not only the true value of impacts covered by the models, but also the uncertainty from impacts that cannot yet be quantified and valued. This implies of course that the values in the literature are almost certainly a sub-total of the full SCC – though as outlined above, we do not know by how much (because the probability and consequences of much of the matrix is not known).

3.3 The Influence of Key Parameters on the SCC

Much of the variation in SCC estimates (for the sub-totals assessed so far, i.e. in addition to the variation in the coverage of impacts in the matrix) arise from a few key parameters in the choice of decision perspectives, most importantly:

- Discount rate used;
- Approach to weighting impacts in different regions (equity weighting);
- Study time-horizon;

There are also a number of other policy relevant aspects that emerge in wider discussions on the SCC:

- Data reporting
- Strong or weak sustainability approach;
- Marginal effects;
- Ancillary benefits.

These parameters and issues are discussed below.

3.3.1 Discount Rate

The impacts of climate change take place in the future, and so the discount rate used is of major importance. The discount rate[23] used determines the present valuation of future impacts and can have a very large impact on the social cost of carbon. The £70/tC illustrative value is based on studies that use a 3% discount rate[24]. These same studies also include SCC value based on a 1% discount rate. The difference between these two discount rates has a dramatic impact on the SCC value, for example, using the original modelling results that the GES value is based on, switching from the current 3% discount rate to 1% increases the illustrative, central value from £70/tC to £170/tC.

Social rate of time preference (SRTP) / Pure Rate of Time Preference (PRTP)

Social Time Preference is defined as the value society attaches to present, as opposed to future, consumption. The Social Rate of Time Preference (SRTP) is a rate used for discounting future benefits and costs, and is based on comparisons of utility across different points in time or different generations. The Green Book guidance recommends that the SRTP be used as the standard real discount rate.

The STPR has two main elements:

- The rate at which individuals discount future consumption over present consumption, on the assumption of an unchanging level of consumption per capita over time. This is the so-called ‘pure rate of time preference’ (PRTP). The Green Book suggests a PRTP value of around 1.5 per cent a year for the near future.
- An additional element, if per capita consumption is expected to grow over time, reflecting the fact that these circumstances imply future consumption will be plentiful relative to the current position and thus have lower marginal utility. This effect is represented by the product of the annual growth in per capita consumption (g) and the elasticity of marginal utility of consumption (μ) with respect to utility. The Green Book indicates the annual rate of g is 2 per cent per year, and the elasticity of the marginal utility of consumption (μ) is around 1.

SRTP is the sum of these two components

$$SRTP = PRTP + \mu * g$$

With a pure time preference rate of 1.5%, and values of 2% of g and 1 for μ, the resulting recommended discount rate is 3.5%. The declining rates are shown in Table 3.

Source: *Green Book. HM Treasury.*

The Green Book recommends a discount rate of 3.5% for projects up to 30 years (see box), with a declining schedule thereafter. The main rationale for declining long-term discount rates results from uncertainty about the future.

Table 3. Green book Declining Discount Rates.

Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Source: *Green Book. HM Treasury.*

The Green book does highlight some exceptions to the use of the above discount rate schedules. Firstly, for international development assistance projects, and secondly when undertaking sensitivity analysis (when the precise value of the discount rate can be analysed in the same way as for other

[23] ‘*Discounting is a technique used to compare costs and benefits that occur in different time periods. It is a separate concept from inflation, and is based on the principle that, generally, people prefer to receive goods and services now rather than later….. **The discount rate is used to convert all costs and benefits to ‘present values’, so that they can be compared.***’. Treasury Green Book.

[24] The discount rate here refers to the use of the social time preference rate (STPR).

parameters in the appraisal – though the rationale for undertaking sensitivity analysis on discount rate should be clearly explained).

Most impact assessment modelling studies present results in terms of the pure rate of time preference (PRTP), as this is the fundamental parameter. The social rate of time preference is given by the pure rate of time preference plus the per capita GDP growth rate multiplied by the negative of the elasticity of utility with respect to consumption, which is a parameter used to determine the equity weights. This also allows the use of different growth rates in different regions, an important aspect for non-OECD analysis. When studies use a PRTP of 0%, they are still discounting but only to account for the extra wealth that future generations will enjoy.

The figure below presents the summary values from FUND[25], one of the climate change valuation models, with a sensitivity analysis looking at different PRTP rates. There is no consideration of socially contingent effects or surprises in the model, and in these numbers no equity weighting. The figure is simply a sensitivity analysis and carries no implication about SCC values that should be used in practice.

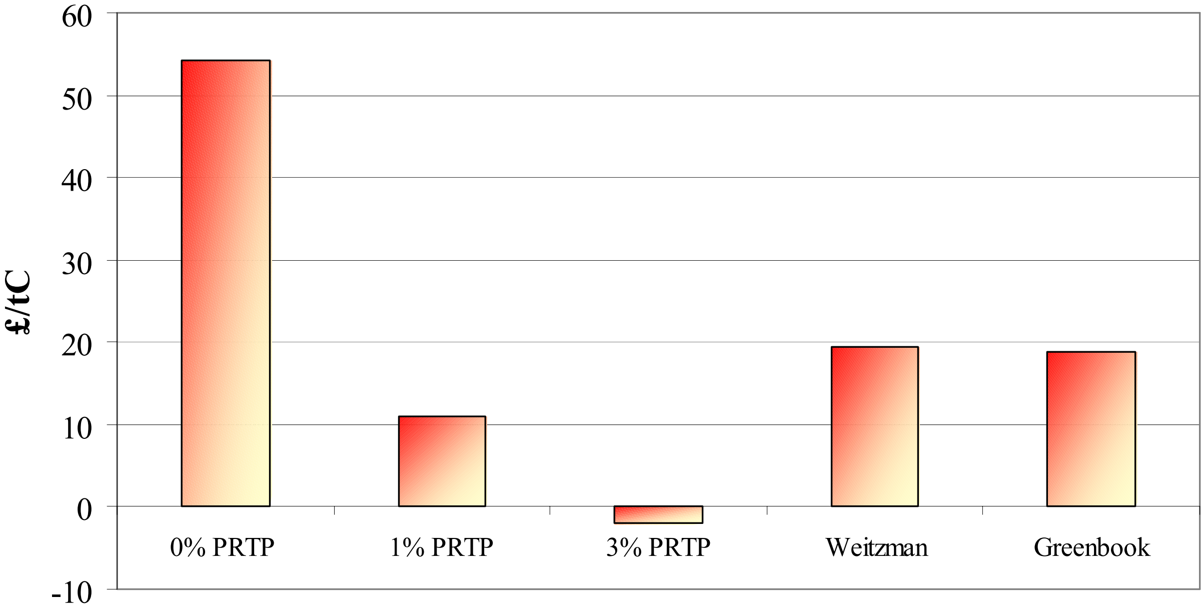


Figure 4. Modelled SCC Values with Different Pure Rate of Time Preference (no equity weighting)

Source: FUND. Version 2.8. Model 'Best Guess'[26]
Time horizon 2300. There is no equity adjustment, it is assumed that costs and benefits can be traded off, coverage of market and non-market impacts is partial, and socially contingent effects and climate system major events are excluded

The figure shows very large variation in the SCC arises from this PRTP parameter alone (all other aspects of the model being constant).With a higher PRTP rate, the aggregate SCC values can be positive. The reason why this switch occurs with the PRTP rate can be shown with the pattern of the SCC over time from FUND – shown below at 0% pure rate of time preference. It can be seen that in the short-term, to 2040, the model finds there are net benefits at an aggregate level. The use of a

[25] The GES illustrative value of £70/tC was based on values from the EC's ExternE project, which used two models -FUND and the Open Framework model. These models were considered (in the review) as '*the most sophisticated of the published studies reviewed'*.
[26] This is the model author's 'best guess' for all parameters. The best guess for climate sensitivity is 2.5 degrees Celsius equilibrium warming for a doubling of the atmospheric concentration of CO_2. Recent evidence suggests that the probability of higher climate sensitivity may have increased – see Report of the Steering Committee, International Symposium on Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, 2-5 Feb 2005.

higher discount rate therefore puts greater importance to these short-term effects, relative to the economic dis-benefits in later years. The results refer only to the subset of impacts quantified (including the omission of socially contingent and major events). They do not include any equity weighting, and the model assumes full trade-offs between categories and regions[28], although the coverage of impacts is by no means complete.

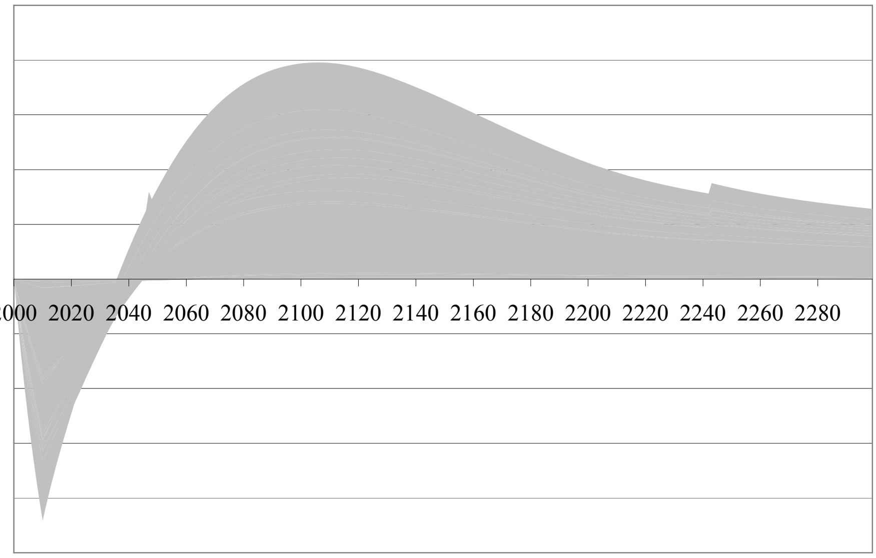


Figure 5. Modelled SCC Profile over Time (0% PRTP)

Source: FUND. Version 2.4.
Time horizon 2300. There is no equity adjustment, it is assumed that costs and benefits can be traded off, coverage of market and non-market impacts is partial, and socially contingent effects and climate system major events are excluded

3.3.2 Distributional Effects (Equity Weighting)

Many models show that at small to moderate climate change, poorer countries (Africa, India, and Latin America) are net economic losers, whereas richer countries, especially mid – northern latitudes, show smaller losses or may gain from moderate warming, at least in the short-term. The IPCC (in it's summary for policy makers) recognises that 'the impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, and other resources.'

The disproportionate impacts of climate change on developing countries occurs because:

- These countries are exposed to significant climatic threats;
- Their economies rely more heavily on climate-sensitive activities;
- They are close to environmental tolerance limits; and they are poorly prepared to adapt to climate change.

In contrast, richer societies tend to be better able to adapt, their economies are less dependent on climatic resources, and climatic hazards are less disruptive to economic growth.

There are issues in applying CBA for climate change, where impacts are spread across countries with very different income levels. An aggregate estimate of the SCC inevitably implies combining benefits and dis-benefits across winners and losers.

There are different ways of aggregating economic effects in different countries or regions, and this influences the global values. This has been a major source of contention in the climate change

[28] This is consistent with the general assumptions in cost-benefit analysis. A different perspective, i.e. one based on strong sustainability, would not consider this assumption valid.

valuation discussion. For example, studies which have adjusted willingness to pay (WTP) estimates for income differentials across regions using local values have led to major debate[29]. As a result, there has been a shift towards the aggregation of monetised impacts using so-called equity weights (distributional weights).

The equity weighting scheme adopted makes a very large difference to the overall SCC, for example, the approach used on how to aggregate between the winners (e.g., agriculture in Finland) and the losers (e.g. sea-level rise in the Maldives or Bangladesh) can alter the SCC by almost an order of magnitude (i.e. by ten times).

Essentially, the more weight we put on the distribution of the impacts from climate change, the more severe the aggregate impacts are estimated to be[30]. As a result, the global picture depends on how we aggregate. If we count in numbers of pounds, under some types of aggregation scheme the world as a whole may appear to lose a little. If we count in terms of numbers of people and associated physical damages, the losses become apparent.

The figure below presents the summary values from FUND, with a sensitivity analysis with and without equity weighting at different PRTP rates. Note there is no consideration of socially contingent effects or surprises in the model, and we stress that the figure is simply a sensitivity analysis and carries no implication about SCC values that should be used in practice.

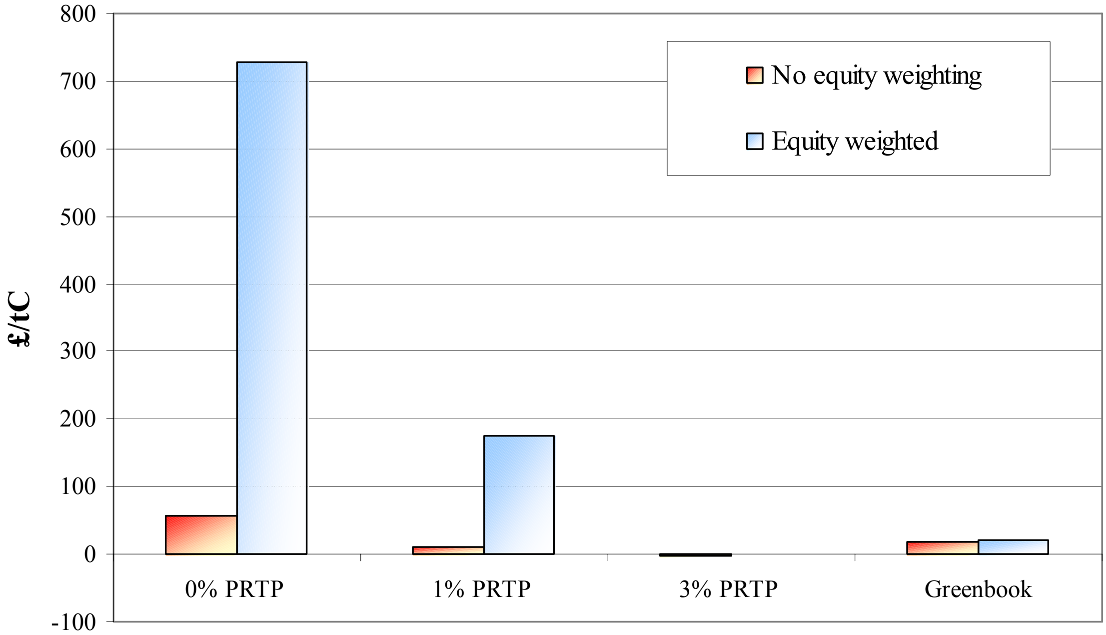


Figure 6. Modelled SCC Values with Different Pure Rate of Time Preference and Equity Weights

Source: FUND. Version 2.8. 'Best Guess' Model Output.
Time horizon 2300. It is assumed that costs and benefits can be traded off, coverage of market and non-market impacts is partial, and socially contingent effects and climate system major events are excluded

[29] When aggregated, this implies lower monetary valuation for a life lost in Bangladesh for example, than in the UK. This approach has led to criticism in international policy discussions, and raises the issue of how to be consistent in policy development between domestic and international expenditure.
[30] Previous work using FUND found order of magnitude differences between three schemes 1) Valuing EU impacts with EU values, plus impacts in other regions valued with local values. This includes the expressed WTP of people outside of the EU, but aggregates money measures over people with very different incomes. 2) Valuing EU impacts with EU values, plus impacts in other regions valued with globally averaged values. 3) Assessing using EU values everywhere. Scheme 3 leads to order of magnitude greater numbers than scheme 1). Tol and Downing (2001).

There is some guidance on distributional effects in the Green book (see box). This recognises the concept of distributional effects, and the potential need to apply distributional weights, but is not explicit on the approach to be used.

Distributional Effects

The Green Book recognises that 'The impact of a policy, programme or project on an individual's well-being will vary according to his or her income; the rationale being that an extra pound will give more benefit to a person who is deprived than to someone who is well off.'

The Green Book requires that 'any distributional effects identified should be explicitly stated and quantified as far as possible'. At a minimum, this requires appraisers to identify how the costs and benefits accrue to different groups in society. It also goes further to say that 'If more in depth analysis is undertaken, it should focus on how the cost and benefits of a proposal are spread across different socio-economic groups. Proposals that deliver greater net benefit to households or individuals in lower income groups are rated more favourably than those that benefit higher'.

Finally, it also allows 'Where it is considered necessary and practical, this might involve explicitly recognising distributional effects within a project's NPV…..A more in depth analysis uses distributional weights to adjust explicitly for distributional impacts in the cost-benefit analysis. Benefits accruing to households in a lower income quantile would be weighted more heavily than those that accrue to households in higher quantiles. Conversely, costs would be weighted more heavily for households in lower quantiles'.

Source. HM Treasury Green Book.

There is no consensus on equity weighting approaches for climate change. There may be different theoretically correct approaches depending on the policy perspective and application. A different approach might be warranted from a UK policy perspective, as distinct from the perspective of a global policy maker. A more detailed summary of this issue is presented below[31].

In a pure utilitarian framework, equity weighting is based upon the *diminishing marginal utility of consumption*. Evidence on the appropriate value of the elasticity of marginal utility (ε), can be found from a variety of sources. However, no definitive guidance exists on the correct value, which can be regarded as an ethical parameter.

A value of $\varepsilon = 1$ is commonly employed in the literature. Some commentators have highlighted that this is not consistent with the current rate of spending on foreign aid in the UK (e.g. Pearce, 2003). Given current rates of foreign aid, a value of ε closer to zero, if not negative, would emerge. However, this does not necessarily mean such values are appropriate for (international) climate change policy.

The appropriate course of action depends strongly on the perspective of the decision maker.

- If we take the perspective of a global decision maker, equity weighting at $\varepsilon \leq 1$ may be appropriate for damages.
- If we employ a strict UK perspective consistent with UK spending in other policy areas, particularly foreign aid, then equity weighting is difficult to justify.

31 Based on a short note commissioned for the study. 'Equity weighting of climate change damages: Where do we stand?' Cameron Hepburn. St Hugh's College, Oxford University.

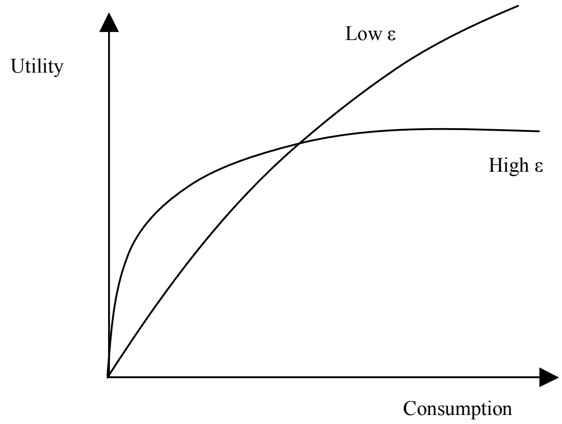
Equity Weighting

With a utilitarian social welfare function, each person's utility counts equally. It is generally accepted that each additional unit of consumption provides diminishing marginal utility.

That is, giving £1 to a rich person produces less utility (*welfare* or *happiness* may substitute as rough equivalents) than giving £1 to a poor person. So, utility increases with consumption, but at a decreasing rate. A common way to represent this is when utility, u, of consumption, c, is represented by an isoelastic utility function: $u(c) = c^{(1-\varepsilon)}/(1-\varepsilon)$, where ε denotes the elasticity of marginal utility.

In this function, the higher ε, the more rapidly marginal utility falls with additional wealth. In other words, a high ε implies that there is little additional utility gained from additional consumption by people who are already rich. A higher ε therefore implies a higher aversion to inequality.

Utility functions for different ε



The impact of different choices for ε can be shown by considering two countries, one rich (R) and one poor (P). Suppose country R has an income ten times that of country P. The table below, adapted from Pearce (2003), shows the value of a marginal pound to R relative to a marginal pound to P. For ε = 0 (no equity weighting), a pound to R is worth the same as a pound to P. For ε = 1.0 (commonly employed in the literature), giving 10 pence to P achieves the same utility increase as giving £1 to R: marginal income to P is valued ten times more highly than to R.

Impact of equity weighting when $Y_R = 10Y_P$

ε	0.0	0.5	0.8	1.0	1.2	1..5	2.0	4.0
Loss to R as a fraction of gain to P	1.0	0.31	0.16	0.10	0.06	0.03	0.01	~0

Hence even though a pure utilitarian would not weight *utility*, a utilitarian would weight *consumption flows* because of the diminishing marginal utility of consumption. These weights on consumption flows are termed *equity weights* and the appropriate equity weight for consumption going to country R is $(Y_N/Y_R)^{\varepsilon}$, where Y_N is a benchmark (or numeraire) income level. The equity weight for consumption going to P is equivalently $(Y_N/Y_P)^{\varepsilon}$. The numeraire level is important and is discussed further below.

Evidence on the *correct* value of ε could come from: (a) lab experiments on individual behaviour; (b) revealed preferences of individuals; (c) revealed social preferences by government spending on programs designed to reduce inequality in the UK; (d) UK government spending on programs designed to assist other countries.

Based on evidence of individual behaviour in categories (a) and (b), Cowell and Gardiner (1999) suggest that values between 0.5 and 4 are plausible. After examining social programs in category (c), Pearce (2003) argues that values above ε = 2 are unreasonable because they imply an unrealistically high level of aversion to inequality. Pearce (1999) concludes that values between 0.5 and 1.2 seem reasonable. Finally, cursory inspection of foreign aid spending in category (d) would suggest that even ε = 1 is extremely high – the UK government spends more on its relatively rich citizens than on aid to relatively poor people in other countries. However, this finding simply reflects the inapplicability of the global utilitarian ethic to the interests of individual nation-states.

There is another aspect to equity weighting which should also be considered. In standard economic models, the elasticity ε used in equity weighting is the same parameter as appears in the Social Rate of Time Preference:

$$SRTP = PRTP + \varepsilon * g$$

where PRTP is the Pure Rate of Time Preference, ε is the negative of the marginal elasticity of utility with respect to consumption, and g is the per capita GDP growth rate. From this perspective, a more consistent approach is to specify the PRTP and elasticity that we wish to use, and derive consistent equity weights and SRTP values.

There are three possible reasons why climate change and standard domestic policies may differ in their approach to equity weighting. These are: (1) Climate change is intergenerational and there is no reliable mechanism of intergenerational transfers; (2) It is non-marginal, so applying the Kaldor-Hicks rule may not be wise; and (3) It is international, and there is no international taxation system. Any policy that satisfies one of these three issues could be argued to have a claim to equity weighting. This would include foreign aid but arguably other domestic and international policies with international or intergenerational consequences (e.g. agricultural subsidies or biodiversity policies)[32].

Other issues with equity weights

An additional issue is the extent to which SCC and marginal abatement costs should be calculated on the same basis. Consistency suggests that if damages are equity weighted to a particular benchmark (e.g. world income), abatement costs should be equity weighted to the same benchmark[33] (see box).

A further issue on Equity Weighting

Based on the scheme outlined in the previous box, equity weighted damages should be compared to abatement costs which are equity weighted *to the same numeraire*. For instance, it would be incorrect to compare climate change damages that have been equity weighted to a world income numeraire with unweighted marginal abatement costs in the UK. For UK policymaking, the numeraire level of income should be UK national income. This effect has not been widely considered in the literature. The key issue is whether a different scheme is relevant for the UK, i.e. is UK greenhouse gas policy to be seen from a UK perspective, or as part of a global policy perspective. This further complicates the different policy perspectives outlined above.

If we want to adopt a SCC value in the UK, it is necessary to decide what policy perspective we are adopting.

- If "we" stands for the global community, then the perspective of a global decision-maker should be employed. This is the approach commonly adopted with equity weighting of damages. However, the implication from the above discussion is that in this case, abatement costs should be equity weighted to a numeraire based upon world average income. This would imply an extremely high SCC, measured at UK incomes in £/tC.
- If "we" stands for the UK, then using a utilitarian framework, while perfectly justified from an ethical perspective, represents a radical departure from accepted public decision making in other areas. This is not consistent with other policies where the interests (i.e. utility) of foreign nationals are placed on a par with the interests of UK citizens (indeed footnote 4 of the Green Book implies that the interests of foreign nationals are secondary to those of UK citizens). To equity weight on top of this would perhaps be inconsistent with other government policy.

Expressed another way. If we equity weight the marginal SCC value, and compare to UK marginal costs, we may not be comparing like with like. Converting climate change damages to a UK numeraire radically increases the social cost of carbon (estimates suggest a factor of 5 is not impossible, at least when working with PRTP values). Equally, converting the marginal abatement cost curve to the global average income numeraire would probably have the opposite effect. That is, equity weighted marginal abatement costs would be far lower in the UK, because the UK has more available income to pay for these costs. In other words, it hurts the UK less (in utility terms), to spend £1 million on abatement than it would hurt a developing country (in utility terms). Both adjustments would have the same effect in creating a larger gap between the MSCC and the MAC.

A final issue that has emerged is that the equity weights to be employed in each period depend upon the assumption about growth rates in different countries, and in particular whether it is assumed that per capita incomes are converging. Under the assumption of convergence, the impact of equity weights is significantly reduced, compared to assuming that incomes remain as unequal as they are today. This might require some form of dynamic (or time varying) equity weighting (i.e. looking at current and future income gaps for our equity weighting)[34]. More detailed results emerging from

[32] This argument does not justify climate change using equity weighting when aid decisions do not, but it presents a case for using equity weights in both instances.

[33] This issues arose from a discussion between Cameron Hepburn and David Anthoff.

[34] The PAGE model does multiply the impacts in each region by (Yworld/Yregion) -elasticity, where Y is GDP per capita. The parameter 'elasticity' does not vary with time, but the expression does, typically getting closer to unity as the regional GDP per capita gets closer to the world average.

research for this project are reported in Anthoff (2004). Much of the above discussion on equity weighting has emerged in response to the study group considerations, the stakeholder consultation and the study peer review comments. Further consideration of this area is warranted and this has been highlighted in the study research recommendations (see later section).

3.3.3 Reporting of Statistical Data

Both the mean and the median have been used as a measure of central tendency for the SCC. Since for skewed distributions they give substantially different results *even with the same underlying data* it is important to consider which is appropriate, so that at least consistent comparisons can be made.

Defining a central value in a data set in the presence of outliers is difficult. The usual measure, the arithmetic mean or average, is an unbiased measure of the expected value if the data form a homogeneous population with few real outliers. However, the data may not be drawn from a single population and the mean is sensitive to the tails of the distribution.

This is important for the SCC, as the models show that the distribution is right skewed, i.e. the mean is higher than the median value[35] and there are often outliers. The median is less sensitive to outliers, and has been regularly quoted in SCC studies, but is biased towards lower values when the probability distribution has a long, high-value tail (as with the SCC – note this may have led to bias in some of the SCC values published.). An alternative is to trim the data to remove some outliers and then calculate a trimmed mean. For this report, on the recommendation of the steering group, we consistently use the mean value as the best estimate. Where this is problematic (because of outliers), we have used a trimmed mean.

3.3.4 Time-Horizon

While there will be losers, aggregate models suggest that aggregate impacts of climate change may be positive in the short term when climate change is still relatively modest, but turn negative for more severe climate change. Uncertainties also increase rapidly in the longer-term, including the chance of large-scale discontinuities (thermohaline circulation, West-Antarctic Ice Sheet, loss of biomass carbon from increased incidence of forest fires or soil drying, destabilisation of methane hydrates or methane release from boreal ecosystems). The SCC is therefore sensitive to the time horizon chosen, and the extent to which the present value of future effects is dampened by discounting. Some models have now started to look at the effects of time-scale. A longer modelling time-scale clearly increases the uncertainty, partly because of the uncertainty about the scenarios and partly because parameter uncertainties accumulate over time. What is clear is that the effects of extending the time horizon, even with discounting, can substantially increase the estimated marginal cost of emissions in the period 2000-2100. The impact on the SCC from extending the time horizons is increased with a low discount rate, and with equity weighting. There is also the issue of the SCC value in different time periods – as the value will go up in future years (due to the profile of impacts shown above for discounting). This is considered in a later section.

3.3.5 Strong vs. Weak Sustainability

In looking at any social cost of carbon value, it is extremely important to realise what is, and is not, included in the value. It is also important to understand the trade-offs implicit in the numbers, i.e. between different regions, or between different positive and negative effects. The use of a single aggregated value implies an assumption about substitution between categories of impact. The existing models assume full substitutability, i.e. between very different impact categories. This means that the aggregated economic cost is the net of the losses from for example damages to natural ecosystems,

[35] Measures based on a cumulative probability function include the quartiles and median. The distribution of the data is captured in the median and quartiles: The minimum, maximum, and three quartiles (lower 25%, median or 50% and upper 25%) are derived from the ordered data set. The median is the value for which 50% of the data are larger.

against the pluses, for example from reduced energy for heating. It is clear that different stakeholders will have different views on whether such substitution is acceptable. In order to help examine these issues, we propose that some detailed analysis be undertaken, showing the balance of positive and negative effects, by region, (rather than single global values). This is taken forward in the later recommendations.

3.3.6 Marginal Effects

For policy appraisal (cost-benefit analysis) we are interested in the marginal social costs of carbon[36]. The marginal damage cost is the damage from an additional tonne of CO_2 emitted. Specifically, it is the change in the net present value of the monetised impacts, normalised by the change in emissions. The models used in the analysis (e.g. in the modelling study) have been used to estimate the marginal social costs of carbon, i.e. the models are run with and without additional pulses of emissions to assess the marginal costs. However, the underlying analysis within the models, such as for loss of land, may not adequately reflect scarcity, i.e. the models may be underestimating the true marginal costs[37]. There have also been concerns that some of the potential changes from climate change are clearly non-marginal (e.g. the risk of major changes to ocean currents, major sea level rise – note these are also non-linear)[38]. Some commentators have responded to this by arguing it still possible to look at marginal changes around policy decisions in regard to climate change policy, whilst recognising that non-marginal impacts are not fully represented.

3.3.7 Ancillary Effects

There is growing recognition that mitigation policies or scenarios that are aimed at reducing greenhouse gas emissions may have important ancillary effects. These potentially include a number of benefits including:

- Reductions in air pollution;
- Reductions in other environmental burdens;
- Increased security of energy supply (and/or energy diversity), including reduced oil imports;
- Improved competitiveness;
- Increased employment;
- Innovation.

There have also been concerns that policies may lead to potential dis-benefits, including

- Impacts on trade and competitiveness and employment (note these are also in the benefits list above);
- Lifestyle changes;
- Security and proliferation with specific technology options.

The literature reports that ancillary benefits of GHG mitigation offset a substantial proportion of mitigation costs. The modeling results reported here do not include these potential ancillary benefits.

Air Quality

Numerous studies have shown that ancillary air quality benefits of GHG mitigation are one of the largest ancillary benefits. Whilst the full benefit of greenhouse gas reductions resulting from further climate action may only be experienced by future generations, the ancillary air quality benefits of climate policy will accrue to the current generation. A number of recent and emerging studies have

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[36] Rather than the total costs of future climate change out-turns, or the average costs associated with for example a doubling of CO_2 concentrations.

[37] In practice, the SCC estimates from models such as FUND are 'average' marginal damage costs.

[38] Threshold effects present particular challenges, both in estimating the physical impacts of climate change and in determining appropriate WTP/WTAC values for these impacts.

assessed the potential ancillary effects of green house gas mitigation policies (see Defra, 2002[39]). The study found 20 estimates of the monetary value of ancillary benefits from the literature. The table summarises location, pollutants and impacts that are analysed by each study.

Table 4. Available monetary estimates of ancillary benefits* (Defra 2002)

Study	Country	Ancillary benefit (£/tC)	Coverage of Study
HAIKU/TAF (1999)	USA	2	Health effects from NOx, incl PM, excl O3
ICF/PREMIERE/Holmes et al	USA	2	Health effects from NOx, incl PM, excl O3
PREMIERE/Dowlatabadi et al (95)	USA	2	Health effects from NOx, incl PM, excl O3
Burtraw et al (1999)	USA	2	Health effects from SO2 & NOx
Coal/PREMIERE (1997)	USA	5	Health effects from NOx, incl PM, excl O3
Coal/ PREMIERE/ RIA (1996)	USA	17	Health effects from NOx, incl PM, excl O3
EXMOD (1995)	USA	17	Health, visibility, environmental effects from NOx, SO2, incl PM excl O3
Goulder/Scherage & Leary (1993)	USA	21	Health effects from SO2, NO2, CO, Pb
Abt Assocs & Pechan-Avantil (1999)	USA	25	Health, visibility and materials damage from SO2, NO2, O3,CO,PM,Pb
Boyd et al (1995)	USA	26	Health/visibility effects SO2, NO2, O3, CO, PM,Pb
Scheraga & Leary (1993)	USA	27	Health effects TSP, PM, SOx, NOx, CO & VOC
Garbaccio et al (2000)	China	34	Health effects from SO2 & PM
Cifuentes et al (2000)	Chile	41	Health effects from SO2, NOx, CO, HC, PM & dust
Viscusi et al (1994)	USA	57	Health/visibility : SO2, NO2, CO, HC, PM, dust
Barker & Rosendahl (2000)	Europe	101	Human & animal health, materials damage, vegetation effects from SO2, NOx, PM
Brendemoen & Vennemo (1994)	Norway	162	Health & environmental effects from SO2, NOx, CO, PM, CO2, VOC, CH4, NO2, traffic noise, road maintenance, congestion, accidents
Dessus & O'Conner (1999)	Chile	170	Health effects from 7 air pollutants (not specified)
Ekins (1996)	-	180	Not specified
Lutter & Shogren (1999)	USA	197	Not specified
Aunan et al (2000) Kanudia & Loulou (1998)	Hungary	334	Health, materials damage, vegetation. Damage from TSP, SO2, NOx, CO, VOC, CO2, CH4, NO2

This table was published by Defra in 'Ancillary Effects of Greenhouse Gas Mitigation Policies' October 2002. Defra adapted the information from OECD (2001), IPCC (2001) & Burtraw & Toman (2000)

The estimates range from £ 2 per tonne of carbon reduced to £334 per tonne of carbon reduced. The average ancillary benefit, calculated from all studies presented in the table is approximately ~£70/tC per tonne of carbon reduced. Studies differ because of differences in methodology, analysis techniques and damages included[40]. Thirteen out of twenty estimates of ancillary benefits from the literature are below £50 per tonne of carbon reduced and studies concentrating purely on health impacts from a limited selection of pollutants tend to report the lowest estimates. Studies considering a wider range of pollutants and additional impacts such as materials damage, visibility and vegetation damage generally report higher ancillary benefits. Another recent study[41] concludes that about 50% of the costs of the Kyoto target can be re-gained in terms of reduced costs of air pollution control.

The Defra study recommended against using any of the above figures in terms of ancillary benefit per tonne of carbon, as ancillary effects are policy-specific and location specific. It is also necessary to keep ancillary effects separate, as these should be covered in existing appraisal (for example, ancillary benefits from air pollution will be picked up separately as part of existing transport appraisal).

[39] http://www.defra.gov.uk/environment/climatechange/ewpscience/index.htm

[40] The US estimates for ancillary benefits are below the European benefits. There are two reasons for this: first the much lower population density for the US; second the direction of the prevailing winds is such that US pollution tends to fall on deserts, mountains and seas, whereas EU pollution is more likely to be deposited on densely inhabited land. Barker (2005).

[41] Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe - Energy Policy; D.P. van Vuuren et al. (in press)

However, Defra is currently reviewing air pollution values and this may lead to some unit values that could be used alongside carbon values for specific applications, dis-aggregated by policy and location.

Other Environmental Improvements
Other environmental benefits from low carbon policies may include:

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

Energy Security and Oil imports
Recent energy projections show an increasing trend towards energy imports in Europe, especially for oil and gas. This raises a number of issues, including:

- Energy security (security of supply including disruptions, fuel price shocks);
- Energy diversity;
- Macroeconomic effects from imports;

It is generally assumed that low carbon technologies will have ancillary benefits from reducing dependence on imports and so increasing energy security, because of greater diversity of supply linked to probable increases in renewables, nuclear generation, coal generation with sequestration, as well as improvements in energy efficiency[42].

Employment Effects, Trade and Competitiveness
The effects of environmental legislation on employment, trade and competitiveness remain the subject of debate. A number of studies (OECD, 2004) have shown that effects from existing environmental legislation are low, and far less important than the effect of labour prices. However, there have been concerns that such effects might be more important for climate policy, given the large structural changes that would be required.

Lifestyle Changes
The move towards a low carbon society could possibly lead to changes in lifestyle. For example aviation costs could rise. Lifestyle changes could also involve more focus on communities and improvement in the local environment.

Technology Specific
Many of the low carbon modelling studies have shown relative increases in the use of nuclear power. The widespread adoption of this option, particularly in new countries without existing nuclear generation, might raise concerns over waste disposal, safety and (potentially) proliferation. These issues do not arise with carbon capture and storage, which might emerge as a significant option for large-scale power generation.

3.4 Possible Approaches for Using the SCC in Policy Analysis

Ideally there would be a single best estimate of the marginal social cost of carbon, which could be applied in a transparent and consistent approach. This would apply to all project and policy applications, policy goals, and design of economic instruments. However, as the above analysis shows,

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

in reality there are large uncertainties associated with the values that currently exist, and the present modelling output refers to a subset of total effects.

On the basis of the literature review and the conclusions of the modelling project, we believe that a universal consensus on a new illustrative central value is unlikely (i.e. to replace the existing illustrative £70/tC value). It might be possible to select a value that lies mid-way between a broad range of views (e.g. half-way between different expert opinions), but using this value would not translate the true uncertainty in the SCC value through to policy analysis, nor necessarily be particularly appropriate for policy decisions.

It is therefore necessary to find some way of using the SCC values in policy applications, whilst taking into account risk and uncertainty. The approach needs to be applicable to the existing policy framework and guidance, which for project and policy analysis is largely based around cost-benefit analysis (see box), bearing in mind that what works best for setting a long-term target for emissions mitigation may differ from an approach suitable for project appraisal of an energy project, regulatory impact assessment of climate change mitigation policy, or regulatory impact assessment of a future transport plan.

Decision Making

There are different decision-making tools for policy. The two main ones used in UK and European policy-making are cost-benefit analysis and cost-effectiveness.

- **Cost-benefit analysis** is designed to show whether the total benefits of a project or policy exceed the costs. It is an absolute measure. It quantifies costs and benefits in monetary terms, including values not captured by markets. As set out in section 1, UK Government favours cost-benefit analysis[43] (though there are exceptions[44]).
- **Cost-effectiveness analysis** compares the costs of alternative ways of producing the same or similar outputs. IT is therefore a relative measure, i.e. it only provides comparative information between choices. It is typically used in one of two ways – it can be used to identify the highest level of benefits given available resources, or it can be used to assess the least-cost approach of reaching a given target (e.g. a threshold level)[45].

The study has undertaken stakeholder consultation on the possible approaches to dealing with risk and uncertainty. The briefing paper described a number of possible approaches for dealing with, and communicating, the risk and uncertainty in the SCC value for policy applications, with a summary of potential advantages and drawbacks. These are reproduced in Appendix 2. The approaches were:

- Use of an illustrative central value;
- Use of a range;
- Switching values;
- Sequential sensitivity analysis;
- Different values for different applications;
- Marginal abatement costs

[43] though we are unlikely ever to be able to value all the important costs and benefits of a particular project.
[44] For example, the UK is committed to using the precautionary principle'. Invoked when: 'There is good reason to believe that harmful effects may occur to human, animal or plant health or to the environment; and Level of scientific uncertainty about the consequences or likelihood of the risk is such that the best available scientific advice cannot assess the risk with sufficient confidence to inform decision making'. Treasury Statement of Intent on Environmental taxes.
This document also recognizes there are some policy areas where target setting is not easily based on an objective assessment of the costs and benefits'…..'Some instances targets will be set through a process of negotiation, such as for the climate change targets agreed under the Kyoto Protocol'….. 'In these cases the process of target setting will help to reveal the weight which society puts on the costs and benefits, but unless all those involved have a good understanding of these there remains a danger that targets will be set at an inefficient level'
[45] Note CBA and cost-effectiveness are not necessarily exclusive.

- Multi-criteria analysis.
- Other risk analysis techniques.

The study has also reviewed the use of different approaches for dealing with the uncertainty in the SCC values in other organisations. Given the low levels of use of SCC values (see previous section above), it is not surprising that we have found very little evidence of uncertainty in policy applications, although some organisations (UK included) present a range of values, as well as a central estimate. Other organisations (e.g. the EC) have used marginal abatement costs. The only other practical use of a different approach is the use of switching value used in energy project appraisal by the EIB (Watkiss et al, 2002).

4 Case Studies

The project has identified a number of case studies, reflecting different levels of policy making, and covering policies and programmes for which climate change mitigation is a major objective, and those for which climate change is a relatively minor concern.

The case studies have been selected to cover each of the potential applications, i.e.:

- Project appraisal (project cost-benefit analysis). Clearly it includes projects that offset GHG emissions (e.g. renewables) by displacing more carbon intensive activities, as well as projects that increase emissions.
- Regulatory Impact Assessment (policy cost-benefit analysis). The key aim has been to provide a regulatory case study (exemplar), to demonstrate the use of the SCC value in policy cost-benefit analysis;
- Analysis of economic instruments (taxes, charges, subsidies);
- Long-term (sustainability) objectives or targets.

A number of potential projects and case studies were reviewed against each of the above categories.

Project Appraisal	Regulatory Impact Assessment
• Renewable projects (including projects and supporting transmission/distribution infrastructure); • Major gas or coal generation plants (and possibly also CHP); • Gas network extension; • Oil and gas extraction projects (e.g. North Sea); • Public transport investment (e.g. urban public transport or rail); • New road infrastructure; • Carbon sequestration projects, e.g. with a forestry project or CO_2 capture and disposal; • Industrial plant (especially energy intensive sectors such as metals, or cement because of direct CO_2 emissions); • Buildings; • Agriculture (including fertiliser production); • Water/sewage treatment works; • Waste projects (landfill/incineration)	• ACEA agreement • Non-road mobile machinery • Auto Oil Programme • 10 year transport plan • IPPC • Large Combustion Plant directive 1988 (and amendment) • National Emissions Ceilings • Sulphur content of certain liquid fuels 1999 • Building regulations • F-gas regulation • UK ETS • EU ETS • International angle with DFID development policy guidelines.
Economic Instruments	**Long-term targets**
• Renewable obligation • Climate change levy • Carbon taxes for aviation • Fuel Duty • Fuel duty escalator • Rail subsidy levels • Waste tax charges • Building regulations • Carbon taxes in other sectors	• The Sixth Environment Action Programme of the European Community (and the seven thematic Strategies) • Longer term UK CO_2 commitments (UK should put itself on a path to reducing carbon dioxide emissions by some 60% by 2050).

These were assessed against a number of criteria, and discussed with the study steering group. These included:

- Applicability and policy relevance;
- Whether there was a defined baseline and scenario;
- Whether emissions and cost data exist.

Applicability and policy relevance
Clearly the case studies should be relevant to the social cost of carbon, and the steering committee suggested that they should capture the different levels of decision-making in Government.

Is the policy or project clearly defined?
In order to assess the projects or policy in a rigorous quantitative analysis, the specific policy must be clearly defined. A good example of a clear policy measure (command and control) is the series of technical standards for emission limits from new vehicles, or national emission ceilings.

Do adequate emissions and cost data exist?
In order to assess projects or policies, there must be data available. It is possible to estimate emissions benefits based on estimates in the National Greenhouse Gas Emissions Inventory, provided activity data are available. However, there was not time within the current study to return and undertake primary economic analysis of policies. The case studies therefore needed to have a clear understanding of baseline, project or policy impact, and cost data. Finally, in order to assess the potential co-benefits of certain projects, then we needed to select projects or policies where these are estimated.

4.1.1 Selected case studies

The following case studies were selected on the basis of the above criteria outlined above:

- A project based example using the New Approach to Appraisal for a road transport infrastructure project (DfT). Time permitting, the study was also going to assess an energy investment project (Ofgem)
- A policy based example using the F-Gas regulation, and the partial Regulatory Impact Assessment (Defra);
- An economic tax example using the taxes for the aviation consultation (DfT);
- Long-term sustainability objectives using the Energy White Paper 60% CO_2 (2050) target (DfT).

A summary of each of these projects follows.

4.1.2 Case Study 1. New Approach to Appraisal: Transport Appraisal

The New Approach to Appraisal (NATA) is an approach for improving the consistency and transparency in decision-making on transport investment projects. It does this via a one-page Appraisal Summary Table (AST)) and associated worksheets. Impacts are assessed against the Government's 5 objectives for transport:

- Economy;
- Safety;
- Accessibility;
- Environmental impact;
- Integration.

Most of the summary information shown on the AST is taken from established economic appraisal and environmental impact assessment techniques. Where possible, impacts summarised in the AST are presented in money terms. Other impacts summarised in the AST are presented in quantitative terms. This includes environmental impacts. DfT is committed to extending valuation to a wider range of the impacts of transport investment, including valuation of noise, local air quality and greenhouse gas emissions. The case study has considered the use of the SCC for use in the monetary evaluation of CO_2 emissions from new schemes.

A specific scheme was chosen to illustrate the approach, with the use of the SCC as for initial analysis by DfT. The scheme was a proposed A road improvement (bypass).

The net estimated increase in CO_2 emitted from this bypass is 4835 tonnes in year one and the appraisal period is from 2010 to 2039 (thirty years). The total present value of costs for the emitted carbon was estimated using the £70/tC (using the estimate that the value increases by £1/tC each year) at £2.4 million. This compared to a present value of accident reduction of £42 million (carbon impact is 6% of this), and a present value benefit of transport economic efficiency of £157 million (carbon impact is 1.5% of this). The values are summarised below.

Table 5. Appraisal Summary Table (AST)

OPTION	DESCRIPTION	PROBLEMS	PVB TO GOVERNMENT
	A14 off-line route between Ellington and Fenstanton providing a southern bypass of Huntingdon with on-line widening between Fenstanton and Fen Ditton. M11 Junction 14 modified. Local Access Roads beside the on-line widening between Fenstanton and M11 / A1307.	Unreliable journey times caused by congestion, exacerbated by mix of strategic and local traffic. Numerous junctions interrupt smooth flow and cause safety problems.	Present Value Cost of Highway Works only to Government = £-243m

OBJECTIVE		QUALITATIVE IMPACTS	QUANTITATIVE MEASURE	ASSESSMENT
ENVIRONMENT	Noise	Moderate increase south of Brampton and Godmanchester. Slight increase along A14 between Fenstanton and Fen Ditton. Moderate decrease along existing A14 between Brampton and Fenstanton. Improvement assuming use of flexible, low-noise road surfacing.	23,900 people affected.	Net impact = -914 people
	Local Air Quality	Moderate increase in emissions south of Brampton and Godmanchester. Moderate decrease along existing A14 between Brampton and Fenstanton. Moderate decrease along A14 between Fenstanton and Fen Ditton.	16,000 people affected.	Change in NO2 = -19 tonnes/yr Change in PM10 = -1.3 tonnes/yr
	Greenhouse Gases	Not applicable.	Not applicable.	Change in CO2 = +4835 tonnes/yr
	Landscape	1. Loss and fragmentation of natural, built and cultural landscape features; 2. A significant loss of high quality landscape character; 3. Visual intrusion imposed from the horizontal and vertical alignment of the road and associated structures; 4. Reduction in the sense of tranquillity and remoteness.	2 landscape features = Large adverse impact 3 landscape features = Moderate adverse impact	The proposed route will have a **large adverse** impact upon the landscape of the general study area due to the combined magnitude of direct and indirect impacts upon a landscape of high quality and national importance
	Townscape	As the route proposal by-passes the main settlements and the larger villages of the general study area, it is expected that a considerable volume of existing through traffic will be redirected away from the main settlements and larger villages. This is expected to lead to an improvement in townscape appearance, encourage human interaction within townscapes and improve townscape character and quality.	5 townscape features = Neutral impact 3 townscape features = Slight beneficial impact	Slight Beneficial
	Heritage of Historic Resources	1. Visual intrusion to and from a heritage feature causing a degradation in a site's setting; 2. Changes in the original landscape or townscape of a heritage feature; 3. Increased noise and vibration disturbances during the construction phase and the normal running of the route; 4. Severance of linked heritage features.	4 heritage features = Slight adverse impact	The proposed route will have a **slight adverse** impact upon the heritage resources within the general study area due to the indirect and slight magnitude of impacts upon heritage features of national and local importance
	Bio-diversity	1. Direct land-take of biodiversity sites leading to a direct loss of habitat and therefore biodiversity; 2. Direct land-take surrounding biodiversity sites leading to the loss and severance of potential feeding and foraging areas; 3. Increased faunal road kills; 4. Impacts associated with direct and indirect untreated road run-off generated from the construction period and the normal running of the route; 5. Potential noise disturbances to sensitive faunal species; 6. Potential light pollution and disturbances to sensitive faunal species.	1 biodiversity site = Significant major adverse 1 biodiversity site = Serious intermediate adverse 8 biodiversity sites = Minor adverse	The route proposal will have a **significant major adverse impact** upon the biodiversity of the general study area because the combined magnitude of the direct and indirect impacts upon some irreplaceable biodiversity areas of high quality and national importance. It should be noted that this is the worst-case scenario based on the potential impacts upon St. Meadow County Wildlife Site.

	Water Environment	1. Reduction in floodplain storage leading to a potential increase in the frequency and severity of flash flooding (unless compensatory storage is provided); 2. Impacts associated with untreated run-off from the construction period and the normal running of the route. This may lead to sedimentation and associated potential changes in water feature geomorphic form and a possible degradation in water quality; 3. Impacts associated with any bridging structures and the need for in-stream structures; 4. Visual intrusion and noise nuisances leading to a degradation in aesthetic value and recreational potential of the water environments.	2 water features = Significantly moderate adverse 1 water feature = Moderate adverse impacts of low significance 1 water feature = Moderate adverse impacts of insignificance 1 water feature = Negligible adverse impacts of insignificance	The route proposal will have a **significant moderate adverse** impact upon water features of the general study area due to the moderate magnitude of most impacts upon some irreplaceable and high quality features of regional importance. It should be noted that this is the worst-case scenario based on the potential impacts upon the River Great Ouse and St. Meadow Water Meadow.
	Physical Fitness	Neutral impact overall for cycling and walking trips. Potential for increased cycling and walking trips on Local Access Road.	Change in walking trips = -7 (-0.78%) Change in cycling trips = -150 (-0.23%)	837 walking / 65986 cycling for more than 30 minutes.
	Journey Ambience	Moderate reduction in traveller stress on A14 due to reduced congestion and improved signing. Large numbers of travellers involved.	Vehs/day on A14 in 2016 = 96,000(119,000). [2010 = 93,000(114,000) 2025 = 99,000(123,000)] [Flows in (brackets) include Local Access Road]	Large beneficial
SAFETY	Accidents	Significant reduction in the number of minor accidents with slight reduction in fatalities. Accident rate/km reduced for all incident categories. (Note : benefits are to a 1998 datum and analysed from opening over 30 years).	Accidents reduced by 47,890 (3.7%) Fatalities decreased by 28 (1.5%) Serious injuries reduced by 400 (2.4%) Slight injuries reduced by 3,166 (2.6%)	PVB = £106m
	Security	Use of modern infrastructure, vehicles, cameras and communications on highway increases personal security.	Vehs/day on A14 in 2016 = 96,000(119,000). [2010 = 93,000(114,000) 2025 = 99,000(123,000)] [Flows in (brackets) include Local Access Road]	Large beneficial
ECONOMY	Transport Economic Efficiency	Large benefit to vehicles on the existing A14 corridor as well as decongestion benefits. (Note : The TEE calculated to a 1998 datum and analysed against years 2010, 2016 and 2025).	Not applicable.	Users NPV = £416m Private Providers NPV = £-8m Public Providers NPV = £-243m Other Government NPV = £-8m
	Reliability	Moderate increase in journey time reliability on A14.	Not applicable.	Moderate beneficial
	Wider Economic Impacts	Slight benefit to freight. Increased accessibility to Cambridge, Huntingdon & St. Ives.	Not applicable.	Not applicable
ACCESSIBILITY	Option Values	No significant change.	Not applicable.	Neutral
	Severance	Public Rights of Way between Fenstanton, Fen Drayton and Conington will need to be diverted. Slight impact on Ouse Valley Way and other recreational footpaths in River Great Ouse environs. Moderate improvement due to Cambridge to Huntingdon cycleway.	Change in number of people = 1,323	Moderate adverse
	Access to Transport System	Improved access to A14.	Not applicable.	Not applicable
RATIO	Transport Interchange	Moderate increase in use of Park & Ride.	Not applicable.	Slight Beneficial
	Land-Use Policy	Compatible with national, regional and local highway policies and plans.	Not applicable.	Beneficial
	Other Government Policies	Improved access to employment opportunities and improves employment catchments.	Not applicable.	Beneficial

4.1.3 Case Study 2: Partial Regulatory Impact Assessment of a Proposal for A Regulation on Certain Fluorinated Gases (F-Gases regulation)

This partial regulatory impact assessment (RIA) examined the implementation of the proposed EU regulation on certain fluorinated gases (COM(2003) 492 final). The regulation aims to reduce emissions of hydrofluorocarbons (HFCs), perfluorocarbons and sulphur hexafluoride (SF_6) within the EU by about 23 Mt CO_2eq by 2010. These gases have a variety of uses, in refrigeration and air conditioning systems, aerosols, foam production, fire protection systems, high voltage switchgear, semi-conductor manufacture and magnesium production and casting. SF_6 is also given off during aluminium production. The proposed Regulation includes measures on preventing and minimising leakage, recovery of used gases, and prohibition or phasing out of certain uses.

The UK already has a number of relevant policies and measures in place, so the partial RIA assessed the additional emissions reductions, costs and benefits associated with implementing the regulation. The benefits were evaluated using an illustrative figure of £70 t/C, with a range of £35t/C to £140 t/C.

As well as implementing the Regulation as currently proposed (Option 2), a number of variants were considered regarding domestic fridges (Option 3), different approaches to reducing emissions of HFCs from air conditioning systems in vehicles (Options 4 and 5), and extending prohibitions on the use of SF_6 in magnesium production and casting (Option 6).

The results of the RIA showed that at £35 t/C the cost of implementing the regulation as proposed (Option 2) significantly exceeded the benefits. At both £70/tC and £140/tC, benefits fell within the range of the cost estimates, i.e. were higher than the lowest estimate of costs, but below the highest estimate.

The only significant reduction in costs was achieved by Option 4, removal of the prohibition on HFC 134a in mobile air conditioning. For this option if emissions reductions were valued at £70 or £140t/C then benefits were greater than the highest estimate of costs.

Table 6. Summary of Costs and Benefits as Estimated in the RIA

Option	**Average Reduction***	**Annualised costs (£M)**	**Annualised Benefits (£M) associated with CO_2 reduction**		
	Mt C/yr		**@ £35/t C**	**@ £70/t C**	**@ £140/t C**
2 Regulation as proposed	1.2 - 1.5	74 - 225	47 - 49	94 - 98	188 - 197
3					
4	1.3 - 1.5	71 - 87	45 - 49	91 - 98	181 - 197
5	1.2 - 1.5	73 - 224	46 - 49	93 - 97	185 - 194
6	1.2 - 1.5	74 - 225	47 - 49	94 - 98	188 - 197
7	1.4 - 1.7	74 - 225	53 - 55	106 - 110	211 - 220

*Emissions reductions vary over the assessment period (2005 to 2025) and this is the annual average reduction over this period. Costs and benefits associated with the emissions reductions over this period have been discounted back to 2005 using the Government discount rate of 3.5% and the aggregate value has then been annualised.

4.1.4 Case Study 3: Aviation Developing Economic Instruments

In its paper "Aviation and the Environment: using economic instruments"(2003), the DfT estimated the climate change costs of aviation in 2000 and 2030, updating work done in a previous paper "Valuing the External Costs of Aviation". This raised the question of what economic instruments could be used to tackle climate change. Stakeholder views were subsequently explored in a series of discussion workshops. In the recent Aviation White Paper "The Future of Air Transport" (2003), the DfT proposed that the most suitable economic instrument would be a well designed emission trading regime, and indicated that it would press for the inclusion of intra–EU air services in the second phase forthcoming EU emissions trading scheme. No detailed proposals or assessment of the costs of such a scheme have been published yet.

Estimating the costs of climate change from aviation
A majority of aircraft emissions (carbon dioxide, oxides of nitrogen, oxides of sulphur, water vapour, hydrocarbons and particles) occur far above the Earth's surface at an altitude range of 9 - 13 km. These emissions alter the chemical composition of the atmosphere in a variety of ways, both directly and indirectly. In accounting for the global warming impacts of aviation emissions it is therefore important to take account of not just CO_2 emissions, but also the impact of other emissions at altitude. The 1999 IPCC report, Aviation and the Global Atmosphere suggested that the radiative forcing index (RFI), the ratio of total radiative forcing to that from CO_2 emissions alone, of aircraft emissions at altitude was 2.7.

The DfT estimated the cost of climate change due to aviation in the UK as £1.4 billion in 2000 rising to £4.8 billion in 2030. The Government has estimated that meeting these costs might lead to a 10% increase in air fares which would reduce demand by roughly an equivalent amount, on the basis of a plausible value for price elasticity of demand[46]. The DfT estimates were based on:

- A cost for carbon emissions of £70/tC in 2000, rising by £1/year £100/t in 2030 (as recommended by the Government Economic Service Working Paper 140: Estimating the Social Cost of Carbon Emissions)
- Applying a radiative forcing index of 2.7 to cruising CO_2 emissions (i.e. those at altitude).
- Allocating half of emissions from international flights to the UK

Table 7. Climate Change Costs from Aviation in the UK

Year	Carbon emitted (million tonnes)	Radiative Forcing Factor	Effective Carbon (million tonnes)	Cost of carbon (£ per tonne)	UK cost (£ billion)
2000	8.2	2.4	20	70	1.4
2030	19	2.5	48	100	4.8

Table 8. Illustrative Climate Change Costs for Short and Long Haul Flights

Specific flight example	Distance (nautical miles)	Carbon emitted (tonnes)	Including Radiative forcing (tonnes)	Cost of carbon (£ per tonne)	Cost of climate change (£ per flight)
Long-haul B747	3724	63.7	171.7	70	12021
Short-haul B737	600	3.0	8.1	70	566

Notes.
A simplified approach based on using a radiative forcing factor of 2.7 for both landing and take off, and cruise related emissions.

46 Regulatory Impact Assessment: The Government's White Paper: The Future Of Air Transport

4.1.5 Case Study 4: the Energy White Paper 60% Reduction Target

The Energy White Paper "Our Energy Future – Creating a Low Carbon Economy" (2003) accepted the Royal Commission on Environmental Pollution (RCEP) recommendation that "*the UK should put itself on a path to a reduction in CO_2 emissions of some 60% from current levels by about 2050*". This is about the level of reduction likely to be needed by developed countries in order to move towards stabilisation of CO_2 concentrations in the atmosphere at no more than 550 ppm, taking account of a realistic assessment of emissions growth in developing countries[47].

The 60% reduction target is equivalent to the UK reducing emission by about 65 MtC from 1990 levels by 2050. The White Paper also committed to making substantial progress towards the target by 2020 and set an interim target of cuts, in addition to those already forecast as a result of the current Climate Change Programme, of 15-25Mt by 2020.

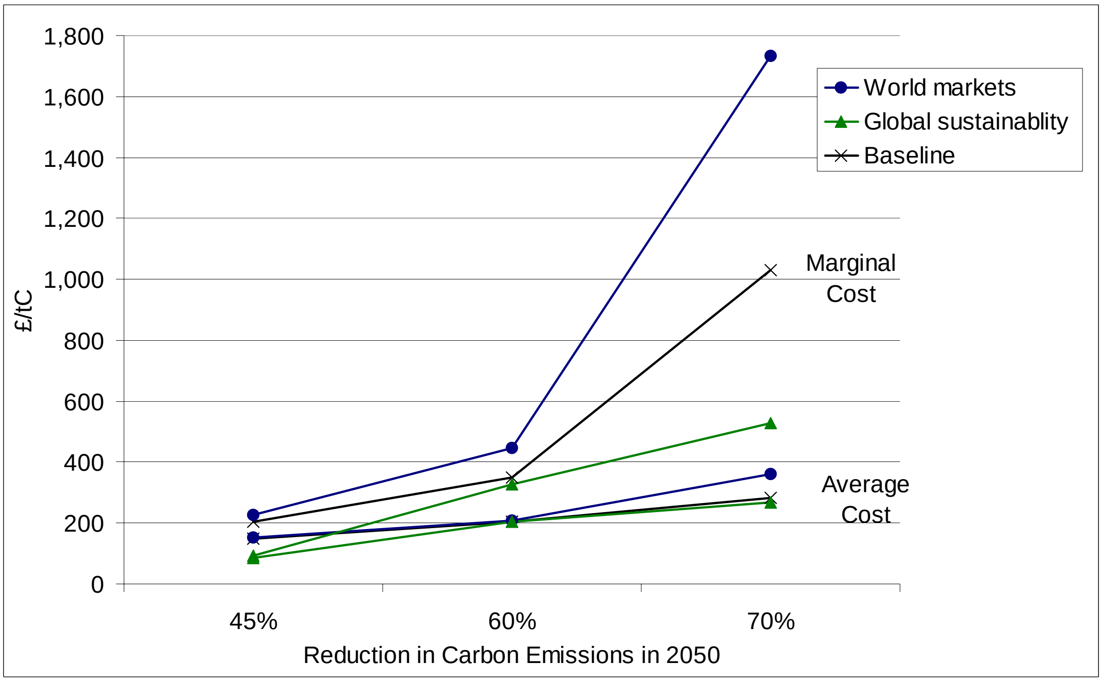
A wide range of analytical work supported the White Paper, and examined the feasibility and cost of achieving these aims. This included work by Government's interdepartmental analysts group, and a study commissioned by the DTI, DEFRA and PIU from AEA Technology and Imperial College[48], to use the MARKAL model to develop a range of bottom up estimates of CO_2 emissions, and to identify the technical possibilities and indicate the costs of abating emissions. Three levels of abatement were considered, a 60% reduction relative to emission levels in 2000 – approximating to the White Paper Target – plus 45% and 70% reductions, together with three future scenarios, a Baseline Scenario, World Markets and Global Sustainability.

The study showed that there is a diversity of options for reducing emissions on both the supply and demand sides and the implementation of energy efficiency technologies is central to achieving the targets. The costs of measures necessary to meet the 2020 interim target of additional reductions of 15-25 MtC were in the range of £10 - 80/t C (note, however, that these are average abatement costs, not marginal abatement costs). The White Paper noted that these average costs were mostly lower or in line with the illustrative marginal damage costs suggested by the Government Economic Service working paper of £70/tC (with a range of £35 to £140t/C).

The average costs of achieving a 60% reduction by 2050 were about £200 t/C. Marginal costs ranged from £330/tC to £450/tC depending on the scenario. Sensitivity analyses showed costs could be higher than this if innovation in low carbon technologies was limited, if energy efficiency improved only in line with past trends or if both new nuclear build and carbon capture and storage were completely excluded in the longer term. The White paper makes no comparison of marginal abatement costs with the marginal damage costs, but from the values quoted, it appears they were broadly comparable for 2030, but the MAC values in later years (2040 and 2050) are higher than the central illustrative SCC value of £180/tC to £190/tC (£140/tC plus a rise of £1/year).

Costs of abatement measures for the range of cuts and scenarios considered are show below. More details are provided later in the report and in the Appendices.

[47] "The Scientific Case for setting a long term emission reduction target" , www.defra.gov.uk/environment/climate change
[48] www.dti.gov.uk/energy/greenhousegas/index.shtml



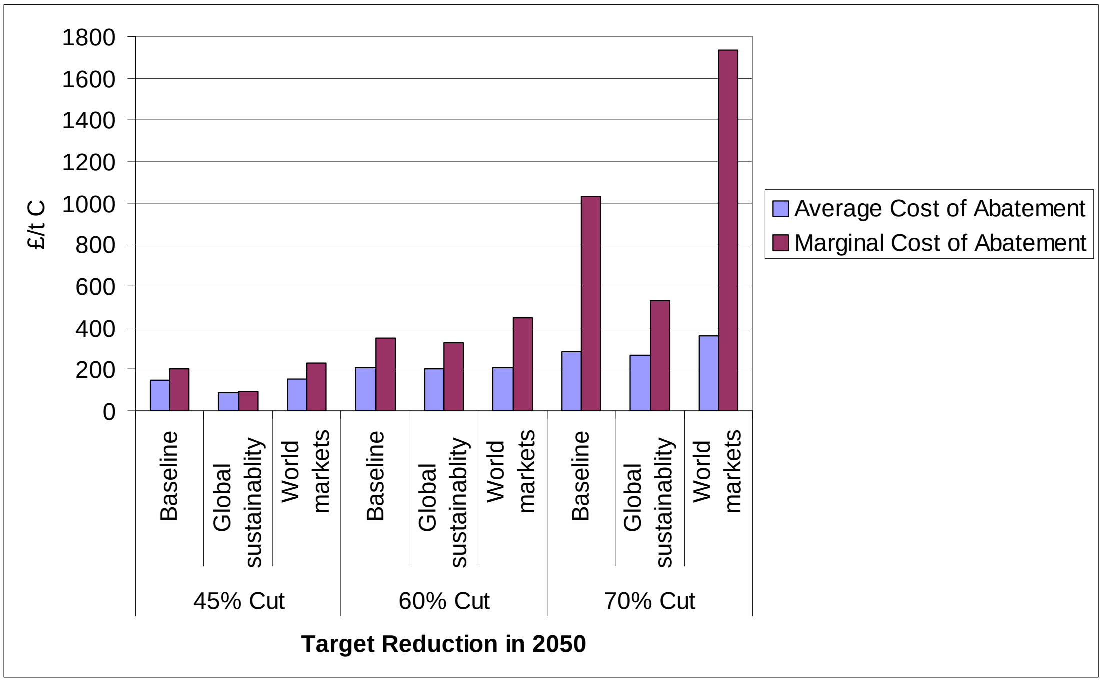


Figure 8. MARKAL Results

5 Stakeholder Consultation

The task has consulted stakeholders and experts about the role and the appropriate uses of SCC estimates in policy assessment. The study has taken forward this consultation by:

- Drawing up a list of relevant stakeholders and notify them of the study, its timing, the opportunity for input, etc;
- Providing a briefing paper on the existing use of SCC estimates in policy assessment, and on the options for dealing with uncertainty and risk;
- Undertaking a number of direct interviews with relevant experts and users;
- Organising a follow-up seminar to the international social costs of carbon workshop, held last year, to present the initial findings from the study.

In collaboration with Defra, a list of relevant stakeholders was drawn up. This totals almost 200 individuals or organisations. About 50 or so key stakeholders were identified from these, who were contacted with the briefing paper and invitation to attend a workshop.

5.1 Briefing Paper

The briefing paper included:

- An updated review of the SCC numbers in the literature, based on review by Richard Tol.
- A review of current use of SCC numbers in policy applications.
- A discussion of the key parameters that influence the numbers, which discount rates are used, time horizons, etc.
- Analysis of the values against the risk matrix and identification of gaps in the numbers.
- Identification of options for dealing with risk and uncertainty in using the numbers.
- A list of key questions with invitation for stakeholder response.

The list of questions asked is included in Appendix 1. The full briefing paper can be downloaded from the project web-site: http://socialcostofcarbon.aeat.com.

5.2 Interviews

The consultation included a number of face-to-face interviews with individuals agreed with the steering group. They included both policy and economic experts, and a selection of the likely users (i.e. representatives of various Government departments or agencies that were already using, or might use, the SCC). Interviews were held with the following.

Table 9. Study Interviews.

Name	**5.2.1 Organisation**
Tom Downing	SEI Oxford
Cameron Hepburn	St Hugh's College, Oxford University
Anil Markandya	Bath University/Metroeconomica
Alistair Hunt	Bath University/Metroeconomica
Chris Hope	Judge Institute of Management/University of Cambridge
David Thompson	Defra
Bob Davies	Defra, EPE
Jim Penman	Defra, GAD
Richard Clarkson	DfT
Stephen Green/Emma Campbell	DTI
Henry Leveson-Gower	Environment Agency
Sarah Samuel/John Costyn	Ofgem
Michele Pittini	Defra, EPE
Mujtaba Rahman	Defra, EPE
Terry Barker	Cambridge Econometrics
Paul Ekins	PSI
Dieter Helm	New College, Oxford University
David Pearce	University College London
Stephen Smith	Department of Economics, University College London
Henry Derwent	Defra
David Warrilow	Defra, GAD
Chris Riley	DfT
Michael Spackman	NERA

The study also received discussion and comments back from

- David Fisk (Dept of Civil and Environmental Engineering, Imperial College);
- Richard Tol (University of Hamburg);
- Kasper Wang (Environmental Assessment Institute, Denmark);
- Marc Davidson (University of Amsterdam, the Netherlands);
- Jane Leggett (US EPA).

These interviews and comments were used to help update the material in the briefing paper, and draw the conclusions and recommendations together for the study.

5.3 SCC Workshop

The follow-up workshop to the Defra International Seminar on the Social Cost of Carbon in July 2003 was held on the 13th September 2004. The presentations from the day are available on the project web-site: http://socialcostofcarbon.aeat.com.

5.4 Results of the Consultation

The results of the stakeholder consultation, including the interviews, written responses to the briefing paper, and the views raised at the SCC workshop, are summarised in this section. We have set out the findings of the consultation against the key themes raised in the questions for consultation (see Appendix 1).

Theme 1. Is it appropriate to try to attach a value to the social cost of carbon (SCC) in order to inform decision-making?

All respondents recognised the need for some assessment of benefits (i.e. of the benefits of climate change mitigation) in order to inform policy decisions through a 'shadow price' of carbon emissions. Views varied (see later) on whether this shadow price should be an SCC estimate or an estimate of marginal abatement costs to achieve a given Government target.

Theme 2. Do you support using SCC estimates in:

1) Project appraisal (cost-benefit analysis);
2) Policy appraisal (regulatory impact assessment);
3) Design of economic instruments;
4) Setting longer-term sustainability goals.

For each of the above decision-making contexts, do your views differ on the use of SCC estimates, depending on whether:

a) The primary objective is in relation to climate change policy (e.g. GHG abatement);

b) The primary objective is in another policy areas (e.g. air pollution, transport congestion) where GHG emissions are only a secondary issue

All respondents saw the need for a shadow price of carbon (whether an SCC estimate or alternative construct) in the first three applications - project appraisal, policy appraisal and design of economic instruments. The general view that this was equally relevant for greenhouse gas (GHG) emission policy, and other policy where GHG emissions reductions were not the primary policy objective (e.g. in transport appraisal).

The interviewees were asked to consider the implications of the use of SCC estimates (or alternative shadow prices) in all applications, recognising that these values could also be used to value GHG emission increases in some cases, and that these would then be traded off against other costs or benefits in appraisal (for example, the increase in road transport GHG emissions from a new road project investment would be included as a negative value, and traded off against the benefits of travel time and accident reductions). Nearly all concluded that shadow prices of carbon emissions should be applied in this way.

The key difference in respondents' views was over the use of SCC estimates in informing long-term target setting/sustainability goals, particularly greenhouse gas emission/climate change policy.

Most respondents had reservations about using SCC estimates in setting longer-term targets. However, the range of views differed strongly: nearly all felt that consideration of SCC estimates was important and did provide useful information on the benefits of climate change policy to help inform policy. However, they felt that aggregated, monetary estimates only represented part of the picture at this level. They felt that for such decisions, it was necessary to make a more thorough analysis of uncertainties, use sensitivity analysis, consider physical impacts as well as economic values, etc.

When questioned on their concerns, most respondents raised the issue of uncertainties, and it was highlighted that climate change was the ultimate test of how far it was possible to push cost-benefit analysis. As the interview progressed, a significant number of these respondents came back to this point and also expressed the view that for strategic policy decisions (e.g. on energy policy and long-term transport plans) it would also be appropriate to consider uncertainty and sensitivity analysis in the benefits analysis.

However, there was also a group of respondents who strongly felt that cost-benefit analysis was necessary across all aspects of policy making. As a general theme, they were concerned that without cost-benefit analysis, policy choices could be inefficient (i.e. they did not believe that policy makers necessarily make efficient choices). They also felt that it was meaningless to apply SCC estimates to lower-level appraisal if these values were not also used to inform the setting of strategic targets.

Finally, there was also a group of respondents who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy. They believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle. Some respondents in this and the other groups also raised the issue of the duty of care and human rights.

The consideration of different policy aims, and specifically the longer-term targets, led many respondents to discuss the inter-relationship between long-term targets and short-term appraisal (using SCC estimates), discussed in more detail below. There were also some broad trends in the responses with types of interviewees.

Theme 3. What are your views on the suggested approaches for addressing uncertainty in the use of the SCC values in policy applications, i.e.:

- Use of an illustrative value;
- Use of a range;
- Switching values;
- Sequential sensitivity analysis;
- Different values for different applications;
- Marginal abatement costs;
- Multi-criteria analysis;
- Risk aversion.

There was an extremely wide response to this question. Even within a relatively small group of experts/users, we found someone who was strongly in favour of each of the approaches listed above. Nonetheless, there was a clear grouping of views into.

- Those who favoured use of a central SCC estimate as a shadow price of carbon emissions;
- Those who favoured use of SCC with a range;
- Those who favoured use of marginal abatement costs (MACs), looking either at a central value or at a range.

Those that favoured use of a SCC (or indeed a MAC) were split between those that favoured a range, and those that preferred a central value. This reflects a trade-off between the two approaches of consistency (using a single value) and communicating uncertainty.

Amongst users (policy analysts working in Government), those that favoured a central value were generally those working on day-to-day appraisal, particularly in areas where SCC estimates did not dominate the appraisal (e.g. energy infrastructure). Those favouring more uncertainty analysis (e.g. a range, sequential sensitivity analysis, other techniques) were involved in major GHG/climate change policies and this group wanted as much information as possible. The broader consensus amongst experts and users was that if GHG emissions were not the primary concern to an appraisal, then it would be better to keep things simple, implying a single central value.

Nearly all interviewees, regardless of their views on the approach used, agreed that the approach should be used consistently across all areas of policy. Several commentators referred to the apparent inconsistencies with forestry (the current SCC estimates would be expected to lead to high levels of afforestation which do not appear to be reflected in policy), nuclear generation (the current SCC estimates are not recognised in the current taxation/subsidy system for carbon taxes for nuclear generation), and renewables (the existing subsidies are above the levels indicated by SCC estimates[49]).

A significant number of interviewees said they believed that the existing 2050 goal had correctly set the overall policy aim, and that policy at lower levels in day-to-day appraisal should aim towards a cost-effective (i.e., least-cost) delivery of this target. To this end, they recommended the use of MAC estimates as shadow prices of carbon emissions for appraisal, to ensure consistency with the long-term target, and ensure delivery of the target as efficiently as possible.

These individuals were either satisfied that policy makers had considered costs and benefits in setting the target (explicitly or implicitly[50]), or felt that the policy was justified on the basis of a precautionary principle (both views were expressed by different respondents). This group felt that for lower level project and policy appraisal, it was not necessary to re-examine and reassess the SCC against other costs and benefits.

Alongside the discussion of the uncertainty associated with the SCC, many respondents also highlighted the uncertainty inherent in MAC estimates, highlighting previous ex ante and ex post analysis out-turns.

Theme 4. Is climate change special?

A series of questions were asked to elicit respondents' views on the appropriate discount rate, equity weighting and time-scale. Effectively, the questions aimed to find out whether respondents believed that the Green Book recommendations should apply to climate change, or whether climate change was a special case and should be subject to different schemes in relation to discount rate, equity, etc.

Again, there were two groups of respondent views. Many respondents believed that the Green Book guidance should be used, though many also expressed the view that climate change, while not 'special', was very challenging in that it involved all of the difficult issues that arise in economic appraisal (e.g. long time-scales, strong inequality themes, potential catastrophes, etc), and pushed the boundaries of cost-benefit analysis and marginal economic appraisal. Another group felt that climate change was fundamentally different to the usual types of policy decisions. They strongly felt that guidance in the Green Book was inappropriate. They usually raised concerns because of irreversibility of effects, non-marginal impacts, non-linearities, duty of care, human rights, precautionary principle, uncertainty, catastrophic risk, and ethical and moral perspectives and responsibility.

[49] though we note that the effective market incentives for renewables are not solely in response to carbon externalities: they also reflect other environmental and social externalities, including air pollution, technology/innovation benefits, etc.

[50] There were also some other who highlighted that IF the 2050 target had been set explicitly after consideration of costs and benefits, and was the efficient target, then it would also be valid to use the MAC, again in order to deliver the long-term target cost-effectively (though in this case, the implicit assumption is that the marginal abatement cost is equal to the marginal social cost, at the policy optimum, and along a path towards this over time).

The interviewees were also asked their specific views on the key parameters affecting the SCC: on discount rate, equity weighting and time-scales.

Discount rates. There was no-one who argued for high discount rates, and most respondents advocated the use of the existing Green Book declining discount rate scheme. Several respondents felt that 0% discount rates, or lower declining schemes (e.g. Weitzman) would be more valid[51]. There was also written comments on the discount rate in response to the briefing paper.

Equity Weighting. Nearly all respondents acknowledged that some form of equity weighting was appropriate. There was less certainty about the exact weighting scheme that should be used (not least because there is no definitive guidance in the Green Book). The exact approach was the subject of a major discussion at the SCC workshop. This centred on the viewpoint that the UK was adopting (e.g. from a UK policy perspective or an international policy perspective – see previous discussion under equity weighting in the previous chapter). Several respondents raised the inconsistencies between adopting a strong equity-weighting scheme for climate change, but not for other policy in relation to international development funding and trade. This was raised as a question in later interviews - the general response being that if the rules were changed for climate change (e.g. in relation to equity weighting or discounting), then the implications for other policy areas would need to be considered.

Time-scale. There were also some disagreements on the appropriate time-scale. Most agreed a period to 2200 was appropriate, not least because of the residence time of greenhouse gases, but also because of the long response times of the climate system. Some felt 100 year was as far as was appropriate, citing the uncertainty in predictions even over periods of 50 years. Many felt that the analysis should be extended to the future point when discounting reduced any effect to zero (though of course, this is linked to the choice of discount rate).

Summary

When views were collated, there were a number of key messages emerging:

- All stakeholders saw the need for using a shadow price of carbon in detailed appraisal. (i.e. for project appraisal and regulatory impact assessment. These reflect appraisal at lower levels compared to strategic long-term objectives. However there was disagreement on how these shadow prices should be derived.
- Nearly all stakeholders recognised the need for some form of benefits analysis for setting long-term targets, though views varied on the form analysis should take;
- All stakeholders agreed that once a long-term goal had been set, detailed (lower level) policy appraisal should be consistent with it;
- All stakeholders agreed the need for concise guidance for day-to-day appraisal, which is implemented consistently across applications;
- All stakeholders agreed that there was a need for further research to progress the analysis of costs and benefits, and in particular, more work on the disaggregation of impacts and values.

This would suggest that a shadow price of carbon emissions should be maintained for project and policy appraisal across Government, that it should be consistent with longer-term policy goals, and that it should be implemented consistently across applications. However, there were three key areas where the respondents had differing views. These were:

- *Whether the shadow prices for appraisal should be based on estimates of marginal abatement costs (MAC) consistent with the existing UK long-term target (a 60% reduction in CO_2 emissions by 2050), or should use the estimate of the marginal damage costs of carbon emissions (SCC).*

[51] The peer review has highlighted that it should not be taken for granted that all regions of the world will experience economic growth in the future (for example, Africa's per capita income has declined over the past quarter century). Estimates of SCC should explore the possibility of negative growth rates in some parts of the world.

These views reflect different methodological viewpoints amongst stakeholders and are discussed further below.

- *Whether to adopt a central value or a range for the value in appraisal*. Whichever approach is adopted (SCC or a MAC), there were different views on whether day-to-day appraisal is best served by the use of single, central value or by a range. In theory a range of uncertainty could be used consistently in different applications. However in practice in several contexts users are likely to prefer to work with a single value. Several stakeholders (specifically from the users group) have expressed concerns that the indication of a range is more open to the risk that practitioners may tend to emphasise the single value within the range that better suits them. Therefore, most interviewees recognised that there was a trade-off between 1) consistency across applications, which would be achieved through the indication of a single value, and 2) consideration of uncertainty, which would be achieved through the indication of a range.
- *Whether to use Green Book guidance or to use an alternative scheme for discounting – and on the appropriateness of equity weighting*. There were different views on whether it was appropriate to use the Green Book guidance (for example with declining discount rates), or to introduce schemes that would recognise that climate change was a special application. There were also different views on whether equity weighting should be included, on the exact equity weights that should be adopted, and over consistency with using equity weights for climate change vs. other policy areas. While there was considerable support for the use of the Green Book declining scheme, there was a wide and divergent set of views on equity weighting.

While respondents recognised the need for shadow prices for appraisal (detailed day to day applications), they had more divergent views on the approach that should be adopted for long-term climate change objectives. This ranged from those who believed cost-benefit analysis was also appropriate in this context, through to those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy. They believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle. Some respondents in this group also raised the issue of the duty of care and human rights.

Other issues that were raised included:

- The large uncertainty over the marginal abatement associated with the 60% long-term target.
- The need to truth test decisions, i.e. to examine the implementation of existing policy appraisal and consider what does value mean for decisions we have taken and are taking in the near future;
- That it might be prudent to consider a wide range of analysis for large-scale investment where there could be sunk costs from later changes;
- The interpretation of the cost of carbon emerging from emission trading schemes, i.e. permit prices, and the need to consider this (or account for it) in certain types of appraisal;
- The potential conflict between using a permit price as a MAC, because of the use of international trades, and the potential inconsistency with delivering domestic emission reduction goals;
- The use of declining discount rates for the SCC within an economic analysis using a 3.5% SRTP.
- Whether to include ancillary benefits.

The peer review of this report has also raised a number of additional issues. Many of these relate to the issue of equity weighting[52].

[52] Related to this is the issue of distributive justice. This is an important component of policy making, and is an especially important issue in relation to climate change, with its differential impacts within and between nations and between generations. Using equity weighting does not capture the concept of distributive justice.

6 Policy Perspectives, Values and Recommendations

This Chapter expands the different policy perspectives outlined at the end of the previous chapter, and assesses the potential values that would follow for appraisal. It also reviews these perspectives and makes recommendations.

The variation in stakeholder views on the use of marginal abatement costs or social costs reflects the different perspectives of individuals towards policy appraisal in general, and towards climate change policy in particular. We have summarised these into three broad groups.

- A first group believes that cost-effectiveness should be the primary consideration when appraising lower-level policies, given that the UK Government has already set a long-term (2050) target for reducing emissions of CO_2. Such an approach should lead to the achievement of this goal at least cost. Within this group there were two related lines of argument. There are those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy and targets. They believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle. Some respondents in this group also raised the issue of the duty of care and human rights. There are also those that believe that when policy is not easily based on an objective assessment of the costs and benefits (as with climate change), the process of target setting helps to reveal the weight which society puts on costs and benefits. They implicitly believe that policy makers use the available information to make the most efficient decisions possible with the knowledge available. Independently of the underlying interpretation of the process of target setting, the policy recommendation from this group is that for day-to-day project and policy appraisal, it would be relevant to use marginal abatement cost (MAC) estimates that are consistent with the existing overall policy goal (the 60% target) as a shadow price for carbon emissions.
- A second group starts from the position that unless policy makers have a good understanding of the costs and benefits, targets may be set at an inefficient level. They believe that formal cost-benefit analysis leads to better policy making, through its transparency and consistency, and its explicit attempt to assess the optimal policy outcome. The policy recommendation from this group isto use the SCC estimates across all levels of policy appraisal, including for the setting of long-term targets as well as detailed, day-to-day project and policy appraisal.
- A third group accepts that cost-benefit analysis is a useful input to policy decision-making, but highlighted concerns over what they see as simplistic application of SCC values for longer-term climate change policy. This group also drew attention to the considerable uncertainty in both MAC estimates and SCC estimates and recommended a pragmatic approach that would consider and compare both sets of estimates to derive a shadow price for detailed, day-to-day project and policy appraisal.

The next sections present the available information on the possible values for use in appraisal.

6.1 The Pattern of Marginal Abatement Costs Over Time

The starting point for the marginal abatement costs towards 2050 long-term CO_2 target is the analysis undertaken for the Energy White Paper (DTI, 2003). Extensive analytical work was undertaken to look at the costs and the implications of meeting the Government long-term goal before the commitment was made in the energy White Paper. In particular, the technological feasibility and the costs implications of reaching such a target were analysed through a major modelling exercise involving the calibration of the MARKAL model to the UK.

The supporting work was published in the Low Carbon Futures study (DTI, 2003), undertaken by AEA Technology Environment and Imperial College, using the MARKAL energy model[53]. The main marginal abatement cost estimates from the analysis are summarised below. The MARKAL analysis only predicts marginal abatement costs in the period 2030 – 2050.

Table 10. Marginal costs (£/tC) to meet 60 % CO_2 reduction in 2050 (constraints start in 2030 with 30 % reduction, increasing to 45 % in 2040 and 60 %in 2050). 2000 prices.

£/tC	2030	2040	2050
Low	0	13	242
Medium	93	193	351
High	143	229	538

Low - global sustainability with optimistic technology costs

Medium - business-as-usual

High - world markets (higher GDP growth)

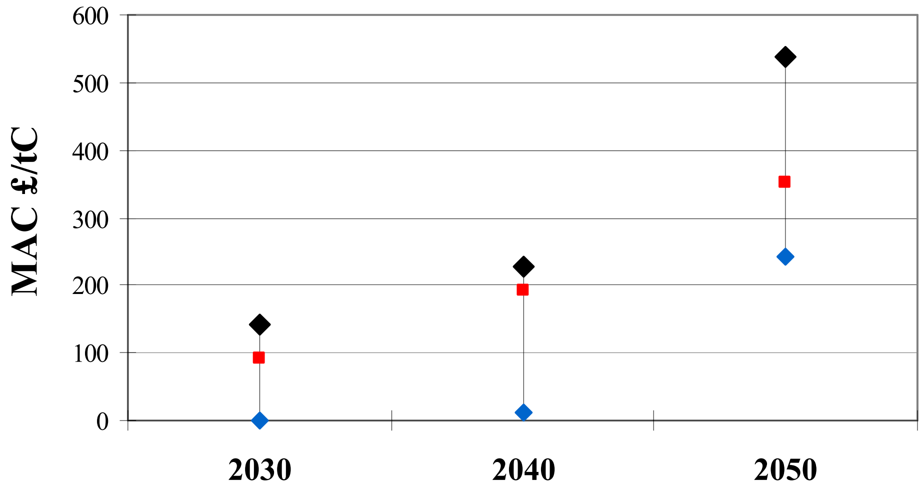


Figure 9. MARKAL Marginal Abatement Costs Towards the 60% 2050 Target.

Source: AEA Technology Environment (Future Energy Solutions)

[53] The work was n input to the Inter-departmental Analysts Group and later to the Energy White Paper development process. It was undertaken by Future Energy Solutions (FES, AEA Technology Environment) and Imperial College Centre for Energy Policy Technology (ICEPT) and investigated scenarios for CO_2 emissions reductions. The study applied the MARKAL model to investigate the technical options for, and costs of, meeting a range of CO_2 emission reductions in the energy sector by 2050 and at some intermediate points. The work was published as Annexes C and D of DTI (2003), and summarised in '*Options for a Low Carbon Future: Review of Modelling Activities and an Update'*.

There is clearly a need to have values for 2000 – 2020 as well[54]. In addition, the use of the marginal abatement costs toward the 2050 target does not help in providing values post 2050. For some cases (e.g. transport infrastructure appraisal) the period of the appraisal extends beyond 2050.

The MARKAL studies estimate costs would rise from a low level today to a range of 0.5-2% of GDP by 2050, in order to meet the 2050 target.

Note the marginal costs above are much higher than the average costs during each period. The marginal costs here reflect the marginal technology (which represents the 'final' tonne of carbon abated), and some commentators felt that using average costs may be more appropriate for policy makers, rather than the actual marginal abatement cost (though the marginal cost is the relevant parameter for a theoretical CBA exercise and we have used this metric here).

This study initially proposed to consider the White Paper analysis, and the marginal abatement costs from the Low Carbon Futures study, as the starting point for discussion about the relevant marginal abatement costs of the current long-term goal (or at least a discussion of relevant shadow prices for appraisal[55]). However, the peer review process made a number of comments criticising this approach, the most important of which are summarised below in the box.

Discussion of the Relevant Marginal Abatement Cost towards the 60% Target

The Energy White Paper accepts that the UK should put itself on a path to a 60% reduction target, but it does not take policy decisions as to specific measures on how to achieve this. The view was taken that the MARKAL work on the costs of achieving the 2050 target was sufficient to allow the RCEP recommendation to be accepted (and demonstrated that the overall (average) costs need not be prohibitive). The medium-term analysis (to 2020), which was not based on MARKAL analysis, concluded that the illustrative package (e.g. Emission Trading Scheme, energy efficiency) could largely be delivered with the illustrative central SCC value of £70/tC.

The steering group and peer review process has raised a number of comments in relation to the MARKAL analysis. A number are included below.

- The MARKAL costs are very uncertain, and the estimates will change over time.
- The SCCs from PAGE and FUND are for a global SCC. The marginal abatement cost in terms of the 60% UK target is not the same, and there are many features about the UK energy system that are missing from the models and that should be taken into account in assessing costs of the 60% under expected UK conditions, e.g. in a multi-criteria analysis also assessing energy security and fuel poverty.
- MARKAL does not use the marginal cost at all, being a least-cost model, based upon partial, not general, equilibrium approaches. (It gets its result for GDP by a simplistic model of economic growth, plus the non-marginal observation that the energy sector in national income accounts is a small percentage of GDP.) Basically, if one feeds in numbers for the costs of defined technologies, to a small base, and uses a crude aggregating growth model, then the result is not surprising.
- The use of costs from top-down models implies that mitigation policies are always costly, whereas macroeconomic effects as measured by GDP in such models and reported in the literature can be negative or positive, i.e. costs or benefits.

Comparing with wider modelling work available at the time, the MARKAL cost estimates of 0.5 to 2% of GDP in 2050 fit well. (http://www.dti.gov.uk/energy/whitepaper/annexes.pdf). For example, analysis for the Pew Centre using a general equilibrium model showed, for a 70% cut in emissions

[54] There was some analysis of the costs of shorter-term measures in the Energy White Paper, which found the average costs of measures necessary to meet the 2020 interim target of additional reductions of 15-25 MtC were in the range of £10 - 80/t C (note these were not the marginal costs).

[55] One point raised by a member of the steering group is that policy makers accepted the long-term target based on the MARKAL analysis. If we accept the premise that the process of target setting reveals the weight which society puts on the costs and benefits, i.e. policy makers implicitly consider this to be the optimal policy path, then these costs are the most appropriate values to use in future appraisal. However, it could also be argued that policy makers also had illustrative information on the SCC at the time they chose the abatement path.

from base for the U.S., costs of –1.6% to +1.2% in 2050, depending on the recycling of tax revenues. Working Group III of the IPCC gave an average of estimated cost impacts of around 1% in 2020, rising to 1.5% in 2050, before declining to 1.3% in 2100. Of studies with above average costs, most are still below 3% of GDP.

Other modelling work undertaken since the White Paper does support these conclusions. Analysis by the US EIA of the requirements of the 2003 Climate Stewardship (McCain-Lieberman) Act concluded that emissions in 2025 would be a third lower than BAU, with an impact on GDP growth of 0.02% per annum over 25 years (EIA, 2003). A review of the EIA work by the Pew Center concluded that even these costs were over-estimated, because of the assumptions used: economy on production frontier; restricted use of new technology; no value attached to ancillary benefits. Similarly, modelling by the CPB Netherlands Bureau for Economic Policy Analysis examining a 30% emissions reduction by 2020 estimated costs of 0.8% of GDP in 2020, provided there was international action and efficient emissions trading.

At a European level, there have been some detailed forecasts of the likely marginal abatement costs policies under the 1st commitment period of the Kyoto Protocol and beyond, and permit prices within the EU GHG Emissions Trading Scheme.. These have been calculated at €12/tCO_2 in 2010, €16/tCO_2 in 2015 and €20/tCO_2 in 2020. This is approximately £30/tC in 2010, £40/tC in 2015, and £50/tC in 2020. These costs are from the report of the European Climate Change Programme (ECCP, 2001), based primarily on the earlier sectoral targets study which looked at the marginal abatement costs of meeting Kyoto for the EU15 assuming an EU15 emissions trading scheme (EC, 2001). The report identified 42 possible measures, which could lead to some 664-765 MtCO_2 equivalent emissions reductions that could be achieved against a cost lower than 20€/tCO_2eq. (~£50/tC). This is about double the emissions reduction required for the EU in the first commitment period of the Kyoto Protocol with respect to 1990. They were therefore used to provide approximate costs for future policy (i.e. post Kyoto) for a 2020 scenario. The ECCP also estimated the likely costs for the Kyoto commitment period and 2015 (€12/tCO_2 in 2010, €16/tCO_2 in 2015 - ~£30/tC and ~£40/tC). However, these do not represent the marginal abatement costs of domestic UK action in the short-term. Firstly, the values are based on the likely marginal abatement costs for a EU (25) wide greenhouse gas emissions trading scheme, and will have lower marginal abatement costs than domestic UK action. Secondly the scheme allows (in the first commitment period (to 2012)) for some level of international (non-EU25) trades. Finally, the emissions reductions are not consistent with a level of abatement required to put Europe on a path towards a long-term (e.g. 60%) target. These values are therefore likely to underestimate the marginal abatement cost profile towards the UK 60% CO_2 reduction (if we assume that the target is reached through domestic action)[56]. We do not believe they represent the implict value that the UK assigns to carbon reductions (for those who give this interpretation to MACs) and they are not directly related to the UK domestic targets or to the assessment of the SCC based on the amount of abatement needed to reduce emissions to the level needed to avoid dangerous climate change.

More recent work has been undertaken as part of the European Commission's post-Kyoto discussions. The European Commission (EC, 2005) has recently reviewed the costs of potential stabilisation targets, expressed either in relation to CO_2 concentrations (e.g. 450, 550, and 650 ppm CO_2 equivalent concentrations) or to temperature change (e.g. a limit of a 2°C rise above the pre-industrial level). It highlights that these estimates are uncertain, and that costs are also influenced by the amount of emission abatement that has to be undertaken to meet a particular target for atmospheric concentrations or temperature rise, and this depends on rates of growth of GDP and greenhouse gas emission intensities: over a period of 50 or 100 years.

[56] For example, the sectoral targets study estimated the marginal cost for emission reduction would be $€_{99}$ 20 per tCO_2 eq assuming full EU-15 trading. However, it also calculated that if each Member State fulfilled their target individually according to the Burden Sharing Agreement, the marginal abatement costs would increase from $€_{99}$ 20/tCO_2 eq. to $€_{99}$ 42/tCO_2 eq. (weighted EU average). The marginal abatement cost in each Member State would range from $€_{99}$ 1/tCO_2 eq. to over $€_{99}$ 100/tCO_2 eq.

An important factor in mitigation costs is the level of environmental ambition targeted post-2012. In addition the shape of the adjustment pathway – i.e. front-loading or back-loading of major reduction efforts – is also of crucial importance. Seen purely from the angle of keeping short-term mitigation costs low, a back-loading strategy that provides for only a moderate level of environmental ambition in the first decade post-2012 may appear preferable. Any such strategy will imply a steeper reduction pathway in later decades linked with higher mitigation costs and/or higher adaptation and residual damage costs.

The impact of the chosen ambition level was assessed in the study *"Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025"*(Criqui, 2005) which compares the economic costs of following pathways to two alternative stabilisation scenarios – 550 and 650 ppm CO_2 equivalent concentration levels – by 2025[57]. Under the more ambitious 550 ppm strategy, costs for the EU-25 in 2025 are in the range of 0.9 to 1.8% of GDP as estimated under a partial equilibrium model (POLES). This corresponds to up to 0.5% under a general equilibrium model. Under the less ambitious 650 ppm strategy, costs for the EU-25 in 2025 are in the range of 0.1 to 0.2% of GDP (partial equilibrium) and up to 0.12% under general equilibrium. The difference in the costs for pathways compatible with 550 and 650 ppm concentration levels is due to the difference in the level of global reductions necessary by 2025. IIASA (Nakicenovic and Riahi) has assessed the GDP effects of a pathway to 400 ppm CO2 only concentration level (comparable to a 500 ppm CO2 equivalent concentration level) against two alternative baselines and concluded that the world GDP in 2025 may decline by some 0.6 to 1.1% and in 2100 may be some 0.3 to 1.7% lower. Other recent studies indicate lower costs, especially as part of multi-gas approaches (e.g. Rao and Riahi, 2004).

Work by Barker et al (2002) has compared the MARKAL estimates to other values in the literature. This work found that the costs of reducing CO_2 emissions by around 60% by 2050 are mostly in the range 1.0 to 3.0% of GDP, as summarised below, with a few outliers of 0% and over 4%[58]. This compares to the results of the MARKAL energy model estimates (above) for the cost of CO_2 mitigation for the 60% target of 0.5 % to 2% of GDP in 2050. In their analysis of why results differ between models, the authors found that model characteristics and assumptions influence the results significantly..

GDP changes (representing the average costs of mitigation), are not closely correlated with the carbon permit price (Barker, 2005). Therefore, it is probably better not to convert GDP costs for an economy into an average cost per tonne of carbon abated because of the risk of confusion with the incremental cost.

[57] The Royal Commission target of 60% by 2050 is consistent with the level of reduction likely to be needed by developed countries in order to move towards stabilisation of carbon dioxide concentrations in the atmosphere at no more than 550 ppm, taking account of a realistic assessment of emissions growth in developing countries. Note the 550 ppm CO2 equivalent concentration level will result in a global mean temperature rise of less than 2°C for a low climate sensitivity value. The EC has recently concluded that if climate sensitivity turns out to be higher, the 2°C target will not be met by following this stabilisation level.

[58] Economic output by the energy industries in the UK accounts for approximately 4.1% of GDP, of which 1.6% is from electricity and 2.5% from oil, gas and coal. The share of the energy industries in world product is also around 4%, though this figure differs greatly between countries depending especially on the contribution of the extractive industries to their national products; the share is rising in developing countries, where the per capita income elasticities of demand are still high (typically around 1.5), and falling in the industrial countries where energy markets are maturing and the per capita income elasticities are around 0.5 and falling. These figures help to explain why the costs are low in GDP terms.

Costs are expressed as a percentage of projected GDP and are estimated by economic modelling methods

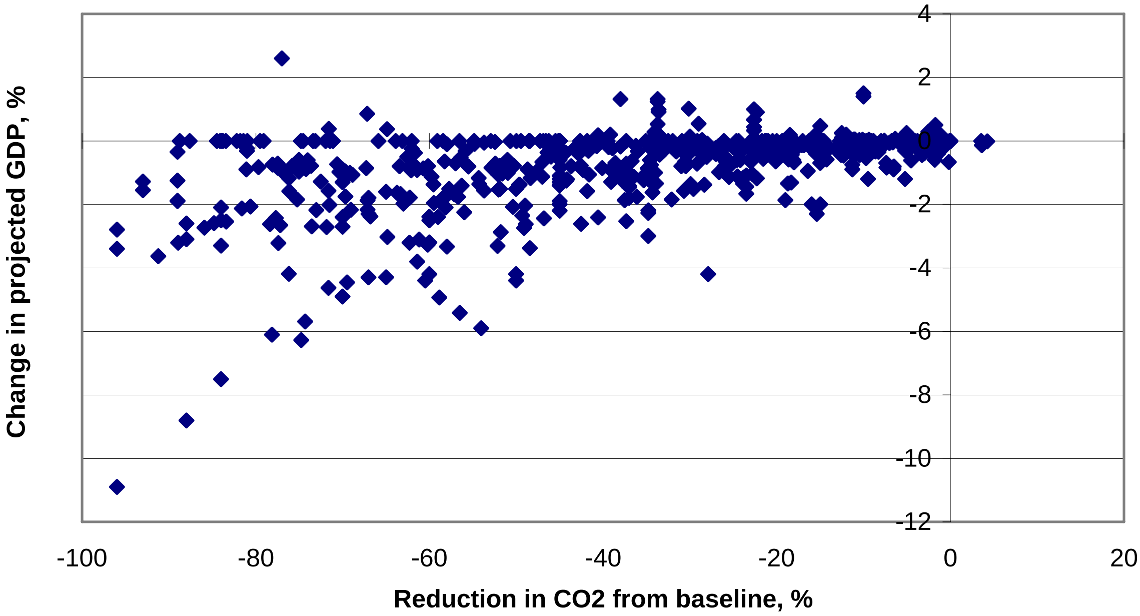


Figure 10. Estimated costs of reducing CO_2 emissions

Source: Taken from the survey and meta analysis of Barker et al (2002). The baseline varies between studies in the models.

Similarly, there have also been recent reviews that have concluded that the MARKAL costs may be too low (Helm, 2004).

The MARKAL analysis was considered alongside other studies discussed at a workshop 'Costs of decarbonising the UK and global economies' held at Imperial College on the 12th October, 2004. The write-up of the workshop (Foxon, 2005) is available at:
http://www.tyndall.ac.uk/events/past_events/decarb04.pdf

A recent review (DT, 2005[59]) after the workshop compared the MARKAL cost estimates (which reported costs of 0.5 to 2% of GDP) and concluded that this lower and upper central value is consistent with the central range of abatement costs in the literature. The review found studies elsewhere have indicated that the full cost range may be wider than this, from less than 0% (which would imply an increase of economic output) to over 4.5%. Most, however, fall in the range 0.5 to 3.5% (with a mean estimate of 2.5%).

The review also found that marginal costs of abatement in 2050 vary across scenarios, with most of the runs having marginal costs of less than £900/tC and more than 50% having costs less than £500/tC. Marginal costs in 2030 are much lower, typically between £25 and £150/tC. Average abatement costs vary much less between scenarios. For almost all scenarios, a similar set of measures is taken up as the most cost effective, with stable and relatively low costs. The very high marginal costs for some scenarios typically reflect the inclusion of one or more expensive options brought in, e.g., through sensitivity analysis. Whilst the costs of these specific measures may be high, they are responsible for a relatively small share of the overall abatement, and thus average costs fluctuate less.

Based on the consultation exercise, and the peer review process, we conclude that there remains significant disagreement on the potential costs of the 60% target, with the literature reporting that the

[59] Options for a Low Carbon Future: Review of Modelling Activities and an Update. Matthew Leach and Dennis Anderson (Imperial College London Centre for Energy Policy and Technology, ICEPT), Peter Taylor and George Marsh (Future Energy Solutions, FES). Published by the DTI, 2005. DTI web site at: http://www.dti.gov.uk/economics/6228-OccasionPaper1.pdf

original MARKAL costs may have been either too low or too high. This is an area that needs further work to move towards an agreed consensus on UK costs (as well as European or global costs). Defra has recently launched a review of the climate change programme, and this may provide information that would allow such estimates, at least for short-medium term measures. This will not, however, address the issue of longer-term costs.

Even the range of estimates in the Low Carbon Futures work is large. The graph below shows the marginal abatement costs from this study (2030 to 2050), and also from the ECCP study (to 2020) compared against the existing Defra guidance over the same time period. The full range of the LCF study is presented, as this broadly captures much of the range of literature values for the future MAC[60]. The graph shows that the ECCP values are lower than the existing guidance. This is not surprising as these reflect short-term abatement costs in a European trading environment. The Low Carbon Future central value is very similar to the existing illustrative central SCC value in 2030 £100/tC in 2030), but rises much more sharply in later years (i.e. for 2040 and 2050). Indeed the 2050 MARKAL MAC value is higher than the upper SCC value (of £240/tC in 2050).

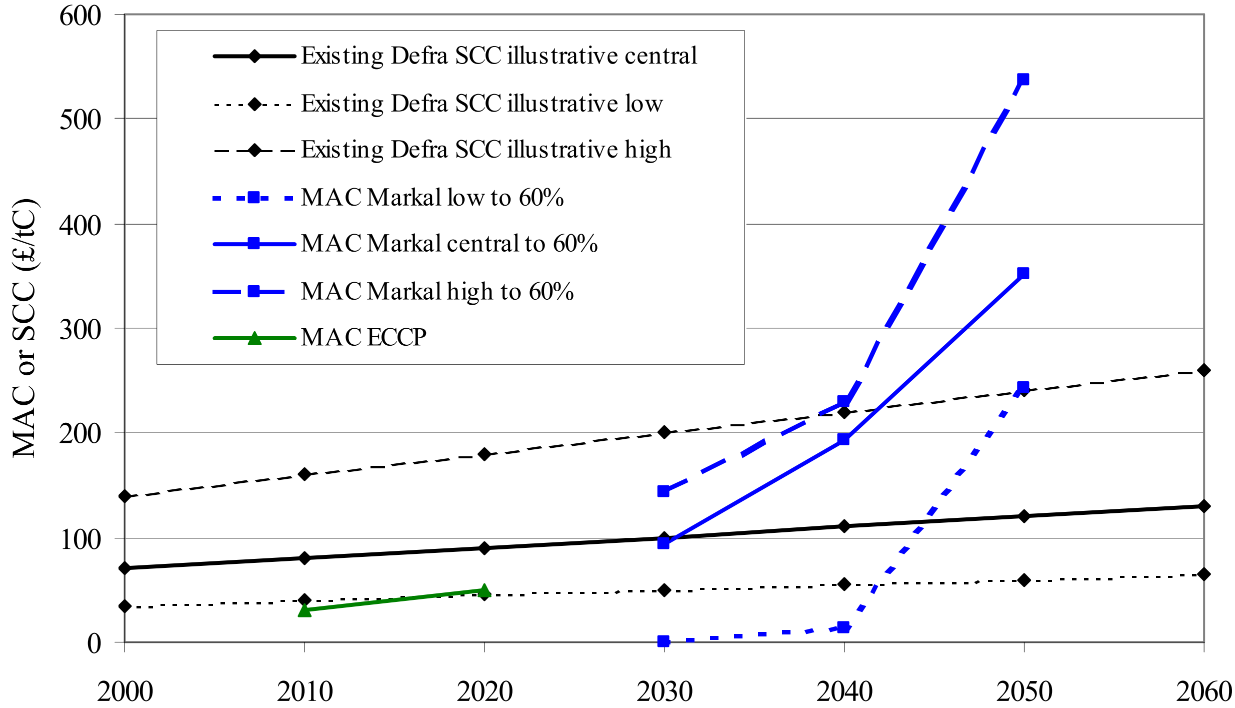


Figure 11. Marginal Abatement Cost from the Energy White Paper of Achieving the 60% target compared to the existing illustrative SCC estimates.

There is ongoing work in the current climate change review (in Defra) that will update the marginal abatement costs to 2010 and 2020. This should provide a valuable input for reconciling short-term estimates. However, further work is needed to investigate, and reach consensus on, the costs of abatement towards mitigation towards the long-term – if these values are to be used for input into shadow prices. This will require the use of a wide range of methods and models. This is highlighted as a priority for future research.

[60] We highlight that there are some studies which imply values below this range (those that imply an increase of economic output), and some above (the highest MAC estimates found would be almost double the high estimate presented below).

6.2 The Pattern of the Social Cost of Carbon Estimates Over Time

The modelling project (Downing et al, 2005) has presented the available information on the Social Cost of Carbon (SCC). The study conclusions on the range of values were:

- Estimates of the social cost of carbon span at least three orders of magnitude, from zero to over £1000/tC, reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables.
- A lower benchmark of £35/tC is reasonable for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting.
- An upper benchmark of the SCC for global policy contexts is more difficult to deduce from the present state-of-the-art, but the risk of higher values for the social cost of carbon is significant.

These conclusions relate to current emissions (i.e. in the period 2000 – 2010), and assume likely global baseline projections that do not include progress towards a stabilisation target (i.e. such as towards the UK 2050 target). For policy analysis, additional information is needed on the SCC values.

- Firstly, we need to know how the marginal social cost of carbon changes over time, with pulses in different periods, e.g. 2000 – 2010, 2010 – 2020, etc. This is needed to estimate future social costs of carbon.
- Secondly, for longer-term policy analysis, we need to know how much the social cost of carbon changes with different policy options. For example, if we want to derive a SCC consistent with the 2050 target, we need to know how the SCC changes under this future global scenario.

These aspects were not fully covered by the modelling work, and so some additional model runs have been commissioned using the FUND and PAGE models. These are summarised below, with details in Appendix 3 and 4.

6.2.1 PAGE

The PAGE model is described in the modelling report. In brief, PAGE2002 is an updated version of the PAGE95 integrated assessment model (Plambeck, Hope and Anderson, 1997, Plambeck and Hope, 1995 and Plambeck and Hope, 1996). The main structural changes in PAGE2002 are the introduction of a third greenhouse gas and the incorporation of possible future large-scale discontinuities into the impact calculations of the model (IPCC, 2001a, p5). Default parameter values have also been updated to reflect changes since the IPCC Second Assessment Report in 1995. The full set of equations and default parameter values in PAGE2002 are given in Hope, 2004. Most parameter values are taken directly from the IPCC Third Assessment Report (IPCC, 2001b).

Rather than only give single estimates, PAGE builds up probability distributions of results by representing 31 key inputs to the marginal impact calculations by probability distributions.

The model has been used to assess the social cost of carbon at different times. Full details are presented in Appendix 3.

Firstly, a baseline scenario has been run, based on the IPCC's SRES A2 scenario. This run includes PPP exchange rates, Green book SRTP, an equity weight parameter of 1.

The analysis gives mean results of $66 (in $2000) per tonne of C, with 5% and 95% values of 13 and 185 $(2000) per tonne of C for 2000 emissions, equivalent to £46/tC, and 9 and 130/tC[61]. The analysis has looked at emission pulses in different years, assessing 2001, 2002, 2010, 2020, 2040, and 2060.

[61] PAGE reports damages in USD2000. Consistent with the modelling study, we have converted PAGE results from USD2000 to GBP2000 ($1.42 = £1) using purchasing power parity exchange rates from 2000.

The results are shown in the table below and also in the graph. The original PAGE $2000 values and values discounted back to the year 2000 are shown in the appendix. Whilst PAGE includes some consideration of major events, it excludes socially contingent effects, thus the SCC may be underestimated.

Table 11. PAGE results for SCC value over time (in £). Values presented for year of emission.

	SCC in year of emission (£/tC)		
	5%	**mean**	95%
2001	9	**46**	130
2010	12	**61**	159
2020	14	**77**	215
2040	27	**127**	324
2060	34	**187**	513

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The best fit to the mean values is a 2.4% increase in SCC each year; the best fit to the 5% and 95% values have them increasing at 2.3% per year. This compares with the Defra recommendation to increase the SCC by £1/tC per year. This is equivalent to an immediate year on year rise of 1/70, or 1.4% per year, but clearly declines in later years (e.g. the central SCC value in 2010 is £80 - in 2011 it is £81 - an increase of 1/80 or 1.25%].

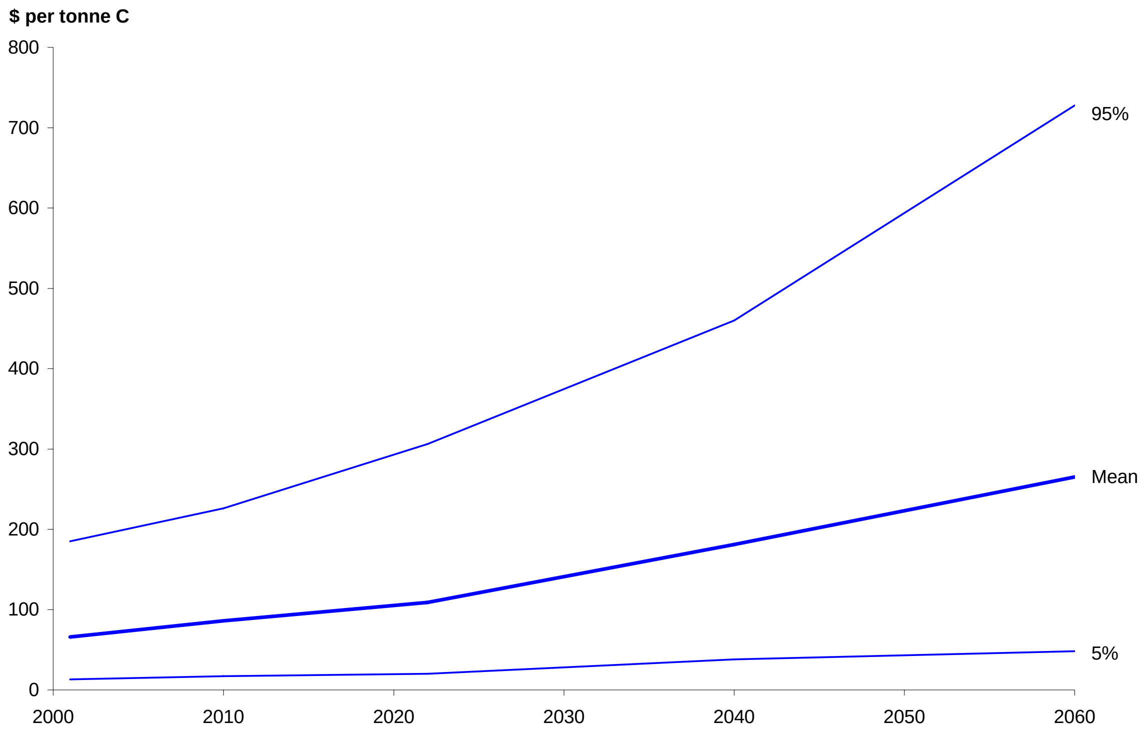


Figure 12. Social Cost of Carbon by Date of Emissions (PAGE). $2000 values. Greenbook

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

A similar analysis has also been made for methane. The mean, 5% and 95% values, for the change over time are shown below.

Table 12. PAGE results for the Social Costs of Methane over time.

	SC in year of emission (£/tCH4)		
	5%	**mean**	**95%**
2001	41	**194**	530
2010	75	**317**	842
2020	102	**458**	1220
2040	196	**920**	2487
2060	302	**1744**	5059

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The social cost (SC) of methane increases far faster than for CO_2, as shown in the graph below. Indeed, the SC discounted to 2000 actually rises over time. This is because of the short atmospheric lifetime of methane; any methane emitted today will have disappeared from the atmosphere before the most severe climate change impacts start. This implies that given a choice today between emitting 1 tonne of methane now, or at some time up to 60 years in the future, we should opt to emit it now. The best fit to the mean values in the year of emission is a 3.6% increase in SC of methane each year.

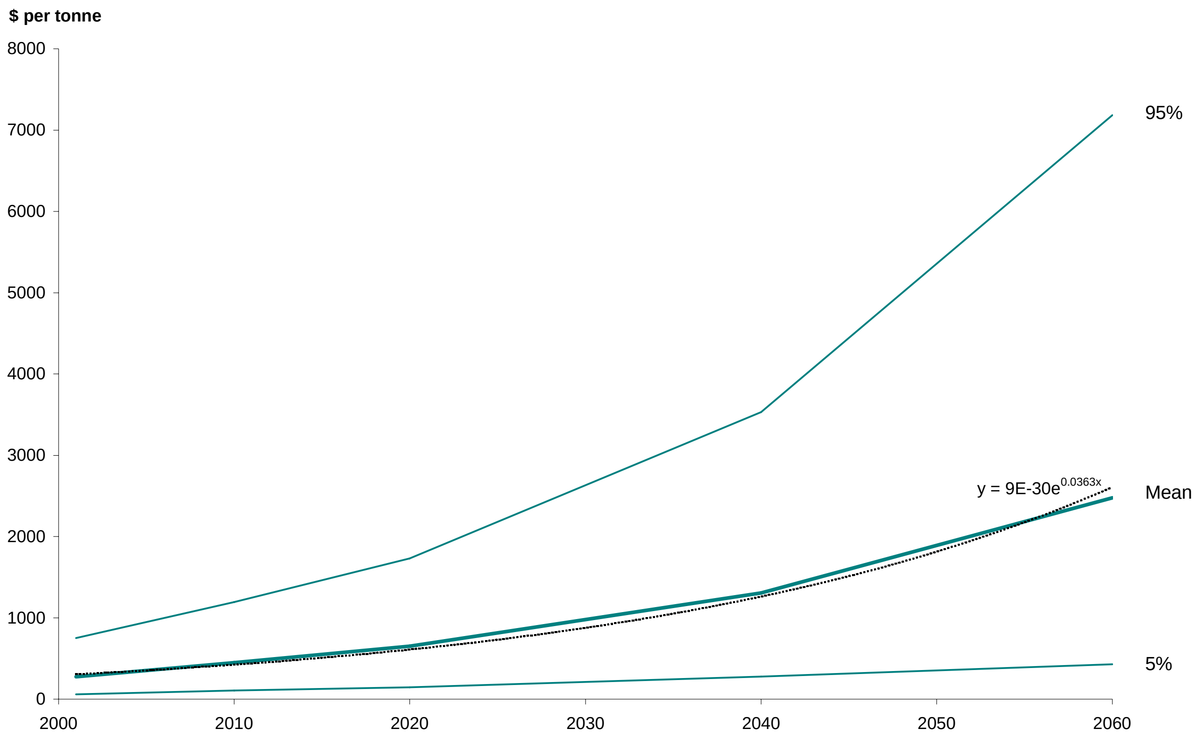


Figure 13. Social Cost of Methane by Date of Emissions (PAGE). $2000 values. Greenbook

Based on the A2 scenarios, with PPP exchange rates, Green book SRTP, an equity weight parameter of 1. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The analysis with PAGE has also started to assess the rise in the SCC under different future scenarios, trying to assess the SCC under a path towards the UK 2050 target, equivalent to a 550ppm CO_2 concentration[62].

[62] Using figure 3 of http://www.defra.gov.uk/environment/climatechange/ewpscience/ewp_targetscience.pdf . Because of the stimulation of natural CO_2 that is included in the PAGE model the scenario does not actually stabilisize at 550ppm. PAGE gives mean concentrations of 650 ppm in 2100 (90%CI: 587 to 717 ppm), and 774 ppm in 2200. This compares to mean concentrations of 815 ppm in 2100 for A2 (90%CI: 725 to 871 ppm), and 1450 ppm in 2200.

The analysis under this scenario gives a present day SCC of 64 $ per tonne C (with 5% and 95% of 13 and 178). This is very similar to the values from the A2 scenario, i.e. it implies a relatively constant SCC value (£ per tonne emitted) under different future scenarios – when it would have been expected that different SCC values would arise under different scenarios[63]. Note, as PAGE does not fully include all major events, and does not include socially contingent effects, both the level and the reduction of SCC may be underestimated.

Sensitivity analysis
A number of additional PAGE runs have been made to test the sensitivity of key parameters. For 0% PRTP rate with equity weights, the value increases from a mean of 64 $(2000) per tonne of C, with 5% and 95% values of 13 and 179 $(2000) per tonne of C (the baseline above), to 385 $ per tonne C (79 to 1037 $ per tonne C).

For 0% PRTP rate with no equity weights, the mean value is 2835 $(2000) per tonne of C (457 to 7867). These assumptions give a 0% discount rate overall, so the values will be underestimates, as they do not include contributions from post-2200, which will be quite significant.

At first glance, this result may seem counter-intuitive - why is the SCC higher with no equity weights?. The reason is that no equity weighting implies that the marginal elasticity of utility with respect to consumption is zero, and so the discount rate is zero if the PRTP is zero. With equity weighting using a value of 1 for the negative of the marginal elasticity of utility with respect to consumption, the discount rate is equal to the increase in per capita GNP, which is 1.5% per year in all regions from 2100 onwards, for instance. This positive discount rate far outweighs the increase in developing country impacts that equity weights bring, giving a higher SCC overall without equity weights than with them.

6.2.2 FUND

The FUND model is described in the modelling report. In summary, FUND (The Climate Framework for Uncertainty, Negotiation, and Distribution model), version 2.8, is an integrated assessment model, which couples demographics, economy, technology, carbon cycle, climate, and climate change impacts. FUND2.8 includes: sea level rise, energy consumption, agriculture, forestry, water resources, cardiovascular and respiratory diseases, malaria, dengue fever, schistosomiasis, diarrhoea and ecosystems, at varying levels of detail. Other impacts are unknown. The model includes reduced forms of more complex models. It values impacts using standard monetary valuation methods, particularly benefit transfer. It has a time period through to 2300, and has 16 world regions.

The analysis has first assessed the social costs under different assumptions. Full details are presented in Appendix 4. The FUND model has been run with a full Monte Carlo analysis, and the median and mean results from this analysis reported. The appendix also shows the results for the parameter choices characterised historically as 'best guess' though this nomenclature is not necessarily appropriate[64]

There has been some debate within the project on which FUND estimates should be used for policy considerations, as the choice of mean or median values has a significant impact on the values. The

[63] The relative insensitivity between scenarios is not straightforward. It is caused by the interplay between the logarithmic relationship between forcing and concentration (which will tend to make one extra tonne under the 550 ppm scenario cause more damage), the non-linear relationship of damage to temperature (which will tend to make one extra tonne under the A2 scenario cause more damage), and discounting (which will tend to make early damage more costly than late damage). Initial additional analysis suggests that broadly the same happens with lower stabilisation targets (e.g. the SCC for a 450 ppm scenario is only slightly lower than for the baseline or the 550 ppm level).

[64] This is the model 'best guess' for all parameters. The best guess for climate sensitivity is 2.5 degrees Celsius equilibrium warming for a doubling of the atmospheric concentration of CO_2. Recent evidence suggests that the probability of higher climate sensitivity may have increased – see Report of the Steering Committee, International Symposium on Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, 2-5 Feb 2005.

mean values are significantly higher than the median, because the distribution is right skewed, and with right skewed distributions the median is less than the mean. The full FUND output includes a substantial proportion of negative SCC values (i.e. showing positive effects from climate change), but it also has a strong skew toward higher numbers, well beyond $150/tC. However, for the full suite of FUND results, there are a considerable number of extreme values. Some may be anomalies in the model and are to be regarded as outliers.. The mean will be sensitive to outliers[66]. We have therefore examined trimmed means. We have trimmed 1,5,10 and 20% of the values – considerations of continuity suggest that the 1% trimmed mean value removes the true outliers since all remaining values appear to be within a plausible distribution in that several runs within the 1000 iterations.

For the following analysis we have concentrated on the use of the Green Book declining discount rate (other schemes are presented in the Appendix). FUND model runs have been undertaken as part of the policy study to look at how the SCC estimates change in future years (i.e. from marginal emission pulses in later decades). The numbers are reported with Green Book declining discount rate scheme and with and without equity weighting. The results are summarised below and presented in full in Appendix 4[68]. The values assume 250 future years of damage in all cases.

Table 13. FUND results for the Social Costs of Carbon over time. GreenBook Discounting. Without and with equity weighting.

	SC in year of emission (£/tC) No equity weighting						
Year of emission	**Trimmed Mean (1% Trimmed)**	**Trimmed Mean (5% Trimmed)**	**5% value**	**25% value**	**Median**	**75% value**	**95% value**
2000-2009	23.1	23.2	-52.2	-11.5	8.7	46.7	173.3
2010-2019	32.9	28.9	-42.0	-11.9	11.2	51.4	202.7
2020-2029	41.6	37.4	-40.9	-11.2	14.4	68.2	241.9
2030-2039	51.2	42.6	-41.0	-10.0	17.7	70.3	260.7
2040-2049	51.2	45.3	-48.5	-9.9	19.9	81.1	271.2
2050-2059	66.3	57.1	-47.9	-8.4	24.4	97.1	319.9
	With equity weighting						
Year of emission	**Trimmed Mean (1% Trimmed)**	**Trimmed Mean (5% Trimmed)**	**5% value**	**25% value**	**Median**	**75% value**	**95% value**
2000-2009	64.6	46.0	-53.2	-9.6	20.7	75.2	309.2
2010-2019	75.0	56.5	-46.1	-10.0	25.4	79.6	378.2
2020-2029	85.0	68.6	-45.9	-10.1	31.2	91.9	481.9
2030-2039	95.0	73.7	-40.6	-6.1	39.5	106.4	458.1
2040-2049	97.4	81.2	-46.9	-5.2	43.1	117.1	497.8
2050-2059	128.8	100.6	-39.6	-2.2	49.1	135.5	575.1

PPP exchange rates, Green book SRTP, with and without equity weighting. The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The trimmed mean values exclude outlier points from the Monte Carlo analysis– the 1% trimmed mean excludes the 10 of the 1000 runs (0.5% at either end), the 5% trimmed mean excludes 50 runs (2.5% at either end of the distribution).

[66] However, extreme values remain that are possibly conditions in which the impacts of climate change are no longer marginal to the projected economy. That is, the impacts have affected economic growth and resulted in large scale changes to regional economies. In effect, the FUND model results may be drawn from more than one population—those scenarios that conform to the model's expectation of marginal impacts and those scenarios that indicate non-marginal changes in regional economies. The full results are included in Appendix 4.

[68] FUND uses USD1995 as the benchmark. Consistent with the modelling study, we have inflated the FUND results to USD2000 by using the average U.K. Retail Price Index over the period from 1995 to 2000, an increase of 22.5%. We have then converted both FUND results from USD2000 to GBP2000 ($1.42 = £1) using purchasing power parity exchange rates from 2000.

The distribution of FUND results with Green Book discounting schemes and equity weighting gives quartile values of £-10/tC, £20/tC, and £75/tC, with a trimmed mean value (1%) of £65/tC (rounding off to convenient whole numbers). The 5% and 95% values are £–50/tC and £310/tC.

The rate of increase for the FUND mean values (trimmed mean) in future years is lower than the PAGE runs (see earlier graph and discussion), but is very similar to the existing Defra guidance (indeed, the 1% trimmed mean is almost identical to the current central value in both starting value and rate of increase). Part of the reason for the higher step change in PAGE in later years is because this model considers some major effects (non-linearities) in later years.

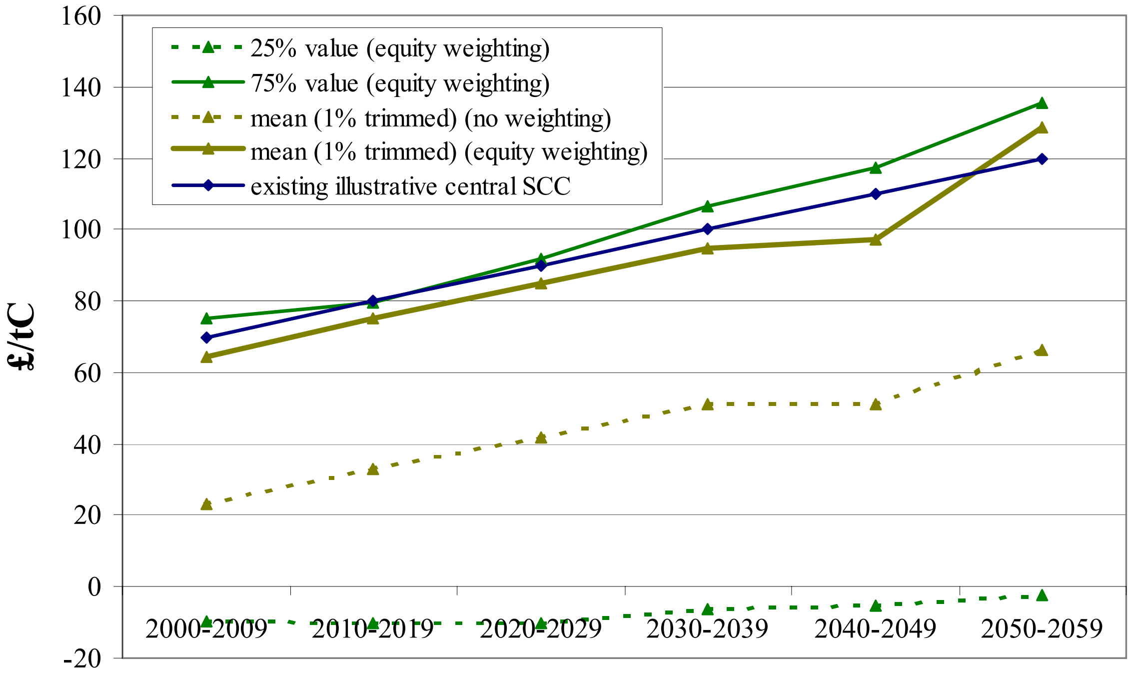


Figure 14. Social Cost of Carbon by Date of Emissions (FUND). £2000 values. Greenbook discounting, with and without equity weighting.

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

With different future scenarios, the SCC values might change, for example on the path towards a 2050 target we might expect lower SCC values in future years. The study has also assessed the possible SCC values from FUND under different future scenarios, consistent with different emissions paths and global policies. Unfortunately it has not been possible to run the full Monte Carlo analysis for this – so results are only given for a single FUND model run. These are included in Appendix 4. A full Monte Carlo analysis is a priority for future work. The results indicate - in contrast to the PAGE results shown earlier - that the SCC falls with lower CO_2 stabilisation concentrations, which is consistent with the expectation that progress towards 550 ppm stabilisation should reduce potential damages of climate change. However, as FUND does not include any of these major events, any socially contingent effects, and excludes many bounded risks, both the level and the reduction of SCC may be underestimated.

6.2.3 Comparison of SCC data and input from the modelling study

The graphs for the main estimates from PAGE and FUND are shown below, set against the existing SSC illustrative guidance. In summary:

- The mean estimate from the PAGE model (with Green Book discounting) shows a lower starting point compared to the existing illustrative central value (the £70/tC). However, PAGE shows a much sharper rise in the SCC estimate in future years (i.e. above the current recommended increase of £1/tC per year), so that the future PAGE estimates are well above the existing illustrative SCC value after 2030. Note PAGE does not include socially contingent effects, so would be expected to be underestimating the SCC values.

- The mean estimate from the FUND model (1% trimmed with Green Book discounting) is very close to the existing Defra illustrative central value, and has a similar rate of increase in later years. Note FUND does not include socially contingent effects or major effects (or all bounded risks), so would be expected to be underestimating the SCC values, particularly in later years.

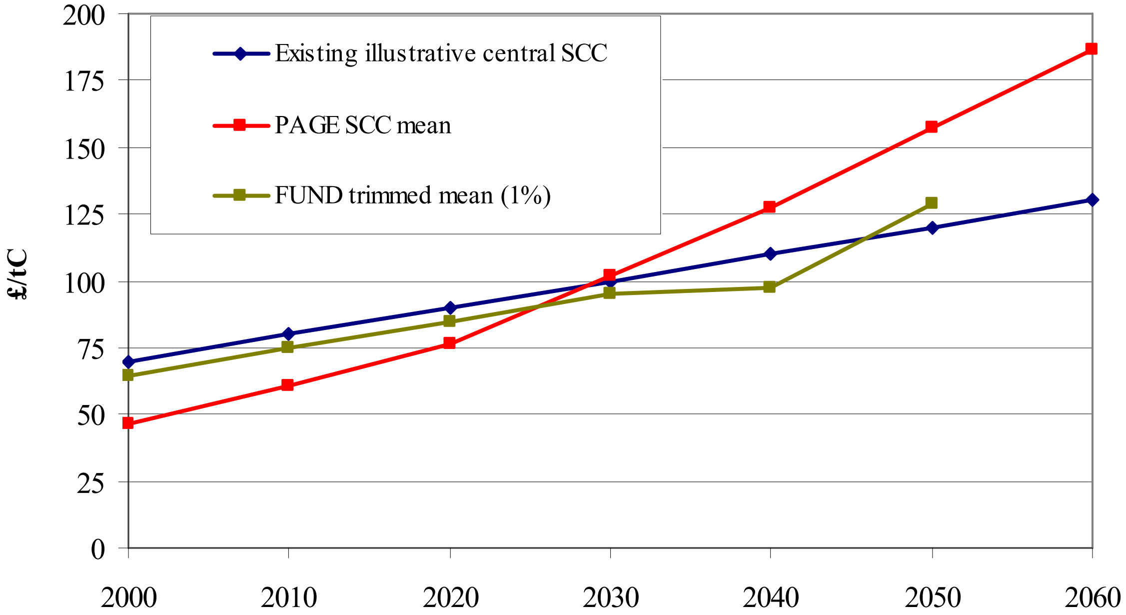


Figure 15. Model SCC estimates (central) compared to the existing illustrative SCC estimates (assuming Green book discounting and equity weighting, business as usual)

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The comparison of the full illustrative Defra range (£35/tC to £140/tC) is compared to the 5% and 95% values from the models below.

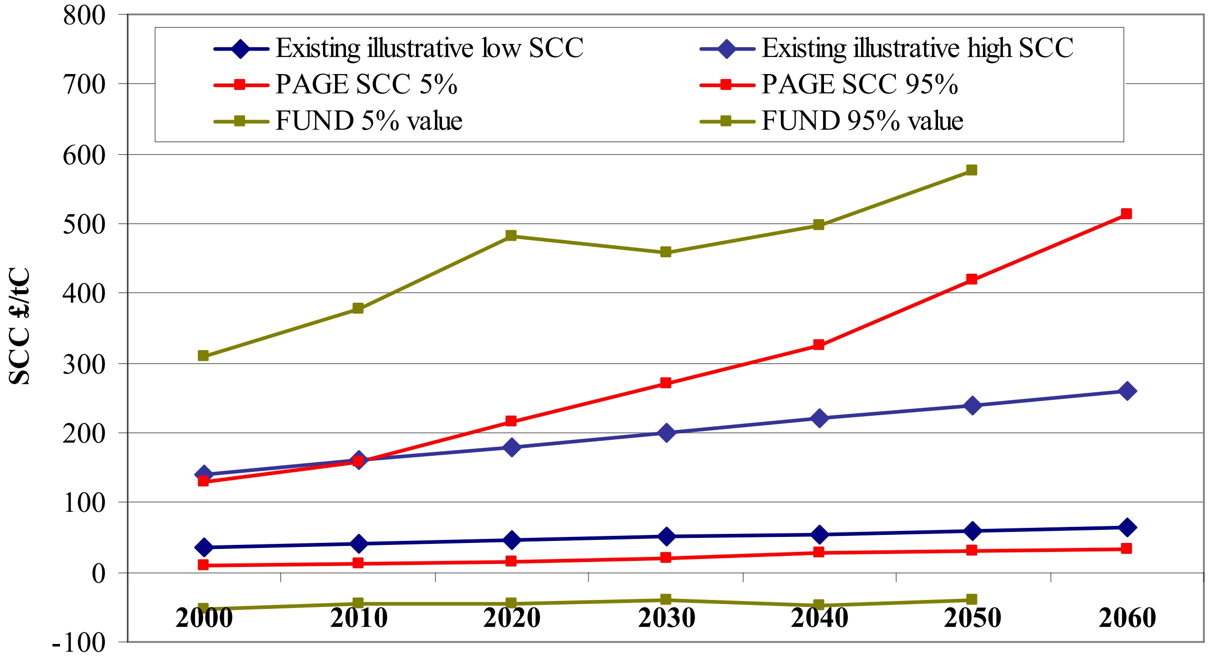


Figure 16. Model SCC estimates compared to the existing illustrative SCC estimates (Green Book discounting and equity weighting, business as usual).

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

It is also necessary to consider the potential impact on the values from consideration of risk and ambiguity aversion, and the surprises and major events and socially contingent effects. The inclusion of these aspects would be expected to increase the estimates above (particularly for FUND: the PAGE model does have some non-linearities already programmed into the model). Therefore the central values and the ranges presented above, should be considered in light of the risk matrix, and the fact that, for example, the FUND results exclude many bounded risks, all socially contingent effects, and major events.

In interpreting the information on the SCC, we also need to take into account the additional results from the SCC review: the knowledge elicitation, and the additional analysis with FUND (on risk and ambiguity aversion, catastrophic changes).

The SCC literature review noted above concluded:

- The mean of the values is £80/tC in 2000 prices (with 5% and 95% values of £-9/tC and £300/tC), or £111/tC as a mean value based on author weights (with 5% and 95% values of £-10/tC and £550/tC). This falls to £43/tC when only peer-reviewed studies are included (with 5% and 95% values of £86/tC and £210/tC)). These values only provide current estimates of the SCC – they do not include any analysis of how the SCC will change in future years.

The modelling study investigated four formal lines of evidence for the estimates of the social cost of carbon — the published literature, new results from the FUND and PAGE models, and the elicitation of estimates from experts. The latter was not designed to produce a probabilistic range of estimates; and the values were reported for comparison. The following conclusions were made from the modelling study on our understanding of the SCC and the possible values:

- Our understanding of future climatic risks, spanning trends and surprises in the climate system, exposure to impacts, and adaptive capacity, is improving, but knowledge of the costs of climate change impacts is still poor.

- The lack of adequate sectoral studies and understanding of local to regional interactions precludes establishing a central estimate of the social cost of carbon with any confidence.
- The balance of benefits and damages in the social cost of carbon shifts markedly over time, with net damages increasing in later time periods. Estimates of the SCC are particularly sensitive to the choice of discount rates and the temporal profile of net damages
- Vulnerability and adaptation to climate change impacts are dynamic processes responding to climatic signals, multiple stresses, and interactions among actors. Large-scale impacts, such as migration, can be triggered by relatively modest climate changes in vulnerable regions.
- Estimates of the social cost of carbon span at least three orders of magnitude, from 0 to over 1000 £/tC, reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables.
- A lower benchmark of 35 £/tC is reasonable for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting.
- An upper benchmark of the SCC for global policy contexts is more difficult to deduce from the present state-of-the-art, but the risk of higher values for the social cost of carbon is significant.

These conclusions are not particularly helpful in providing possible values for the SCC for appraisal. Indeed, a number of the peer reviewers have commented that the uncertainty (the range of estimates, the fact it is not possible to provide a robust central estimate, and the lack of an upper confidence interval) effectively rule out the SCC as an effective policy construct.

Nonetheless, the modelling study did report some consistency in the central estimates. To illustrate, the mean of the FUND results is £65/tC, and the mean of the PAGE results is £46/tC: averaging these information sources provides an estimate of £56/tC.

At the low end of the range are SCC estimates that give net benefits of £-5 to -10/tC. The lower range of climate scenarios produced estimates of this order from the expert elicitation. The modeling studies show a range around these low estimates, with PAGE reporting a 5% value of £9/tC and FUND a 5% value of $-50/tC and a 25% value of £-10/tC.

The modelling study also concluded that a lower benchmark of 35 £/tC is reasonable[69]. This conclusion draws upon two lines of evidence. First, the model results show that this benchmark has a significant likelihood of being exceeded. In FUND, with the Green Book discounting scheme and equity weighting, there is about a 40% chance that the SCC exceeds £35/tC, and similarly, the mean value from PAGE is £46/tC. Second, a number of scenarios judged by the experts give rise to values near or above £35/tC.

The maximum expectation of an SCC estimate, based on the expert elicitation, was as high as £500/tC. A high value is supported by the FUND estimates, which produced a 95% value of £310/tC (with green book discounting) for current emissions. The PAGE model provided a 95% estimate of £130/tC.

[69] The modelling study evaluated whether the lower benchmark in the Defra paper is credible. It did not attempt to define a plausible, robust minimum value for all contexts. Note that this estimate is specifically related to a global decision context that has already agreed to the UNFCCC commitment to prevent dangerous climate change. The global context also implies at least a modest aversion of large scale risks, a long term view often associated with relatively low discount rates, and concern for global welfare that implies at least a modest level of equity weighting.

Whilst the modeling study did not reach a consensus for an upper benchmark for the SCC, ithe modeling study concluded that under pessimistic scenarios of climate change, it is not implausible to consider estimates of the illustrative value proposed of £140 /tC or even higher[70].

6.3 Study recommendations

As the examination of the MAC and SCC estimates above has shown, there is considerable uncertainty in using any approach to derive shadow prices for appraisal. In summary:

- There is no agreement on the relevant marginal abatement costs to use, and there has been considerable discussion over the published values in the supporting analysis for the Energy White Paper. Indeed, there has been a recent debate on the likely costs of the 60% target, which appears to have led to greater divergence of views rather than consensus. A recent review (DT, 2005) of the likely costs of the UK 2050 target has shown that estimates differ by over an order of magnitude. There is ongoing work in the current climate change review (in Defra) that will update the marginal abatement costs to 2010 and 2020. This should provide a valuable input for reconciling short-term estimates. However, further work is needed to investigate, and reach consensus on, the costs of abatement towards mitigation towards the long-term – if these values are to be used for input into shadow prices. This will require the use of a wide range of methods and models. This is highlighted as a priority for future research. It does not appear any agreed estimates will emerge in the short term.
- The modelling report reveals that estimates of the social cost of carbon span at least three orders of magnitude, from about zero to more than 1000 £/tC, reflecting uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables. Moreover, the models do not fully capture the full risk matrix (and the full SCC). The report concluded that it was not possible to provide an illustrative central, or an upper benchmark of the SCC for global policy contexts.

Nonetheless, policy appraisal requires a value. Our conclusions and recommendations therefore propose a pragmatic approach, combining the stakeholder consultation responses, the information from the modelling study, and discussions by the study team and steering group. Our reasons for this are set out below:

- There is debate on whether MAC estimates (based on 2050 target) or SCC estimates are the most appropriate basis for a shadow price of carbon emissions for use in appraisal.
- While there is uncertainty in relation to SCC estimates, there is also large uncertainty over the MACs estimates towards the Government's 60% long-term target.
- There is no universal agreement on the best approach for dealing with risk and uncertainty.
- There are differing viewpoints on the benefits of a single value (consistency) vs. the consideration of uncertainty.
- There are potentially different needs for different levels of policy making.
- There are differing views on approaches to discounting and equity in deriving SCC estimates.

The findings of stakeholder consultation need to be added to this, as outlined in the previous chapter, i.e.:

- All stakeholders saw the need for a shadow price of carbon in detailed appraisal (i.e. for project appraisal and regulatory impact assessment – at lower levels compared to strategic long-term objective setting);
- Nearly all stakeholders recognised the need for some form of benefits analysis for setting long-term targets, though views varied on the form analysis should take (many respondents had

[70] With Greenbook discounting and equity weighting, 12% of the FUND Monte Carlo results exceeded £140/tC. With a 0% PRTP, 73% of the FUND results exceeded £140/tC. Note the FUND model excludes some bounded risks, and excludes major climatic system events and socially contingent effects

concerns about the use of SCC estimates for setting long-term goals, specifically with the use of a single value or a restricted range of values – see also paragraph below);

- Many recognised the need for policy consistency with the existing 2050 goal set by the UK Government.
- All stakeholders agreed that once a long-term goal had been set, detailed (lower level) policy appraisal should be consistent with it;
- The aim of policy appraisal should be to ensure this goal is achieved in the most cost-effective way. Many considered that it was potentially attractive at the level of individual policies or projects to apply shadow prices of carbon that reflected MAC estimates instead of SCC estimates.
- There were some concerns over whether the 2050 target was economically efficient and hence whether the MAC path towards this target represented the efficient policy path. It may be that more emissions abatement is justified earlier, or conversely later, according to the pattern of SCC and MAC estimates over time under different abatement scenarios.
- All stakeholders agreed the need for guidance for day-to-day appraisal, which is implemented consistently across applications;
- The use of a single value would lead to consistency across application. However, the use of a range would enable more representative analysis of the uncertainties in the values, though there is a danger that it would inconsistencies.
- All stakeholders agreed that there was a need for further research to progress the analysis of costs and benefits, and in particular, more work on the disaggregation of impacts and values.

We stress that while respondents recognised the need for shadow prices for appraisal at a detailed level, they had more divergent views on the approach that should be adopted for long-term climate change. This ranged from those who believed cost-benefit analysis was also appropriate in this context, through to those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy. The latter group believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle (and some respondents also raised the issue of the duty of care and human rights).

These points were used to draft an initial set of recommendations on the derivation and use of the SCC. These were presented at the SCC workshop on the 13th September, 2004. Based on further consideration and reflection by the study team and steering group, the report recommendations are that:

1. Benefits of climate change policy should be considered when setting long-term targets and goals. Some benefits can be directly estimated as monetary values, but a wider framework is needed to take all relevant effects into account. Single monetary estimates of the SCC should be avoided for such policy decisions. The framework should include a disaggregated analysis of economic winners and losers by region and sector, and a disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems. The full risk matrix identified in the study (including risk of major change) should be considered, and the analysis should include extensive uncertainty analysis. Green Book recommendations should be used for assumptions on discounting, but with sensitivity analysis. The uncertainty analysis should also consider equity assumptions. Benefits analysis should consider ancillary effects, but the analysis of these should be kept separate in the assessment. This is an informed process leading to a long-term goal.
2. Detailed policies follow from, and should be consistent with the long-term goal, once set. The aim should be to ensure the target is achieved in the most cost-effective way, and there is a need for consistency in appraisal across policy areas to achieve this.
3. To this end, it is useful to examine the current MAC estimates towards the current 2050 target over future decades. For any revision of long-term goals, it would also be useful to examine MAC estimates under different emission reductions targets. At the same time, it is still useful and instructive to compare pathways of MAC estimates with pathways of SCC estimates although both set of estimates are highly uncertain.

4. The SCC estimates generated in this study would provide useful information for the analysis of costs and benefits of policy steps to put the UK on a path towards the 60% 2050 target. However, we highlight that any such application of these estimates should recognise the limitations in the SCC values (the omission of major categories of impacts) and be consistent with recommendation 1 above – notably that when setting long-term climate change targets and goals, a wider framework (the full risk matrix) is needed for considering benefits, to take all relevant effects into account, complemented with consideration of the disaggregated SCC values, and uncertainty and sensitivity analysis.
5. We believe that a pragmatic way forward to the choice of shadow prices for use in (day-to-day) appraisal is to examine the marginal abatement cost curve towards the existing 2050 target, and to compare against the SCC estimates over time. These values should be used consistently across all applications.
6. The values derived could be presented as a single illustrative value or a range. In theory a range of uncertainty could be used consistently in different applications. However in practice in several contexts users are likely to prefer to work with a single value, particularly in lower-level appraisals. Hence presenting a single value would ensure consistency across all areas of appraisal. On the other hand a central value does not properly take into account all the inherent uncertainties. While a single value would be preferable for areas where GHG reductions are not the primary concern, a range would be preferable for cases where major greenhouse gas emissions reductions or policies were being considered.. However, the use of a range may lead to inconsistencies between applications (as with the current guidance).
7. To address this, we recommend a multi-level (stepped) approach, which varies with application:
   - For project appraisal, a single central illustrative value (rising over time) could be used.
   - For policy appraisal affecting greenhouse gas emissions, a central range (rising over time) could be used, allowing some consideration of uncertainty.
   - For major long-term policies, e.g. for climate change policy, or for a revised Energy White Paper, a full range and additional sensitivity analysis could be used, within the wider framework proposed in 1. above.
8. Ancillary effects (e.g. air pollution benefits, energy security) are important but should not be combined within the shadow price, as they will be specific to particular technologies and circumstances. They should therefore be assessed separately.

The key recommendations is that given the uncertainty over the SCC and the MAC, it would be sensible to review both sets of data, and use this to derive a standard set of values. We acknowledge that combining the SCC and MAC to derive a ‘value’ of carbon over time for appraisal can be criticised by those that favour a pure cost-effectiveness approach (using MAC based on the existing 2050 target), and those who believe strongly in the use of cost-benefit analysis (and therefore the use of the SCC[71]). We have therefore investigated whether a theoretical case can be made and believe there are strong arguments for adopting such an approach.

The pragmatic approach aims to identify efficient shadow prices under major uncertainties on both sides of the cost-benefit equation. It presents a way of including uncertainty, and combining insight from explicit and implicit assessments of benefits. It compares an envelope of pathways of social cost of carbon estimates (which we know represent only a subset of the impacts) with an envelope of estimated marginal abatement costs implied by reaching a stabilisation level that could prevent major shifts in the climate system and costs that we cannot quantify. In a sense the first approach is just standard CBA but looking at envelopes as opposed to single pathways. The second approach is an attempt to bring together a precautionary/sustainability perspective with a cost-benefit perspective.

[71] Determining optimal carbon abatement targets requires information on the time profiles of costs and benefits of abatement

As outlined in more detail in the box below[72], if the MAC and MSCC time profiles were derived using the same set of assumptions, and those assumptions included the optimal emissions path through time, then the MAC and the MSCC would give the same time pathway for the price of carbon. The fact that the MAC and MSCC curves do not give the same price of carbon indicates that: either (1) the curves are derived using different underlying assumptions (including potentially the assumed emissions path); or (2) although they have consistent assumptions, the assumed emissions path is suboptimal. In an ideal world, if the curves use different assumptions, one would request simulations to be carried out with consistent assumptions.

Once this has been done, if the MAC and MSCC curves continued to diverge, modellers would then calculate the emissions pathway that equalises these two curves. The resulting carbon price path would be employed in policy. In the real world, the foregoing is probably not feasible in the short term. Further, if it is impossible to judge which path is based on more accurate assumptions, then an appropriate response is to employ a weighted mean of the two pathways, where the weights are a function of the emission elasticities of the MAC and MSCC curves. If the emission elasticities of the two curves are much the same, then policy could be based upon a simple mean of the MAC and the MSCC (though some peer reviewers have questioned, however, whether the MAC and SCC curves are derived with a reasonably consistent set of assumptions to allow this).

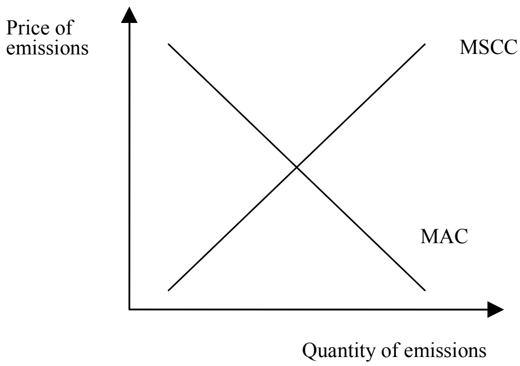
Determining the time path of the carbon price

Given the divergence between profiles of the marginal social cost of carbon (MSCC) and the marginal abatement cost (MAC) of carbon emissions, there is a question as to which one should be preferred for policy making. There are also some specific circumstances when an average of the two time paths could be defended.

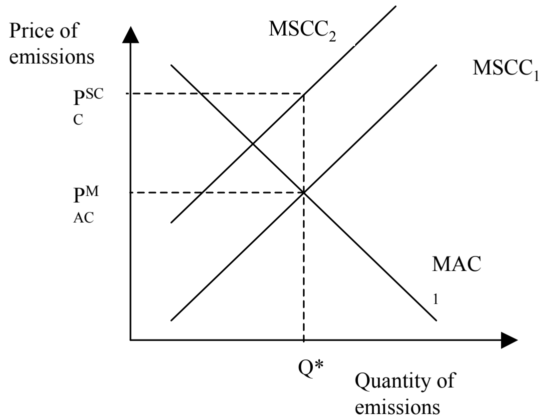
- The **MSCC** is an estimate of the social costs of emitting a tonne of carbon today. It is calculated as the net present value of the damage done by an additional tonne of carbon over the next several hundred years. A tonne of carbon *emitted today* will inflict different amounts of damage in different years in the future. In addition, the MSCC today is expected to be different to the MSCC for a tonne of carbon emitted *several years from now*, and is widely thought to increase in later years. The particular shape of the increase in the MSCC over time is a function of what emissions pathways we expect other countries, and the world in aggregate to follow.
- The **MAC** is an estimate of the cost of reducing carbon emissions by one tonne. Some abatement technologies are cheaper than others – the MAC therefore depends upon the total quantity of emissions that need to be abated. The time profile of the MAC depends, like the MSCC, on the assumed emissions (i.e. abatement) forecast for the globe. It also depends strongly upon assumptions about technological progress. Models such as MARKAL estimate that the MAC is also expected to rise through time. However, the time profile of the MAC differs from the time profile of the MSCC.

It is commonly assumed that the MSCC is increasing with emissions, while the MAC is decreasing with emissions (abatement becomes increasingly costly as more emissions are reduced). At an optimum, the MSCC = MAC. If the MSCC is greater than the MAC, we can conclude that emissions are sub-optimally high. In contrast, if the MSCC is less than the MAC, we can conclude that emissions are too low. However, other reasons for divergence between the MSCC and the MAC are possible. If the two curves are plotted based upon different forecasts of future global emissions levels, technological progress and other relevant variables, then a divergence between the MSCC and the MAC does not necessarily imply that we are not at the optimum. If $MSCC_2$ is calculated using a different set of forecasts to $MSCC_1$ and MAC_1, and policy making employs the $MSCC_2$ estimates, then at the optimum emissions level (Q*) the estimate for the MSCC will be higher than the estimate for the MAC. Using the logic above to conclude that emissions are sub-optimally high would be incorrect.

[72] An explanation for this logic was provided by Cameron Hepburn, University of Oxford, though with the caveat that he does not necessarily advocate this approach.

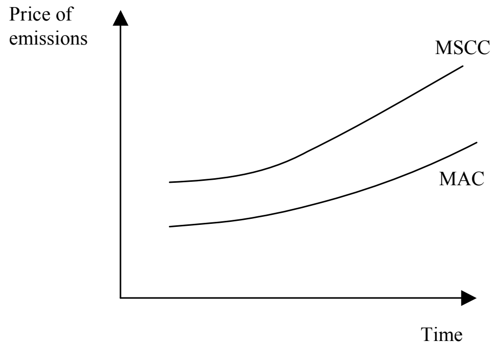


MSCC and MAC as a function of emissions



MSCC and MAC calculated differently

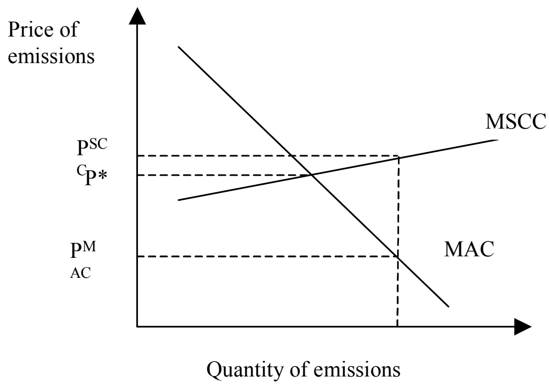
In practice, simulations indicate that the MSCC and the MAC are both rising with time, with the MSCC above the MAC. According to the theory above, we might conclude: the emissions path supporting the MSCC and the MAC curves is not optimal - emissions are sub-optimally high along the path; and/or the assumptions used to generate the MSCC and the MAC curves — particularly the assumed amount of abatement— are inconsistent with one another in a manner that systematically implies the MAC curve is lower than the MSCC curve. For instance, it may be that the MAC curves are derived assuming lower levels of abatement than the MSCC curves.



MSCC and MAC over time

Applying to policy. If the assumptions underlying, say, the MAC curve were judged to be more accurate than the MSCC curve, it is obvious that policy should be made based upon the approach using the more accurate set of assumptions. However, if the assumptions are the same, or if it is impossible to determine whether the set of assumptions underlying the MSCC is any better than those underlying the MAC curves, then the correct approach would appear to depend upon the elasticities of each curve with respect to emissions.

Suppose the elasticity for the MSCC is relatively high (that is, a small percentage change in damages from carbon is generated from a large increase in emissions),[73] then the situation would appear as below.



MSCC and MAC as a function of emissions

In this situation, a smaller “error” would be made by using a carbon value at the MSCC than the MAC. An even smaller error would be made if a weighted average of the MSCC and the MAC were employed, where the weights are determined by the relative elasticites of the curves.

Suppose the elasticity for the MSCC is low (relatively to the MAC), then the opposite conclusion applies and using P^{MAC} would entail a smaller error. If the elasticities are much the same, then employing a simple mean of the MAC and MSCC will not be too inaccurate.

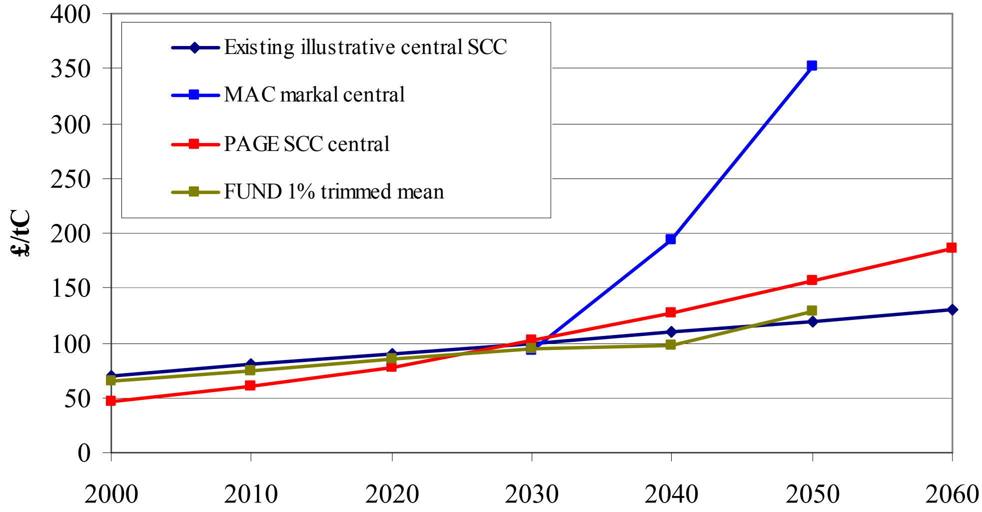
[73] Note that, for simplicity, the curves in Figure 4 are straight lines, and hence have varying elasticities. Nevertheless, they illustrate the basic intuition behind the argument.

6.4 Examining the Approach for Deriving Values for Appraisal

The recommendations in the previous sections have been used to draw up a set of **example** shadow values for appraisal. The analysis has used

- The MAC implied by the Energy White Paper analysis of the 2050 target and other literature estimates of the costs of long-term targets - recognising the issues and lack of consensus on these estimates as set out in the earlier chapter;
- The conclusions from the modelling study (see above), including the results of the SCC review, and the additional modelling runs with PAGE and FUND, undertaken as part of policy project – specifically looking at the profile of SCC values over future years, recognising these models do not fully capture the full risk matrix (and the full SCC).

The analysis has first considered a central illustrative estimate – with the aim of providing an example value for project level appraisal. Note we recognise that producing a robust central estimate of the SCC or the MAC is not possible: the aim here is to provide a central shadow price consistent with the recommendations above. The information on the MAC and SCC profiles above is summarised in the graph below, set against the existing SCC guidance (for a central illustrative estimate).



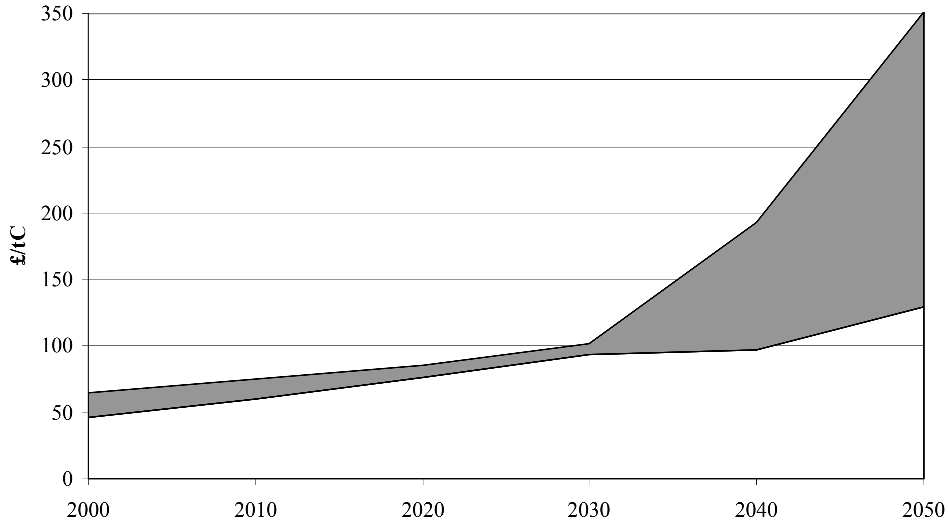


Figure 17. Comparison of the Marginal Abatement Costs, Model SCC estimates, and the Existing Illustrative SCC Estimates (top), and the Envelope of values (bottom)

The FUND model results exclude some bounded risks, major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The estimates are shown in the table below.

Table 14. Central estimates from the evidence.

Year of emission PAGE/FUND	Existing guidance	Literature Review	£/tC			
			FUND SCC (1% Trimmed)	PAGE SCC	MARKAL MAC	Average (all)*
2000/2000-2009	70	80/ 111/ 43	65	46		56
2010/2010-2019	80		75	61		68
2020/2020-2029	90		85	77		81
2030/2030-2039	100		95	(102)	93	97
2040/2040-2049	110		97	127	193	139
2050/2050-2059	120		129	(157)	351	212
2060				187		

Values for PAGE in brackets are interpolated.
Three values are shown for the literature review, the unweighted mean of studies, the mean of author weights, and the mean of peer review studies. These estimates are not included in the average values.
The calculated average values do not include the literature review values
The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

To derive a central illustrative value, we have derived values from 2000 to 2020 using the average of the SCC modelling values – specifically the average of the FUND model mean (1% trimmed mean of £65/tC) and the PAGE model mean (£46/tC) - which provides an estimate of £56/tC (for year 2000). The analysis with both models uses the parameters agreed for UK policy analysis with the steering group, i.e. it applies Green Book declining discount rates and equity weighting (the use of these parameters explains the choice of only using these two models to derive the value). The mean values from these models sit within the range from the wider SCC literature review, which gave an unadjusted mean of £80/tC, and a mean of peer reviewed studies £43/tC.

The runs with two models have been used to investigate SCC estimates in later years. The mean value from FUND rises at a very similar level to the existing SCC guidance. The mean value from PAGE rises at a higher rate post 2030. In interpreting the model output, it is important to note that these SCC estimates still do not include consideration of the full risk matrix – they exclude socially contingent effects and major events, and (for FUND) only have a partial coverage of bounded risks and non-market impacts. The SCC estimate has been compared to the MAC in the Energy White Paper supporting analysis (towards the 2050 target 60% goal, based on the MARKAL model). Interestingly these estimates show a similar value in 2030 to the SCC values, at around £100/tC. The MAC estimates increase faster than the SCC values in 2040 and 2050. The MARKAL estimates have been compared against other abatement cost estimates in the literature, which shows they are broadly in line with other studies.

Overall, we believe that a value of about £55/tC in 2000, but rising more sharply than the current guidance, would seem to capture the evidence using a pragmatic approach. This could be proposed as an illustrative central shadow price – for use at simple project level appraisal as outlined in the multi-level approach.

These values are similar to the existing guidance, at least in early years (i.e. the £70/tC in 2000). However, post 2030, the evidence suggests a faster rate of increase than the current guidance (i.e. at a higher rate than the current £1/tC per year), such that values in later years (2040 and 2050) are significantly higher than the current guidance.

For a low and high central estimate, as might be used in the multi-level guidance for more important policies (e.g. in RIA involving GHG emissions), and the minimum and maximum value, for the multi-level guidance for major (longer-term) policies, a wider set of evidence is available.

The modelling study provided a lower benchmark of 35 £/tC as reasonable for a global decision context committed to reducing the threat of dangerous climate change and includes a modest level of aversion to extreme risks, relatively low discount rates and equity weighting. It made no firm conclusions on an upper bound.

The full range suggested by the SCC modelling analysis (5 and 95% values) is from –£50/tC to £500/tC for current emissions, even with parameters such as discounting fixed. A more constrained range, based on a narrower statistical analysis might suggest a range from £10/tC to £150. This is also reflected in the SCC literature review (see Table 2).

The modelling analysis has also considered how the SCC estimates change in future years, with analysis using the PAGE and FUND models. These estimates have been compared to the MARKAL estimates on the range of marginal abatement costs associated with the 60% target. We acknowledge that this only draws on one study – but given the MARKAL values themselves span almost an order of magnitude, we use them as an illustration of the potential range of values that exist in relation to the MAC estimates. The lower and upper central value is also consistent with the central range of abatement costs in the literature – to illustrate the MARKAL estimates of the 60% target report costs of 0.5 to 2% of GDP – studies elsewhere have indicated that the cost range may be wider than this, from less than 0% (which would imply an increase of economic output) to over 4.5%. Most, however, fall in the range 0.5 to 3.5% (with a mean estimate of 2.5%). When considered as MAC estimates, the analysis of the wider literature review finds that most marginal costs of abatement in 2050 are less than £900/tC, with more than 50% less than £500/tC. Marginal costs in 2030 are much lower, typically between £25 and £150/tC.

The values are summarised in the Table below.

Table 15. The Full Range of Estimates from the Review

Year of emission PAGE/FUND	PAGE 5%	PAGE 95%	FUND 5%	FUND 25%	FUND 75%	FUND 95%	EWP MARKAL Low	EWP MARKAL High	Wider MAC Low	Wider MAC High
2000/2000-2009	9	130	-53	-10	75	309				
2010/2010-2019	12	159	-46	-10	80	378				
2020/2020-2029	14	215	-46	-10	92	482				
2030/2030-2039	(20)	(270)	-41	-6	106	458	0	143	25	150
2040/2040-2049	27	324	-47	-5	117	498	13	229		
2050/2050-2059	(30)	(418)	-40	-2	136	575	242	538		500 (900)
2060	34	513								

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.
Values for PAGE in brackets are interpolated.

The shaded area below indicates the range included by the 5 and 95% values from FUND.

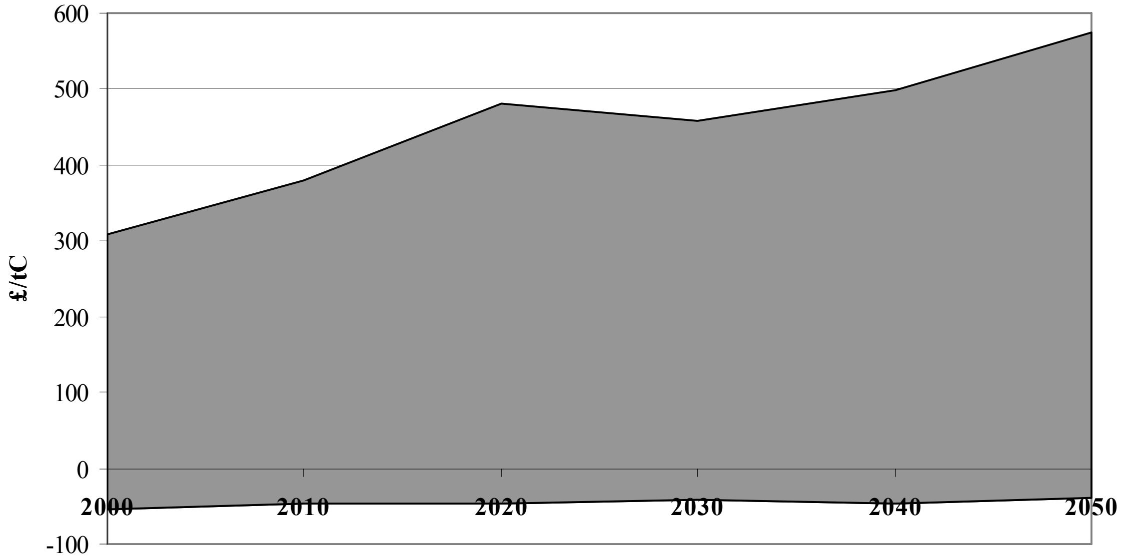


Figure 18. Full Range of Values from the Marginal Abatement Costs, Model SCC estimates, and the Existing Illustrative SCC Estimates

The FUND model results exclude some bounded risks, and major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

Interestingly, the range of estimates from a single MAC study (the MARKAL analysis) is also extremely large, with 2050 high estimates similar to the 95% SCC values from FUND. The PAGE SCC 5% and 95% estimates are within a narrower range, though this is still gives rise to an order of magnitude difference between low and high estimates.

The estimates provide a much broader range than the current illustrative estimates for the SCC (values of £35/tC and £140/tC). They imply negative SCC values at the low end of the range (i.e. net benefits), and an extremely wide range between the low and high estimate.

We believe that a large range of estimates would be valid for use in considering major, long-term policy initiatives. However, we also believe that such as a range is impractical for day-to-day policy appraisal – as shown in the case studies (see next chapter), a range s this large leads to ambiguity in decision making because employing the upper and lower bounds of the range can lead to conflicting conclusions.

To derive the central illustrative range, we have adopted the lower benchmark of 35 £/tC recommended in the parallel modelling study for our example. The modelling study did not make any recommendations on an upper benchmark, but reported that the risk of higher values for the social cost of carbon is significant. To try and capture this upper benchmark, we have based the upper central estimate on the PAGE 95% values, and its path over future years (the PAGE 95% values start at £130/tC in 2000 and rise to £400/tC by 2050). The lower and upper central values are consistent with the central range of abatement costs in the literature – to illustrate the MARKAL estimates of the 60% target report costs of 0.5 to 2% of GDP (and most studies fall in the range 0.5 to 3.5%). The literature indicates that marginal costs in 2030 are much lower. These data have been used to propose an illustrative central range for use in policy appraisal as outlined in the multi-level approach.

To derive a wider range of values, we have considered the lower SCC estimates (5% values) from the PAGE model. These are consistent with the lower estimates of MAC from the wider literature (outlined above). There remain lower values than this within the full range of reported SCC values - which include negative SCC values; and the full range of reported MAC values - which includes abatement cost estimates less than 0% GDP. For the upper bound, we have drawn on the SCC 95%

values from PAGE and FUND, the upper estimates of the MARKAL model, and the wider abatement cost literature. Again, there are higher SCC and MAC values outside this range. This broad range of values is proposed for use in uncertainty analysis of major, long-term policies, as outlined in the multi-level approach. . Note our recommendation for such appraisal (see above) is that it should be considered as part of a wider framework including analysis of disaggregated physical impacts and values by sector and region and the full risk matrix.

After some smoothing this leads to the following set of example values.

Example Shadow Price Values from the Study, consistent with Recommendations

Year of emission	Central guidance	Lower central estimate	Upper central estimate	Lower bound	Upper bound
2000	55	35	130	10	220
2010	65	40	160	12	260
2020	80	50	205	15	310
2030	100	65	260	20	370
2040	140	90	330	25	450
2050	210	130	420	30	550

Notes
Consideration of the SCC as part of these numbers is dependent on the assumed low discount rates (specifically declining discount rates), and includes equity weighting from a global policy perspective. The issue of equity weighting is the subject of continued debate, both in relation to the approach, and the consistency with other policy areas. At the present time, we have not recommended adjustments between the SCC and the MAC.
The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects. The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.The consideration of the MAC is based primarily on the full range from the Government analysis (the White Paper analysis), though we also benchmark these values against the wider literature. We highlight the current debate on the accuracy of these values and the need for further modelling work.
The SCC from PAGE and FUND are global estimates (i.e. global social costs). The MAC in terms of the 60% UK target is in relation to UK marginal abatement costs, though these values have also been compared against the wider literature.
Successful mitigation policy will reduce the SCC estimates, as progress is made towards the 2050 target, and some of the major effects from climate change are avoided (i.e. we move below a threshold of effects for some impacts). Therefore in looking at long-term policies, further work is needed to look at the potential effect of different policies on the SCC over time.

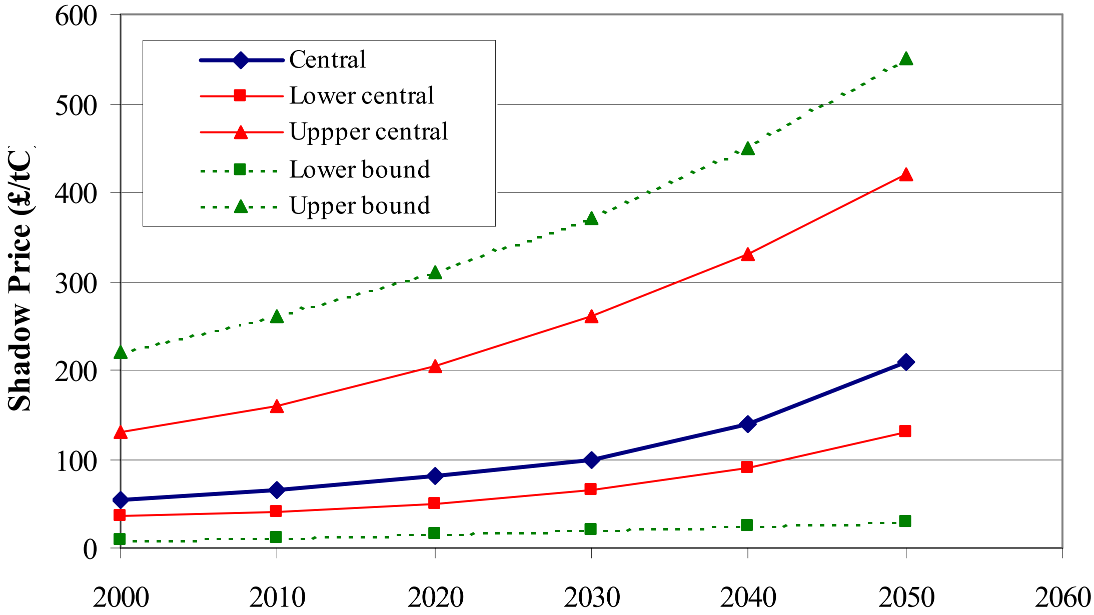


Figure 19. Example Shadow Price Estimates (£/tC), consistent with study recommendations

See notes under the summary table above

In demonstrating the proposed approach , there are a number of important caveats with these values:

- The SCC estimates depend on the discount rates assumed (specifically declining discount rates), and include equity weighting and a global policy perspective. The issue of equity weighting is the subject of continued debate, both in relation to the approach, and the consistency with other policy areas. We have not suggested adjustment between the SCC and the MAC (see earlier discussion on the potential consistency issue for comparing equity weighted damages to abatement costs which are equity weighted to the same numeraire).
- The SCC models and estimates do not cover all bounded risks, and exclude major events and socially contingent effects.
- Consideration of the MAC is based primarily on the Government analysis (the White Paper analysis), though we have benchmarked these values against the wider literature. We stress that there is further work needed to progress an accepted set of MAC values.
- The SCC from PAGE and FUND are global estimates (i.e. global social costs). The MAC in terms of the 60% UK target is in relation to UK marginal abatement costs.
- Successful mitigation policy will reduce the SCC estimates, as progress is made towards the 2050 target, and some of the major effects from climate change are avoided (i.e. we move below a threshold of effects for some impacts). Therefore in looking at long-term policies, further work is needed to look at the potential effect of different policies on the SCC over time.

Following the other study recommendations, the sort of values here could be used in a multi-stage approach - for detailed (lower level) appraisal using a central number only – for day-to-day policy appraisal the lower and upper central estimate - and for major (long-term) policies using the full range, along with consideration of impacts, sensitivity and wider uncertainty[74]. This approach has been demonstrated with application to a case study in each of the four application areas in the next chapter.

It is also possible to use the information above to present a separate SCC estimate over time, rather than the combination of the SCC and MAC as recommended here. This does provide useful information for the analysis of costs and benefits of policy steps to put the UK on a path towards the 60% 2050 target, so for example, for the analysis of benefits of the ongoing climate change review (to allow consideration of costs and benefits of the short-term (to 2020) policy steps to put the UK on a path towards the 60% 2050 target). However, we highlight that any such application of these estimates should recognise the limitations in the SCC values (the omission of major categories of impacts) and be consistent with recommendation 1 above – notably that when setting long-term climate change targets and goals, a wider framework (the full risk matrix) is needed for considering benefits, to take all relevant effects into account, complemented with consideration of the disaggregated SCC values, and uncertainty and sensitivity analysis. The average of the FUND and PAGE values have been used to derive this SCC profile and are presented below (note the lower bound profile is based on the same relative increases starting at £35/tC, consistent with the modelling study recommendations).

[74] The team was also asked to consider an additional perspective at the steering group meeting. This was based around the question ‘does the new evidence (from the modelling study) provide sufficient evidence to warrant a change in the existing guidance (i.e. £35/tC to £140/tC)’. Our response is that it does. Although the modelling study has concluded that a lower bound of £35/tC is credible (for current emissions, for setting global policy, assuming relatively low discount rates and equity weighting), and the average value derived from MAC, PAGE and FUND (average) are not dissimilar to the current guidance, the profile of the estimates over time appears significantly different.

Example SCC Values from the Study.
Note these should only be used as part of a wider framework that considers additional effects of non-quantifiable impacts across the full risk matrix (including major change).

Year of emission	Central guidance	Lower central estimate	Upper central estimate
2000	56	35	220
2010	68	43	270
2020	81	51	350
2030	99	62	365
2040	112	71	410
2050	143	90	500

The use of these SCC values for CBA of future climate change policy objectives and measures should be consistent with recommendation 1 above, i.e. undertaken within a wider framework that considers all the impacts of climate change, using disaggregated information, considering uncertainty, and ensuring that additional effects of non-quantifiable impacts in the full risk matrix (including risk of major change) are included.

7 Application to Case Studies

This section discusses how the example estimates above could be used in the four different policy applications.

7.1.1 Case Study 1. New Approach to Appraisal: Transport Appraisal

This example is a project appraisal example. Based on the recommendations above, we believe that this type of appraisal is best served by the use of a single central estimate

The net estimated increase in CO_2 emitted from this bypass is 4835 tonnes in year one and the appraisal period is from 2010 to 2039 (thirty years). The previous illustrative central value (the £70/tC) estimated the total present value of costs for the emitted carbon of £2.4 million. We have used the new central illustrative values, allocated by year (interpolating between decades above), which does not change the previous result significantly. The use of these values leads to a total present value of emitted carbon of £2.3 million. This would be incorporated into the AST as outlined in the earlier section. The use of the range of values is also shown.

Existing Guidance	New Central	New Central Lower	New Central Higher	Full low	Full high.
£2.4 million	£2.4 million	£1.5 million	£5.7 million	£0.4 million	£8.5 million

Note, even using the full range, the shadow price for carbon does not change the decision – the value at under £10 million as an NPV for carbon is low in relation to the estimated present value of accident reduction of £42 million and estimated present value benefit of transport economic efficiency of £157 million.

7.1.2 Case Study 2: Partial Regulatory Impact Assessment of a Proposal for A Regulation on Certain Fluorinated Gases (F-Gases regulation)

The F-Gas RIA is a policy within the overall framework and clearly the shadow price of GHG estimate will be material to the RIA outcome. . In such a case, use of the lower and higher restricted range would be useful, and would be consistent with the previous approach used. The values are shown below, along with the implications of using the full range of estimates.

Original analysis

Option	**Average Reduction***	**Annualised costs (£M)**	**Annualised Benefits (£M) associated with CO_2 reduction**		
	Mt C/yr		**@ £35/t C**	**@ £70/t C**	**@ £140/t C**
2 Regulation	1.2 - 1.5	74 - 225	47 - 49	94 - 98	188 - 197
3					
4	1.3 - 1.5	71 - 87	45 - 49	91 - 98	181 - 197
5	1.2 - 1.5	73 - 224	46 - 49	93 - 97	185 - 194
6	1.2 - 1.5	74 - 225	47 - 49	94 - 98	188 - 197
7	1.4 - 1.7	74 - 225	53 - 55	106 - 110	211 - 220

With revised estimates

Option	Average Reduction*	Annualised costs (£M)	Annualised Benefits (£M) associated with CO_2 reduction				
	Mt C/yr		@ £35/t C	@ £55/t C	@ £130/t C	@ £10/tC	@ £220/tC
2 Regulation	1.2 - 1.5	74 - 225	54 to 66	86 to 105	216 to 264	16 to 20	340 to 418
3							
4	1.3 - 1.5	71 - 87	56 to 66	90 to 105	225 to 264	17 to 20	354 to 418
5	1.2 - 1.5	73 - 224	54 to 66	86 to 105	216 to 264	16 to 20	340 to 418
6	1.2 - 1.5	74 - 225	54 to 66	86 to 105	216 to 264	16 to 20	340 to 418
7	1.4 - 1.7	74 - 225	62 to 75	99 to 118	247 to 295	18 to 22	380 to 464

Note the exact profile of emissions is not known, so the analysis with the new values has assumed constant emission reductions – this illustrates the effects of the values, but estimates should not be compared back to the original RIA estimates.

The central and central range numbers do not differ that much from the previous guidance – though the differences would be greater if the policy extended past 2030 (when the proposed new values increase sharply).

These central numbers provide a guide to the relative attractiveness of different policies, but they also provide information on the absolute policy intervention (is it justified; do the benefits outweigh the costs). The use of the narrow range shows that the policy is justified with the use of the central or upper central values but not with the lower central value. The use of the full range makes any policy conclusions ambiguous: nothing appears justified using the low value, and everything appears justified using the high value. This highlights the reasons for the narrow range recommended from the study.

7.1.3 Case Study 3: Aviation Developing Economic Instruments

The DfT estimated the (global) social cost of climate change due to aviation in the UK as £1.4 billion in 2000 rising to £4.8 billion in 2030. These values, and the new estimates, are shown below. While the range is useful in helping to inform the possible levels of taxes and charges – ultimately it is only possible to have a single tax level, though the information on the central lower and central upper value is also useful (as these values only provide an input to any potential consideration of taxes). Again, the full range of values prove less useful for policy analysis – at the lower end they imply subsidies – and at the upper end extremely high charges (especially for the 2030 scenario).

Year	Carbon emitted (million tonnes)	Radiative Forcing Factor	Effective Carbon (million tonnes)	Cost of carbon (£ per tonne)	UK cost (£ billion)
2000	**8.2**	**2.4**	**20**	**70 (original)**	**1.4**
				35 (lower central)	0.7
				55 (central)	1.1
				130 (upper central)	2.6
				10 (low)	0.2
				220 (high)	4.4
2030	**19**	**2.5**	**48**	**100 (original)**	**4.8**
				65 (lower central)	3.1
				100 (central)	4.8
				260 (upper central)	12.5
				20 (low)	1.0
				370 (high)	17.8

7.1.4 Case Study 4: the Energy White Paper 60% Reduction Target

This is an example of a major policy initiative, where greenhouse gas emissions are material and suggest a a different approach to the examples above.

- While SCC estimates (benefits) can be usefully aggregated into monetary values, a wider framework is needed than single monetary estimates like SCC estimates.
- The framework should include a disaggregated analysis of economic winners and losers by region and sectors, physical impacts and the full risk matrix. The modelling study recommended further work this area, although some estimates are available.
- The disaggregated analysis of the impacts of climate change including key indicators such as health and ecosystems.
- The analysis should include extensive uncertainty analysis. For key assumptions (discounting and equity), the Green Book recommendations should be used, but with sensitivity analysis with other parameters. We would recommend alternative pure rate of time preference discount rates and alternative declining discount rates, as well as sensitivity around different equity weighting schemes.
- The full model estimates on uncertainty should be considered. This would include the full range, as well as the narrow central estimates.
- Finally, any benefits analysis should consider ancillary effects, but the analysis of these should be kept separate in the assessment.

To undertake this properly, would require (amongst other things) assessment of SCC estimates under different future policy scenarios (i.e. the possible reduction in SCC estimates with progress towards different 2050 targets, reductions in CO_2 concentrations and reductions in average global temperatures increases). This implies consideration of the feedbacks between policy, emissions and impacts[75]. A full analysis using this approach is beyond the time and resources of the current study. We identify work to progress the above areas as the most immediate research priority from the current study. This would include analysis to assess the disaggregated effects of the SCC value, by sector and region, and work to establish estimates of the physical impacts for consideration of different long-term policies.

[75] Some initial runs show that the PAGE model indicate that the marginal SCC is almost unaffected by different policy outcomes, i.e. the marginal SCC estimate is broadly constant as progress is made towards lower global CO_2 concentrations. In contrast the FUND model shows a significant reduction in the marginal SCC values with lower CO_2 concentrations, consistent with mitigation action towards the 2050 target (and similar action in other developed countries, which is explicitly stated in the UK goal). However, FUND does not include major surprises or socially contingent effects – which would increase SCC estimates above key thresholds (where non-linearities occur).

8 Research Recommendations

The study has identified a number of research priorities in addition to the recommendations of the modelling study.

Clearly there is modelling work needed to fully capture the full SCC, i.e. to assess the excluded impacts (including major events and socially contingent effects).

There is also an immediate priority to assess the disaggregated effects of the existing SCC values, by sector and region, and work to establish estimates of the physical impacts for consideration of different long-term policies.

Linked to this, there is a need for further modelling to assess the SCC estimates in future years, under different policy scenarios, i.e. towards different stabilisation targets.

We highlight that the areas above could be usefully combined to provide a case study on the long-term goal (to 2050) towards a low carbon economy.

There is also a need for specific consideration of the approach for equity weighing, both in relation to the approach but also in relation to policy consistency with other areas. We recommend that an appropriate expert group should take this specific area forward, but with experts representing the full range of views on this subject.

There is also a need to improve the MAC estimates. The costs of short-term measures will emerge from the current Defra review of the climate change programme, but further work is needed to investigate, and reach consensus on, the costs of post 2020 abatement - it is clear that such work will require the use of a wide range of methods and models.

Finally, there is a need to continuously review and update the analysis here, as the evidence on the SCC, the MAC, and future policy emerges. This needs to be taken through to the policy side with regular reviews of the shadow price estimates proposed in this report.

As a concluding note, we highlight that to derive a new set of shadow prices for appraisal of greenhouse gas emissions across Government (consistent with the study aims and consistent with the study recommendations above[76]), either:

- The example values above should be accepted as the best available, whilst recognising the limitations associated with the estimates of both MAC and SCC, and used to produce a new set of shadow prices, or
- Further work should be taken to progress the marginal abatement costs, and/or further work to progress the analysis of the full risk matrix for SCC values. This will significantly delay the derivation of a new set of values.

Unfortunately it has not been possible within the current project time-scale to reach agreement on the first way forward. We highlight that there is some ongoing analysis (summer 2005) as part of the climate change review in Defra that will provide agreed short-term marginal costs to 2020. This is a positive step forward towards improving the evidence base. However, there is still a need for further work to progress post 2020 MAC values, and to capture the full estimates of the SCC (as highlighted in the modelling study).

[76] Or for that matter for use of either the MAC or SCC values individually to set a new set of shadow prices.

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Appendices

APPENDIX 1. Stakeholder Consultation Questions.

APPENDIX 2. Different Approaches for Dealing with Risk / Uncertainty for the SCC

APPENDIX 3. PAGE runs

APPENDIX 4. FUND runs

Appendix 1. Questions from the Briefing Paper

Key Questions for Consultation

The study team requests responses on the following questions. The focus is on the policy applications for the SCC values, though we would also welcome input on the values themselves.

Comments on Using the SCC Values in Policy

- ❑ Do you think it is appropriate to try to attach a value to the social cost of carbon (SCC) in order to inform decision-making? In particular, do you support using SCC estimates in:

  1) Project appraisal (cost-benefit analysis);
  2) Policy appraisal (regulatory impact assessment);
  3) Design of economic instruments;
  4) Setting longer-term sustainability goals.

- ❑ What are your views on the suggested approaches for addressing uncertainty in the use of the SCC values in policy applications, i.e.:

  - Use of an illustrative value;
  - Use of a range;
  - Switching values;
  - Sequential sensitivity analysis;
  - Different values for different applications;
  - Marginal abatement costs
  - Multi-criteria analysis.
  - Risk aversion.

- ❑ Do you believe that different approaches should be used for different decision-making contexts - so that for example, a different approach would be applied to project appraisal than to longer-term goal setting?

- ❑ For each of the above decision making contexts, do your views differ on the use of SCC estimates, depending on whether:

  a) The primary objective is in relation to climate change policy (e.g. greenhouse gas emissions abatement);

  b) The primary objective is in another policy areas (e.g. air pollution, transport congestion) where GHG emissions are only a secondary issue

- ❑ Do you prefer an alternative approach to consider the potential effects of climate change? Does this vary with the type of policy application (1-4), and the type of context (a-b).

- ❑ Has sufficient account been taken of other European and international research activities? If not, please name additional sources that could be used.

Comments on the Social Cost of Carbon Estimates

- ❑ What are your general views on the social cost of carbon values in the literature (summarised in this paper), and the underlying uncertainty with the numbers?

- ❑ Do you agree with (and support the use of) the risk matrix suggested to classify different categories of effects?
  - o Have we missed any categories of impacts?
  - o Which of the cells of the matrix should be included in the policy applications noted above?
  - o Do you propose an alternative approach?

- ❑ Do you have a view on the discount rate used? In your view are there any reasons for using assumptions that are different from the Green Book recommendations? If so, how would one deal with the inconsistency between climate change policy and other policies?

- ❑ What are your views on the weighting of impacts to account for distributional concerns (including equity weighting)?
  - o Distribution weighting is not appropriate
  - o Equity weighting according to per capita income
  - o Weighting losers more than winners

- ❑ Do you have a view on the appropriate time-scale over which impacts are quantified for inclusion in the SCC value?

Appendix 2. Different Approaches for Dealing with Risk and Uncertainty for the SCC

The following examples are taken from the Briefing Paper. Note the following discussion seeks to present some brief details of each approach, and set out some of the key advantages and disadvantages. We stress that during the stakeholder consultation, we made no recommendations nor stated any preference for a particular technique.

Use of an Illustrative Central Value

The value of £70/tC is referred to as an illustrative value for use in policy application. It would be possible, at least in theory, to derive a new *illustrative* value for policy applications – though we believe that consensus that this value was the 'real' SCC is very unlikely.

The previous illustrative SCC value was based on the central estimates from a limited number of models. It only considered the model output directly. The analysis did not take into account a number of categories, such as surprises, or socially contingent effects, as these were excluded in the models. As the literature review above has shown, more recent estimates from the models tend to have lower SCC values, due to greater consideration of adaptation, etc. If we were to adopt a similar approach as before (i.e. taking current model output as a best guess and ignoring additional categories), then a revised illustrative value would be significantly lower than the GES value of £70/tC. How much lower is a contentious issue – though to illustrate, the value would be unlikely to exceed £30/tC, and could be lower than £15/tC.

However, such a value would only represent a sub-total of the effects of climate change. Given the other categories outlined in the risk matrix above (e.g. socially contingent, surprises), then we can be fairly sure that the 'real' SCC will be higher than this value, not least because the probability of large negative impacts are more likely than large positive benefits. There then becomes a trade-off over the confidence we have in the central illustrative number, and the coverage of impacts included in that value. The question is therefore whether government project and policy appraisal should be taking a conservative evidence based approach, or a precautionary approach?

It is important to distinguish the principles of a single value from the issues about how to select that value. Specifically, quite apart from the uncertainties and lack of consensus that complicate the choice of a single illustrative value, there are some clear advantages and disadvantages in applying a single benchmark which relate to a trade off between consistency / simplicity on the one hand, and the appropriate representation of uncertainty on the other. The key advantages and disadvantages of using an illustrative central value are summarised below:

Advantages

- Project and policy application is very simple. This allows for consistency and clarity.
- Single value (through consistent application) should help to achieve the most cost effective methods of reducing carbon emissions.

Disadvantages

- Very difficult to get an agreed consensus value for the central *illustrative* value of the SCC.
- A single value fails to communicate the uncertainty to the user.

Use of a Range

Along with the central value of £70/tC, there is also an *illustrative* range for the SCC in the GES recommendations, from £35 to £140/tC. It would be possible to only recommend the use of a range, i.e. with no central estimate.

There are a number of ways of deriving a range. It is possible to assess the statistical uncertainty in the model output – and use this to convey the uncertainty in the values. The consideration of the full statistical uncertainty would lead to a very large range around a central value. The consideration of too wide a range may do little to help improve policy decision-making (an extremely low value becomes insignificant, and a very high value dominates everything). An alternative is to undertake sensitivity analysis around an agreed illustrative central value. Such a sensitivity analysis can look at a number of the key parameters described in the previous section. This is a more formalised approach to that taken by the GES paper[77]. It would be possible to identify a range using key assumptions with different discount rates, including or excluding equity weighting, with and without 'surprises', etc. This would allow some consideration of the full risk matrix.

Another way forward would be for Government to take some explicit decisions on those parameters that have an ethical dimension or an element of choice, as well as an empirical element, e.g. discount rate, equity weighting, attitude towards risk. This would leave the modellers to grapple with the true (or objective) uncertainties of assessing and monetising marginal impacts of GHG emissions, as well as with the issues raised by the limited coverage of SCC estimates according to the "risk matrix". One key issue on the specification of the range is whether the same assumptions on key parameters (e.g. discount rates or distribution) should be used as for the appraisal of other policies and the potential implications for inconsistent decision making between climate change policy and other policies.

Where probabilities are available for the range of values, we could also use a risk premium method to allow for uncertainty, as discussed in a later section. Possible values from the parallel modelling SCC study can be used to provide this range. Given some of the early results from the modelling analysis, it might lead to a larger range than currently recommended within the current GES recommendations.

The key advantages and disadvantages of using a range are summarised below:

Advantages

- Relatively simple to implement.
- Allows consideration of the uncertainty.

Disadvantages

- Difficult to get an agreed consensus value for the range of the SCC.
- Leads to some ambiguity in decision making if employing the upper and lower bounds of the range lead to conflicting conclusions as to the 'best' course of action.
- Potential for inconsistent (and inefficient) decision making between different policy applications.

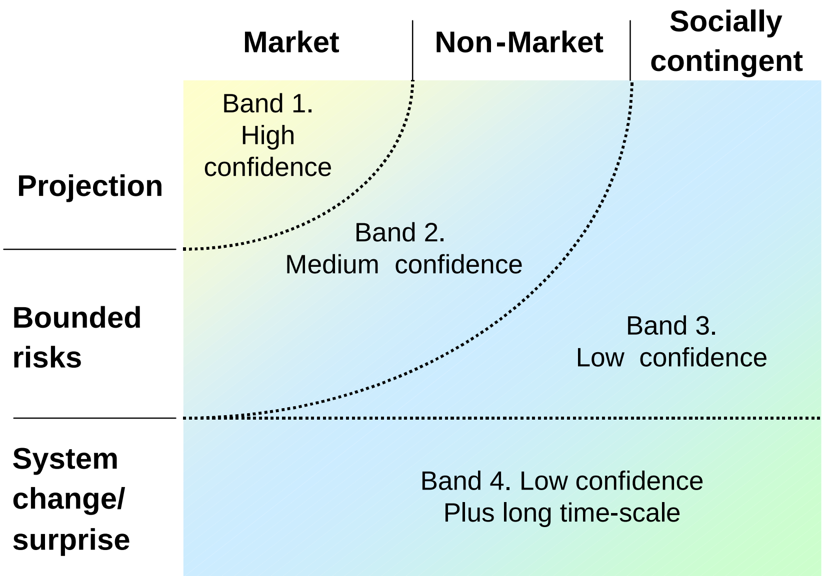
[77] The GES paper selected the range on the basis that ' a pragmatic solution may be to employ two other values in sensitivity analysis. One of which could be half the size of the central estimate (i.e. £35) and another twice as big as the central estimate (i.e. £140), thereby representing the disproportional upside risk.

Sequential Sensitivity Analysis (Uncertainty Bands)

A number of environmental policy appraisals have used sequential sensitivity analysis to include uncertainty in a cost-benefit framework[78]. The approach works by separating different elements of the 'benefits' into confidence or uncertainty bands, and building these into the cost-benefit analysis in turn.

The approach lends itself well to the analysis of the SCC, because application is extremely simple through the use of cost per tonne estimates for different components of the SCC. It also fits extremely well with the risk matrix approach outlined in the previous section. Potentially it could work with the nine different cells within the matrix. For practical purposes, we propose three or four sets of values, as in the figure below.

For implementation, a standard project or policy appraisal (cost-benefit analysis) is undertaken, but the individual benefits streams for the different climate change effects (each with difference confidence rankings) are kept separate.



The costs of a project or policy are compared against the benefits in turn, starting with the most certain impacts first (i.e. impacts with highest confidence). The benefits of more uncertain impacts are then added into the calculation sequentially, to assess at which point the project benefit to cost ratio becomes positive.

If the project or policy is justified with only highly certain impacts (i.e. band 1), then the confidence in the decision will be high. If all impacts, including the long-term effects and surprises, are needed to justify a project or policy, then the confidence in the decision is much lower. An example is illustrated in the figure – policy 2 requires more uncertain and long-term effects to be included, and so is less attractive than policy 1.

This has the advantage of linking the policy or project appraisal to the risks impacts and risks being considered, and is capable of helping to set long term policy goals.

[78] The approach has been used in air quality policy, to categorise impacts with high scientific consensus (e.g. impacts on buildings), and more uncertain effects (e.g. long-term health impacts), e.g. Holland et al. UNECE. Watkiss et al. STC&C, DfT.

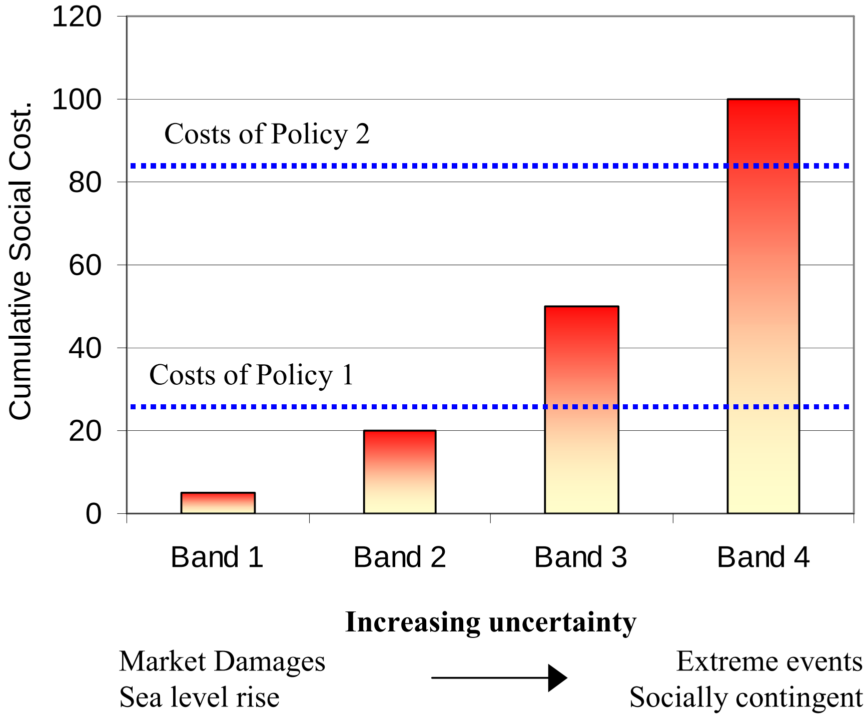


Figure illustrating the use of sequential sensitivity analysis for the SCC

It would also be possible to set different criteria for different decisions – for example, in short-term project appraisal, the longer-term effects might not be considered relevant, whilst for longer-term policy goals, all impacts – even the most uncertain impacts- could be included.

The key advantages and disadvantages of the approach are summarised below:

Advantages

- Can take account of the risk and uncertainty associated with different elements of climate change and the SCC. Extremely useful for communicating the risks and uncertainty to users.
- Works well with the analysis of risks and uncertainties identified below. Lends itself well to the risk matrix approach.
- Ideal for the SCC, due to the simple application through cost per tonne of carbon for each category and because location does not matter[79].

Disadvantages

- Could make the analysis more complicated when greenhouse gas emissions are not the primary aim of the project or policy.
- May be difficult to obtain a consensus value for the SCC for each band of impacts (particularly those relating to the more uncertain impacts).
- Leads to some ambiguity in decision making if employing the values for different bands of impact leads to conflicting conclusions as to the 'best' course of action. Potential for inconsistent (and inefficient) decision making between different policy applications.

[79] The impact of GHG emissions is same irrespective of the location of the emissions (application in other areas such as air pollution has been much more involved as impacts must be quantified separately, and the impacts are themselves extremely site-specific).

Switching Values

Recent work for the European Investment Bank (EIB) has used a different approach when working with a range of SCC values. This is important because our previous work has shown it is much easier to get consensus on a range of values, than it is to achieve consensus on a 'best' estimate. The approach uses a low and high SCC estimate as *switching values*. This is effectively a specific approach to employing a range (see previous section).

The switching analysis assesses whether a low or high value of carbon would alter the project appraisal and the attractiveness of the project – so consistent with the Green Book guidance, to see whether the benefits of intervention would still exceed the costs[80]. The approach has been used in energy project appraisal within an economic rate of return calculation (used to rate the attractiveness of projects). Consistent with project appraisal, it can also help in options appraisal to choose between projects.

In the case above, the switching values were not based on the statistical range (i.e. they are not a traditional low and high value). Instead they were agreed consensus values on the likely lowest and highest range of values for the SCC. To illustrate, in the EIB analysis, switching values of £3.3/tC and £83/tC were used[81]. These values were based on a review of the SCC values in the literature, and an informal poll of experts. The low value was based on market-based damages only. The high value also included longer-term impacts[82]. A similar approach, or one using model output on the probability distribution could be used.

An example of using switching values is given below. The project is assessed in terms of greenhouse emissions, and a project cost-benefit analysis is undertaken. However, the SCC value is separated out from the rest of the economic calculation. The switching value is then applied as the final stage in the analysis, to see if this alters the project attractiveness, either positively or negatively (e.g. to see how this alters the net present value). The switching value that is applied will depend on the type of project.

1) For projects that reduce carbon emissions, such as renewables (which are generally not economically attractive without a SCC value), we are interested in the <u>added benefit</u> to the scheme appraisal from adding a SCC value. We therefore apply a <u>high</u> switching value (£83/tC). In this case we are confident - because our high switching value is an upper consensus value - that the 'real' SCC value is probably lower than the switching value. The switching value is therefore used as a screening tool: projects that are still not economically attractive, even with the high switching value, are not considered economically attractive. The aim here is to filter out the good and bad carbon positive projects. This is illustrated in the figure below.

2) For projects that increase carbon emissions, such as a coal generation project that has high carbon emissions, we are interested in the <u>added impact</u> on the cost-benefit appraisal from adding a SCC value. We therefore apply a <u>low</u> switching value (£3.3/tC). In this case we are confident (as our low switching value is a lower consensus value) that the 'real' SCC value is higher than the switching value. If this low switching value alters the project attractiveness (e.g. so that the benefits are no longer higher than the costs), then we can be confident the project is not economically attractive (because in practice, the 'real' SCC is likely to be higher).

[80] The Green Book mentions switching values, and mentions their use to show by how much a variable would have to fall (if it is a benefit) or rise (if it is a cost) to make it not worth undertaking an option.

[81] Euro 5/tC and Euro 125/tC.

[82] The low value was consistent with the current traded price for carbon (at the time of the study) – the high value with marginal abatement costs for longer-term GHG reductions.

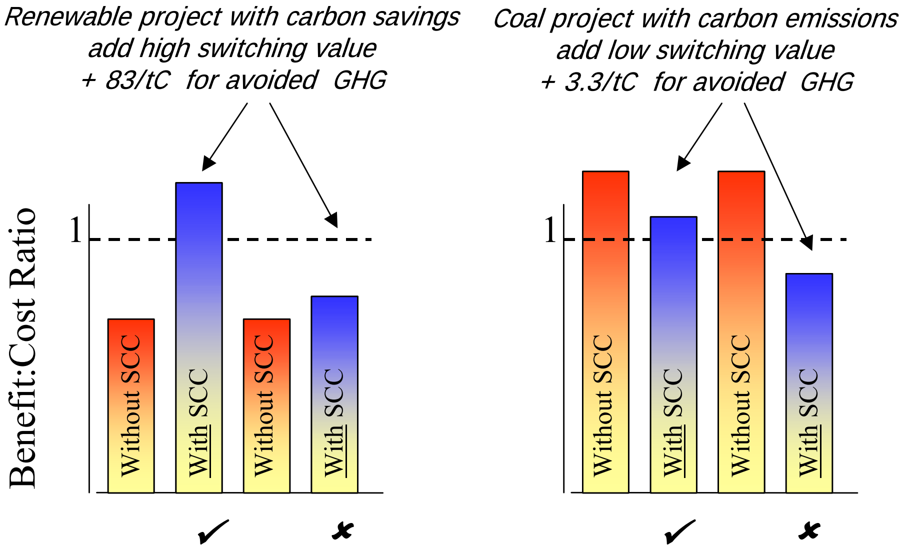


Figure illustrating the use of switching values for the SCC

The key advantages and disadvantages are summarised below:

Advantages

- Allows policy analysis where there is no agreed central value, but when there is a consensus for a 'low' and 'high' value.
- Good for projects where greenhouse gas emissions important, for example for looking at renewable schemes, or conventional fossil fuel based schemes (especially in relation to NPV or benefit:cost ratio).
- Demonstrated, and in use, for energy project appraisal.

Disadvantages

- Not particularly informative for projects where greenhouse gas emissions are not important, or where carbon makes a relatively small difference to the NPV (good or bad). This includes the road transport sector (where travel time benefits dominate).
- Application for general policy appraisal may be too limited.
- Difficult to get an agreed consensus value for low and high values.
- May give rise to apparent inconsistencies in the use of different values for different types of projects.
- Does not avoid the ambiguity associated with using a range.

Different Values for Different Applications

Essentially, this puts forward the idea that estimates of marginal costs can be interpreted with respect to their application. Therefore, one way of tackling uncertainty is to recognise that different policy applications may require different SCC values, built on consideration of different elements of the risk matrix. The applications considered would be consistent with the four main areas identified in part 1 of this report (project CBA, policy CBA, design of economic instruments, and sustainability goals).

For ***project appraisal,*** the use of externalities is already well developed. The impact of the externality is to include effects that may or may not be sufficiently large as to influence the choice of one project over another or to alter the design of options to abate the externalities. For project appraisal, the choices are constrained to similar types of options, thus, there are not large differences in the value systems applied to each project. For such an approach, a relatively conservative value might be appropriate, based around consideration of projected market damages, with possible consideration of some non-market effects / bounded risks, i.e. the top left hand area of the risk matrix (where uncertainty is lower), or alternatively a restricted range of values. In project appraisals, there is economic assumption of (acceptable) trade-offs between winners and losers.

For policy appraisal, the choices are more open-ended and different value systems are sometimes inherent. Policy appraisal takes account of serious environmental threats, and looks at marginal populations or sectors that may suffer adverse consequences. Higher SCC values might therefore relevant - taking into account projected and bounded risk, for market and non-market damages. In RIA, there is still an economic assumption of trade-offs between winners and losers, though these can lead to rejection of policies where these are unacceptable.

The final area is ***environmental sustainability***, and leads to consideration of the widest analysis of SCC values. Given the longer-term policy framework, this area often reflects consideration of non-marginal effects, taking account of maximum probable losses, irreversible impacts and the ethical issues of sustainable development. This is a policy area that is centred on the consideration of the precautionary principle, with strong sustainability criteria, and cost-benefit analysis is generally not considered appropriate (because the assumptions about trade-offs between winners and losers inherent in CBA are counter to the strong sustainability viewpoint). Values might include strong globally ethical dimensions and long time-scales, with consideration of the highest uncertainty and non-marginal effects. They would probably lead to the very much higher values than for the other three policy areas above.

Advantages

- ❑ Allows consideration of different values for different approaches – so can reflect the risk or uncertainty that is appropriate to the policy.

Disadvantages

- ❑ Different values could lead to inconsistency in policy making (and potential confusion for analysts).

Multi-Criteria Analysis (MCA)

There is a widespread use of multi-criteria analysis in environmental policy analysis.

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

A multi-criteria framework could be used for greenhouse gas emissions and climate change. Indeed, this approach has been widely proposed. It has been included as the final stage in transport appraisal, for example, to compare certain environment categories (such as greenhouse gas emissions) alongside the existing cost-benefit framework in DfT’s Appraisal Summary Table.

MCA frameworks allow consideration of quantitative and qualitative data together (and monetised and non-monetised effects). In cases where monetary data exists (e.g. with costs), direct quantitative values can be used to score different options. In cases where only qualitative data exist (e.g. expert judgement of risk), different options can be assigned a score. Relative weightings are then given to different categories, usually through stakeholder workshops or expert opinion.

MCA can be a useful tool, especially for comparing options. However, it has a number of limitations here, due to the need to integrate within (primarily) economically led decision guidance in the UK. It does complicate project appraisal, especially when the primary policy aim is not greenhouse gas emissions abatement or climate change based. It is also less directly relevant for helping set taxes or charges. However, it might be more relevant in the longer sustainability goals, where examples of such approaches already exist.

The key advantages and disadvantages are summarised below:

Advantages

- ❑ Avoids the use of a monetary SCC value.
- ❑ Allows a range of risk categories (e.g., loss of life) to be included in the decision analysis.
- ❑ Analysis becomes more transparent. Can allow more easy access to assumptions.

Disadvantages

- ❑ Complicates the analysis.
- ❑ Difficult to get agreed weighting factors to compare other categories against climate change effects. Issue with transparency on the trade-offs between different costs and benefit in the weighting factors.

Marginal Abatement Costs

Given the uncertainty over the SCC, a number of organisations have considered using marginal abatement costs (MAC) as a surrogate for the SCC in policy decisions. To illustrate, this would use the marginal abatement cost of greenhouse gas emission reductions, as an indication of the benefits of avoiding or increasing greenhouse gas emissions in wider project or policy appraisal. The European Commission has considered such an approach in environmental policy cost-benefit analysis[83].

It would be possible to use marginal abatement costs to replace the SCC in the applications listed above. Using marginal abatement costs from short-term commitments might lead to problems, since the market valuation of carbon that is emerging is relatively low and may significantly underestimate the real benefits of carbon reductions for the foreseeable future. An alternative would be to provide a value that takes into account longer-term policies and goals, for example, using a marginal abatement cost based on meeting the UK's 60% CO_2 reduction target (as this represents a social consensus as to what the UK should be aiming to achieve)[84]. As such targets have implicitly considered costs and benefits, it can be argued it is only a case of meeting that target in the most cost effective way possible. The marginal cost of abatement would then be used in project and policy appraisal on a routine basis.

While this might seem to offer a more certain number, it does not fufill the explicit aim of project and policy CBA. There is nothing within this approach to assess specifically whether targets were set optimally. Finally, it can be potentially problematic when such values are applied for policies that seek to reduce greenhouse gas emissions, because of circular reasoning (the same values may end up being used to assess both costs and benefits).

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[83] The costs considered are from the European Climate Change Programme (ECCP, 2001), which identified 42 possible measures, which could lead to some 664-765 $MtCO_2$ equivalent emissions reductions that could be achieved at a cost lower than 20€/tonne CO_2eq. This is about double the emissions reduction required for the EU in the first commitment period of the Kyoto Protocol. They provide approximate costs for Kyoto and post Kyoto (e.g. 2020) scenarios of €12/tCO2 in 2010, €16/tCO2 in 2015 and €20/tCO2 in 2020, broadly equivalent to £30/tC, £40/tC, and £50/tC. The EC is now also re-considering the SCC values.

[84] This might involve an assessment of the rates of a hypothetical carbon tax over time (the shadow price of carbon) that would achieve the 60% reduction in CO_2 emissions by 2050.

As a final note, it is highlighted that there are often significant uncertainties associated with these cost estimates – uncertainty is not restricted only to the analysis of the benefits of climate change!

The key advantages and disadvantages are summarised below:

Advantages

- Avoids the uncertainties in the SCC value, and allows easier consensus on a central value.
- Help to achieve consistency between strategic goals and the appraisal of options for the policies which will deliver these goals.

Disadvantages

- Does not comply with existing guidance on appraisal.
- Does not help in optimising policy or strategic goals.
- Leads to potential circular reasoning in CBA.
- Significant uncertainty with measurement of abatement costs.

Other Methods to Deal with Risk and Uncertainty

There is some guidance on dealing with risk and uncertainty from Annex 4 of the Green Book, with provides guidance in each of the following areas:

- Risk management;
- Transferring risk;
- Optimism bias;
- Monte Carlo analysis;
- Irreversibility; and
- The cost of variability in outcomes.

A number of these are relevant for the SCC.

Monte Carlo analysis allows an assessment of simultaneous uncertainty about key inputs. It involves replacing single entries with probability distributions for key inputs. By undertaking a Monte Carlo analysis, we can simulate possible values of the input variables, weighted so that the 'best guess' value is more likely than the extreme values'. Monte Carlo analysis is already inbuilt in many of the SCC models, such as FUND. The output from such analysis is included in the discussion below. However, the selection of 'best guesses', whilst it deals with uncertainty, may not fully address the issues of risk that are relevant for the SCC value.

'Irreversibility occurs where implementation of a proposal might rule out later investment opportunities or alternative uses of resources'. Relevant examples of irreversibility are the destruction of natural environments from climate change or, on a larger scale, permanent shifts in the climate system. The Green book states that 'it is particularly important to make a full assessment of the costs of any irreversible damage that may arise from a proposal.' Appraisal of different proposals should not ignore the 'option' value of avoiding or delaying irreversible actions, and the benefits of ensuring flexibility to respond to future changed conditions.'

A decision-maker who is **risk averse** cares about the potential variability in outcomes, and is willing to pay a sum in exchange for certainty (or willing to put up with variability on receipt of compensation). This compensation is the cost of variability, and should be included in appraisal when it is considered appropriate. Generally, a variability adjustment may be required when:

- Risks are large relative to the income of the section of the population that must bear them (including very large risks borne by the whole population); or
- When risk is correlated systematically with income or GDP, and so cannot be diluted by spreading across the economy.

This is highly relevant for the SCC. Estimates could incorporate potential catastrophes valued using an appropriate coefficient of risk (and ambiguity) aversion, perhaps using an some agreed confidence limit (possibly higher than 95% given the magnitude of the potential risks). The modelling project has investigated the potential impact on the SCC values from the use of a risk and ambiguity aversion co-efficient. Note consideration of such an approach is not independent of other options above – it could be used to help set the range or define different uncertainty bands.

The key advantages and disadvantages are summarised below:

Advantages

- Explicit consideration of the most serious risks of climate change, which are a key factor in driving policy
- Works together with other approaches, particularly the range or sequential sensitivity analysis identified above.
- Use of these methods gives additional rigour to treatment of uncertainty obtainable through other approaches outlined above.

Disadvantages

- Getting consensus on the appropriate risk or ambiguity co-efficient to apply, and to which underlying values to apply them to.
- Option values very difficult to determine with present measurement techniques.
- These methods are somewhat technical and less easy to understand for the range of potential users of SCCs.

Other Potential Approaches

There are clearly many other approaches for dealing with uncertainty in decision-making. These range from complex risk based analysis (e.g. belief nets, risk estimate modelling), to softer, decision support approaches. We welcome suggestions for additional approaches, though we stress any approach must primarily fit within the existing guidance, and be practical enough to be used in a wide variety of policy applications, in a range of areas.

Appendix 3. PAGE Runs

Baseline scenario: A2
PPP exchange rates
Green book SRTP
Equity weight parameter: 1
Model version: PAGE2002 V1.4e green book

Implementation of green book

2000-2020: 3.5%
2020-2040: 3.25%
2040-2080: 3%
2080-2200: 2.5%
in all world regions

Social cost of carbon

Immediate cutback:

5%, mean and 95% values are <13,64,179> $(2000) per tonne of C as CO_2. This compares with the values of <13,62,165> $(2000) presented at the Defra workshop on 13th September for a constant 3% SRTP.

Delayed cutbacks:

Analysis years are 2001, 2002, 2010, 2020, 2040, 2060. The table below shows the way cutbacks are implemented in PAGE. y_i is the analysis year. Implementation of emissions in PAGE is that 1 tonne of emissions in analysis year i contributes $0.5(y_i-y_{i-1})$ tonnes ($Extra_1$) at year $0.5(y_i-y_{i-1})$ and $0.5(y_{i+1}-y_i)$ tonnes ($Extra_2$) at year $0.5(y_{i+1}-y_i)$, giving a total of $y_{i+1}-y_{i-1}$ tonnes (Total) .

y_i	y_i-y_{i-1}	$y_{i+1}-y_i$	$Extra_1$	at year	$Extra_2$	at year	Total
2001	1	1	0.5	2000.5	0.5	2001.5	1
2002	1	8	0.5	2001.5	4	2006	4.5
2010	8	10	4	2006	5	2015	9
2020	10	20	5	2015	10	2025	15
2040	20	20	10	2030	10	2050	20
2060	20	20	10	2050	10	2070	20

The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

So, to get a 1 billion tonne drop in 2002, we need to drop emissions in that year by 12.5/4.5=2.78%. Implementing this in ‘v1.4e green book’ gives an SCC discounted back to 2000 of <14,63,164>.

But this has been discounted by 2 years at 3.5%=0.9335, so, in the year it occurs, it needs to be increased by $(1.035)^2=1/0.9335$, to give <15,67,176> (Note that by the same logic, the value for 2001 should really be multiplied by 1.035 to give <13,66,185>).

Thus values are essentially the same in 2001 and 2002, as we would expect, to within the margin of error. This confirms that the calculation method is right (In fact most of the ‘2002’ cutback occurs at 2006, as the table shows, so it is not appropriate to describe it as the value for 2002 ; but it does show calculation method is right).

Running for cutbacks in 2010, we need 12.5/9=1.39% cutback to get a cutback of 1 billion tonnes of C. Implementing this in 'v1.4e green book' gives an SCC discounted back to 2000 of <12,61,160>. But this has been discounted by 10 years at 3.5%=0.709, so, in the year it occurs, it needs to be increased by $(1.035)^{10}$=1/0.709, to give <17,86,226>. So the mean value increases from 66 to 86 in the nine years from 2001 to 2010.

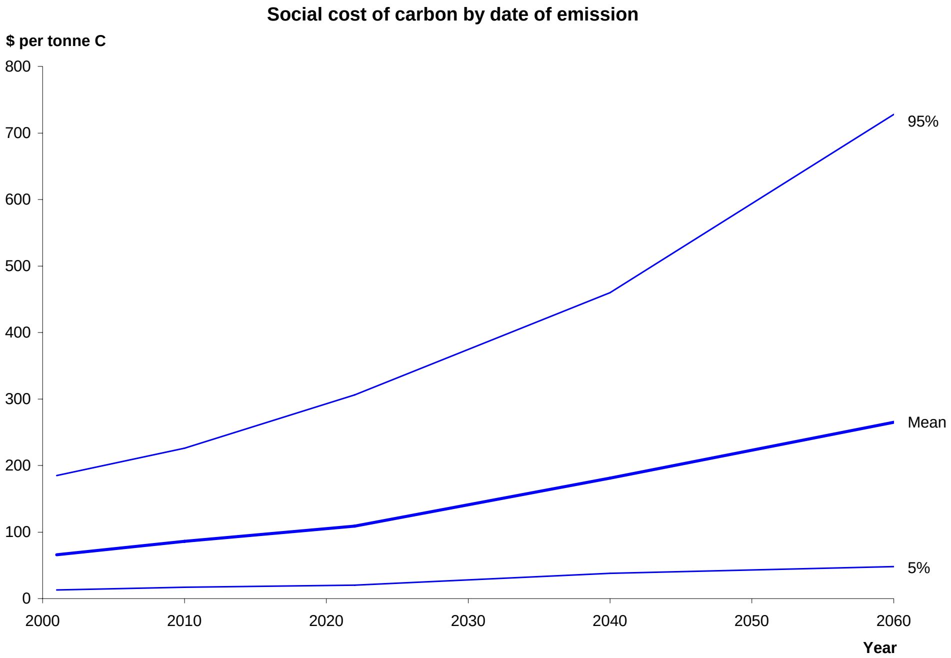
The complete analysis is shown in the table below.

	SCC discounted to 2000				SCC in year of emission		
	5%	mean	95%	df	5%	mean	95%
2001	13	64	179	0.966	13	66	185
2010	12	61	160	0.709	17	86	226
2020	10	55	154	0.503	20	109	306
2040	10	48	122	0.265	38	181	460
2060	7	39	107	0.147	48	265	728

The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The only other thing to note is that the value for 2020 is actually on average for 2022 (5/15 tonnes in 2015, 10/15 in 2025). Results are shown in the chart below (with the 2020 value displayed at 2022).

The best fit to the mean values is a 2.4% increase in SCC each year; the best fit to the 5% and 95% values have them increasing at 2.3% per year. This compares with the Defra recommendation to increase the SCC by 1/70, or 1.4% per year over the next few years. In absolute terms, the increase of about \$2 per year to 2020 is close to the Defra recommended increase of £1 per year.



The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

Methane

Base year emissions are 323 Mtonnes. So 31% of base year emissions is 100 Mt.

Immediate cutback:

5%, mean and 95% values are <59,267,726> $(2000) per tonne.

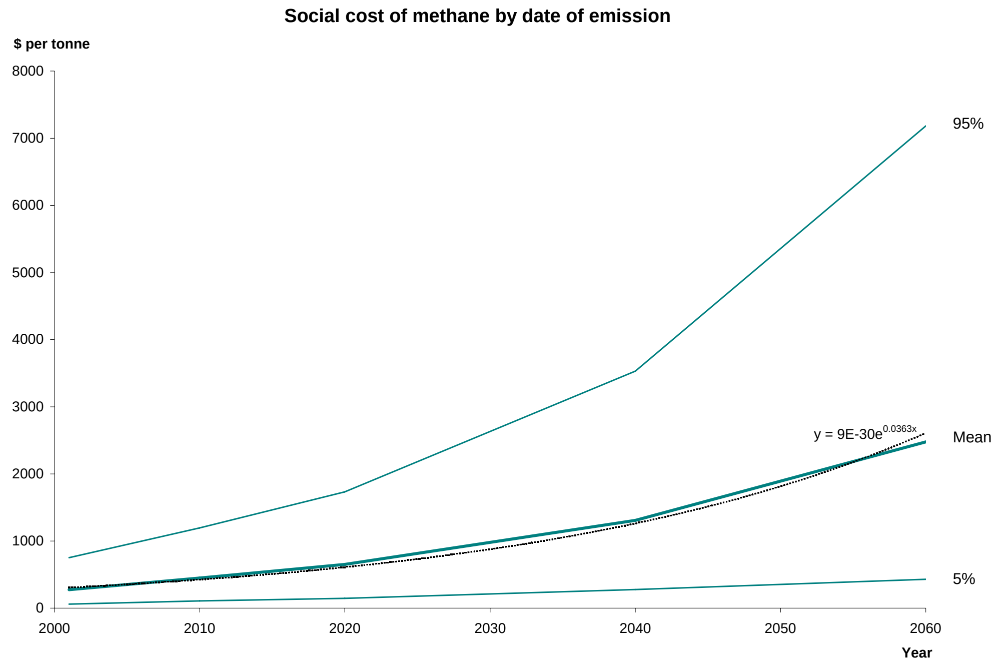
Delayed cutbacks:

Running in other years gives the following set of results:

	SC discounted to 2000				SC in year of emission		
	5%	mean	95%	df	5%	mean	95%
2001	56	267	726	0.966	58	276	752
2010	75	319	847	0.709	106	450	1195
2020	73	327	871	0.503	145	650	1732
2040	74	346	936	0.265	279	1306	3532
2060	63	364	1056	0.147	429	2476	7184

The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

The SC of methane increases far faster than for CO2. Indeed, the SC discounted to 2000 actually rises over time. This is because of the short atmospheric lifetime of methane; any methane emitted today will have disappeared from the atmosphere before the most severe climate change impacts start. Given a choice today between emitting 1 tonne of methane now, or at some time up to 60 years in the future, we should opt to emit it now. The best fit to the mean values is a 3.6% increase in SC of methane each year.



The PAGE model results include some (but not all) major climatic system events but exclude any socially contingent effects.

Other scenarios

Running with the Defra 550 ppm scenario from figure 3 of http://www.defra.gov.uk/environment/climatechange/ewpscience/ewp_targetscience.pdf in ‘v1.4e green book defra 550’ gives a present day SCC of <12,62,172> $ per tonne C, or <13,64,178> when adjusted for the 1 year discounting back to 2000. This is almost identical to the values from the A2 scenario.

Although it is meant to be a 550 ppm scenario, PAGE gives mean concentrations of 650 ppm in 2100 (90%CI: 587 to 717 ppm), and 774 ppm in 2200. This compares to mean concentrations of 815 ppm in 2100 for A2 (90%CI: 725 to 871 ppm), and 1450 ppm in 2200. However, the insensitivity of the SCC to emissions means that even a true 550 ppm scenario would have very similar values.

Other discount rates and equity weights

0% ptp rate with equity weights:

<79,385,1037> $ per tonne C. Average discount factor now about 0.985 for the one year from 2000 to 2001, so this comes to about <80,390,1050> $ per tonne. The discount rate is 1.5% per year in all regions from 2100 onwards. The mean contributions to the SCC are $2 in 2100, $3 in 2150 and $4 in 2200.

0% ptp with no equity weights:

<457,2835,7867> $ per tonne C. These assumptions give a 0% discount rate overall, so the values will be underestimates as they do not include contributions from post-2200, which will be quite significant. The mean annual impacts in 2200 are $53, up from $22 in 2150, and $7 in 2100, and these feed directly into the SCC, as the discount rate is zero, so it is quite likely that the values actually go to infinity, as some of the emissions never disappear from the atmosphere.

The main message is that even a horizon of 200 years is not enough to capture all the contributions to the SCC with such low discount rates as these.

Appendix 4. FUND Runs

The FUND model is described in the modelling report. In summary, The Climate Framework for Uncertainty, Negotiation, and Distribution model, version 2.8, is an integrated assessment model, coupling demographics, economy, technology, carbon cycle, climate, and climate change impactsolicy. FUND2.8 includes sea level rise, energy consumption, agriculture, forestry, water resources, cardiovascular and respiratory diseases, malaria, dengue fever, schistosomiasis, diarrhoea and ecosystems. Other impacts are unknown. The model includes reduced forms of more complex models. It values impacts using standard monetary valuation methods, particularly benefit transfer. It has a time period through to 2300, and has 16 world regions.

The analysis has first assessed the social costs of different greenhouse gas, under different assumptions. The model has been run with the parameter choices characterised historically as 'best guess' though this nomenclature is not necessarily appropriate [85]. It has also been run with a full Monte Carlo analysis, and the median and mean results from this analysis reported. The results are presented below[87]. The numbers are first presented for different parameters for current emissions. Equity weighting affects a pure rate of time preference significantly. It does not have this affect with the Greenbook declining discount rate.

[85] This is the modellers 'best guess' for all parameters. The best guess for climate sensitivity is 2.5 degrees Celsius equilibrium warming for a doubling of the atmospheric concentration of CO_2. Recent evidence suggests that the probability of higher climate sensitivity may have increased – see Report of the Steering Committee, International Symposium on Stabilisation of Greenhouse Gases, Hadley Centre, Met Office, 2-5 Feb 2005.

[87] FUND uses USD1995 as the benchmark. Consistent with the modelling study, we have inflated the FUND results to USD2000 by using the average U.K. Retail Price Index over the period from 1995 to 2000, an increase of 22.5%. We have then converted both FUND results from USD2000 to GBP2000 ($1.42 = £1) using purchasing power parity exchange rates from 2000.

Full FUND results for current emissions.

Marginal Damage		**Social Costs in $95**			**Social Costs in (£ 2000)**		
Weighting Scheme	**Run**	**C**	**CH_4**	**N_2O**	**C**	**CH_4**	**N_2O**
Greenbook, Equity weighted	'Best guess'	$23.6	$189	$8,367	20.4	163.3	7,218
	Median	$22.2			19.2		
	Average	$109.5			94.4		
	Standard Deviation	$1,409.7			1,216.1		
Greenbook, No equity weighting	'Best guess'	$22.2	$112	$7,056	19.2	96.3	6,087
	Median	$9.8			8.5		
	Average	$0.5			0.4		
	Standard Deviation	$799.5			689.7		
Prtp=0%, ew	'Best guess'	$843.1	$2,183	$190,917	727.4	1,883.2	164,700
	Median	$778.4			671.5		
	Average	$4,809.5			4,149.1		
	Standard Deviation	$64,050.3			55,254.7		
Prtp=0%, w/out ew	'Best guess'	$64.9	$167	$16,441	56.0	144.5	14,183
	Median	$55.9			48.2		
	Average	$1,385.8			1,195.5		
	Standard Deviation	$36,573.0			31,550.7		
Prtp=1%, ew	'Best guess'	$201.7	$1,218	$59,835	174.0	1,050.8	51,618
	Median	$183.1			157.9		
	Average	$706.9			609.8		
	Standard Deviation	$5,377.9			4,639.4		
Prtp=1%, w/out ew	'Best guess'	$12.8	$95	$5,179	11.0	81.6	4,468
	Median	$8.1			7.0		
	Average	$136.3			117.6		
	Standard Deviation	$3,307.6			2,853.4		
Prtp=3%, ew	'Best guess'	-$1.0	$521	$13,551	-0.8	449.3	11,690
	Median	$1.2			1.1		
	Average	$50.4			43.5		
	Standard Deviation	$1,296.9			1,118.8		
Prtp=3%, w/out ew	'Best guess'	-$2.6	$41	$1,187	-2.3	35.7	1,024
	Median	-$3.7			-3.2		
	Average	-$4.2			-3.6		
	Standard Deviation	$215.3			185.7		

Emissions 2000 – 2009. FUND 2.8

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

The numbers are reported for emissions in future years (discounted to the year of emissions), with the Greenbook declining discount rate scheme and with and without equity weighting, as the best guess, mean and median. The values assume 250 future years of damage in all cases.

FUND Future Damages – discounted to the year of emission.

Marginal Damage (USD1995)

	No equity weights greenbook discounting,		Emission period			
Decade	**2000-2009**	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
Median	$10.12	$13.02	$16.65	$20.49	$23.12	$28.23
Mean	$0.72	$64.45	$39.05	$305,382.40	-$57.53	-$228.10
'Best Guess'	$22.67	$28.54	$35.53	$47.31	$51.06	$59.30
5% value	-$60.50	-$48.72	-$47.45	-$47.57	-$56.23	-$55.49
95% value	$200.92	$234.96	$280.36	$302.15	$314.47	$370.85

	Average equity weighting, greenbook discounting					
Decade	**2000-2009**	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
Median	$22.42	$26.91	$29.44	$33.55	$38.95	$45.98
Mean	$109.78	$434.25	$105.19	$220,466	-$17.35	$102.19
'Best Guess'	$24.05	$29.49	$36.19	$45.74	$49.98	$56.87
5% value	-$61.72	-$53.46	-$53.17	-$47.04	-$54.33	-$45.85
95% value	$358.45	$438.44	$558.63	$531.06	$576.98	$666.69

Marginal Damage (2000 £)/tC)

	Weighting scheme greenbook discounting		Emission period			
Decade	**2000-2009**	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
Median	8.73	11.23	14.36	17.68	19.95	24.35
Mean	0.62	55.60	33.68	263446	-49.63	-196.78
'Best Guess'	19.55	24.62	30.65	40.81	44.04	51.16
5% value	-52.19	-42.03	-40.93	-41.03	-48.51	-47.87
95% value	173.33	202.69	241.86	260.65	271.29	319.93

	greenbook discounting, average equity weighting					
Decade	**2000-2009**	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
Median	19.34	23.22	25.40	28.94	33.60	39.66
Mean	94.71	374.61	90.74	190191.25	-14.97	88.15
'Best Guess'	20.75	25.44	31.22	39.45	43.11	49.06
5% value	-53.24	-46.12	-45.87	-40.58	-46.87	-39.55
95% value	309.22	378.23	481.92	458.13	497.75	575.14

Note there are minor differences in the values for current emissions between this analysis and the previous analysis.
The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

The unadjusted mean is distorted by some of the very extreme runs. For this reason, a trimmed mean is also presented. The exact trimming applied has a considerable effect on the values. We exclude 1, 5, 10, and 20% of the values. The values are shown below. The effects are most significant with equity weighting applied.

Mean Trimmed results FUND Future Damages – discounted to the year of emission.

No equity weight, Greenbook $95	2000-2009	2010-2019	2020-2029	2030-2039	2040-2049	2050-2059
Median	$10.12	$13.02	$16.65	$20.49	$23.12	$28.23
Mean (untrimmed)	$0.72	$64.45	$39.05	$305,382	-$57.53	-$228.10
'Best guess'	$22.67	$28.54	$35.53	$47.31	$51.06	$59.30
5% value	-60.50	-48.72	-47.45	-47.57	-56.23	-55.49
95% value	200.92	234.96	280.36	302.15	314.47	370.85
Trimmed mean 1%	$26.72	$38.14	$48.19	$59.38	$59.38	$76.89
5% value	-55.56	-45.46	-44.42	-44.83	-52.92	-48.99
95% value	184.12	221.15	262.82	292.46	301.29	342.39
Trimmed mean 5%	$26.93	$33.49	$43.35	$49.41	$52.50	$66.17
Trimmed mean 10%	$21.30	$26.31	$34.99	$39.10	$43.24	$53.89
Trimmed mean 20%	$18.30	$21.62	$29.24	$32.89	$36.93	$45.92
£2000						
Median	8.73	11.23	14.36	17.68	19.95	24.35
Mean (untrimmed)	0.62	55.60	33.68	263446.09	-49.63	-196.78
'Best guess'	19.55	24.62	30.65	40.81	44.04	51.16
5% value	-52.19	-42.03	-40.93	-41.03	-48.51	-47.87
95% value	173.33	202.69	241.86	260.65	271.29	319.93
Trimmed mean 1%	23.05	32.90	41.57	51.22	51.22	66.33
5% value	-47.93	-39.22	-38.32	-38.68	-45.65	-42.26
95% value	158.84	190.78	226.73	252.30	259.92	295.37
Trimmed mean 5%	23.24	28.89	37.40	42.62	45.29	57.08
Trimmed mean 10%	18.38	22.70	30.18	33.73	37.30	46.49
Trimmed mean 20%	15.78	18.65	25.22	28.37	31.86	39.61

With equity weight, Greenbook	2000-2009	2010-2019	2020-2029	2030-2039	2040-2049	2050-2059
Median	$22.42	$26.91	$29.44	$33.55	$38.95	$45.98
Mean (untrimmed)	$109.78	$434.25	$105.19	$220,466	-$17.35	$102.19
'Best guess'	$24.05	$29.49	$36.19	$45.74	$49.98	$56.87
5% value	-61.72	-53.46	-53.17	-47.04	-54.33	-45.85
95% value	358.45	438.44	558.63	531.06	576.98	666.69
Trimmed mean 1%	$74.94	$86.95	$98.57	$110.15	$112.89	$149.34
5% value	-55.87	-49.09	-48.27	-44.88	-51.19	-42.31
95% value	348.06	413.17	518.11	496.42	550.64	619.22
Trimmed mean 5%	$53.33	$65.54	$79.55	$85.38	$94.11	$116.63
Trimmed mean 10%	$40.66	$50.57	$59.89	$65.66	$73.95	$91.18
Trimmed mean 20%	$34.31	$40.80	$48.29	$54.22	$61.14	$75.29
£2000						
Median	19.34	23.22	25.40	28.94	33.60	39.66
Mean (untrimmed)	94.71	374.61	90.74	190191	-14.97	88.15
'Best guess'	20.75	25.44	31.22	39.45	43.11	49.06
5% value	-53.24	-46.12	-45.87	-40.58	-46.87	-39.55
95% value	309.22	378.23	481.92	458.13	497.75	575.14
Trimmed mean 1%	64.65	75.01	85.03	95.03	97.38	128.84
5% value	-48.19	-42.35	-41.64	-38.72	-44.16	-36.50
95% value	300.26	356.43	446.96	428.25	475.03	534.18
Trimmed mean 5%	46.01	56.54	68.63	73.66	81.19	100.62
Trimmed mean 10%	35.08	43.62	51.67	56.64	63.80	78.66
Trimmed mean 20%	29.59	35.20	41.66	46.78	52.74	64.96

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

The full distribution is shown below.

Marginal Damage (£2000)

	greenbook discounting. No equity weighting					
	2000-2009	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
0% value untrimmed	-20520.8	-4918.9	-6217.5	-11687.3	-100574.1	-362175.8
1% value untrimmed	-676.3	-258.0	-199.7	-257.1	-152.8	-182.4
5% value untrimmmed	-52.2	-42.0	-40.9	-41.0	-48.5	-47.9
10% value untrimmed	-28.3	-25.4	-28.3	-29.2	-31.3	-28.1
15% value untrimmed	-19.8	-18.4	-21.3	-21.3	-21.2	-20.7
20% value untrimmed	-14.5	-14.8	-17.1	-15.9	-15.0	-14.9
25% value untrimmed	-11.5	-11.9	-11.2	-10.0	-9.9	-8.4
30% value untrimmed	-7.2	-7.5	-7.1	-4.5	-5.0	-2.5
35% value untrimmed	-3.2	-3.2	-2.1	0.9	0.8	2.9
40% value untrimmed	0.3	1.5	2.5	6.4	6.7	10.0
45% value untrimmed	4.5	5.4	8.5	11.8	11.6	17.1
50% value untrimmed	8.7	11.2	14.3	17.5	19.9	24.3
55% value untrimmed	14.1	16.4	21.3	26.1	25.8	33.2
60% value untrimmed	20.1	25.7	28.3	33.5	35.8	42.8
65% value untrimmed	26.9	32.5	38.1	44.6	49.4	56.8
70% value untrimmed	35.4	41.5	51.5	57.3	62.6	74.5
75% value untrimmed	46.7	51.4	68.2	70.3	81.1	97.1
80% value untrimmed	58.3	66.7	87.3	92.1	100.6	119.1
85% value untrimmed	78.3	83.2	116.8	115.9	133.4	157.5
90% value untrimmed	106.5	125.6	156.3	167.2	176.7	218.4
95% value untrimmed	173.3	202.7	241.9	260.7	271.3	319.9
99% value untrimmed	534.9	513.5	482.4	856.9	564.5	870.9
100% value untrimmed	2804.4	14820.2	1212.1	263411497.9	3164.9	76876.0

Median	8.7	11.2	14.4	17.7	19.9	24.4
Mean	0.6	55.6	33.7	263446.1	-49.6	-196.8
'Best guess'	19.6	24.6	30.6	40.8	44.0	51.2
Trimmed mean 1%)	23.1	32.9	41.6	51.2	51.2	66.3
Trimmed mean 5%)	23.2	28.9	37.4	42.6	45.3	57.1
Trimmed mean 10%)	18.4	22.7	30.2	33.7	37.3	46.5
Trimmed mean 20%)	15.8	18.6	25.2	28.4	31.9	39.6

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

Marginal Damage (£2000)

	greenbook discounting, average equity weighting					
	2000-2009	**2010-2019**	**2020-2029**	**2030-2039**	**2040-2049**	**2050-2059**
0% value untrimmed	-18883.0	-4381.4	-6018.5	-8504.8	-98543.4	-360321.2
1% value untrimmed	-714.5	-308.4	-290.4	-105.9	-134.6	-202.1
5% value untrimmmed	-53.2	-46.1	-45.9	-40.6	-46.9	-39.6
10% value untrimmed	-30.8	-28.7	-29.3	-27.4	-29.5	-23.5
15% value untrimmed	-21.2	-20.1	-21.1	-19.0	-19.3	-14.6
20% value untrimmed	-14.6	-15.6	-14.6	-11.0	-13.3	-9.8
25% value untrimmed	-9.6	-10.0	-10.1	-6.1	-5.2	-2.2
30% value untrimmed	-4.7	-5.0	-3.4	-0.2	0.7	3.9
35% value untrimmed	1.0	2.0	3.6	6.7	6.8	12.4
40% value untrimmed	6.2	6.5	11.2	12.6	14.6	21.0
45% value untrimmed	11.9	15.3	17.8	19.7	22.8	29.1
50% value untrimmed	19.3	23.1	25.2	28.8	33.4	39.6
55% value untrimmed	26.3	30.9	33.7	39.6	41.3	49.8
60% value untrimmed	36.0	40.1	43.4	50.1	55.1	66.6
65% value untrimmed	45.9	49.7	56.0	65.9	75.1	84.8
70% value untrimmed	59.4	63.6	73.2	82.8	93.4	110.7
75% value untrimmed	75.2	79.6	91.9	106.4	117.1	135.5
80% value untrimmed	96.0	104.6	123.7	135.9	152.1	169.1
85% value untrimmed	119.5	160.7	179.9	182.8	206.7	252.7
90% value untrimmed	165.8	221.8	254.1	264.0	304.1	358.4
95% value untrimmed	309.2	378.2	481.9	458.1	497.7	575.1
99% value untrimmed	2019.3	1633.7	1264.6	1635.6	1281.2	2158.8
100% value untrimmed	27355.4	166492.1	8216.5	190095594.8	26633.2	241827.9

Median	19.3	23.2	25.4	28.9	33.6	39.7
Mean	94.7	374.6	90.7	190191.3	-15.0	88.2
'Best guess'	20.7	25.4	31.2	39.5	43.1	49.1
Trimmed mean 1%)	64.6	75.0	85.0	95.0	97.4	128.8
Trimmed mean 5%)	46.0	56.5	68.6	73.7	81.2	100.6
Trimmed mean 10%)	35.1	43.6	51.7	56.6	63.8	78.7
Trimmed mean 20%)	29.6	35.2	41.7	46.8	52.7	65.0

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

The values above are based on a future world without mitigation.

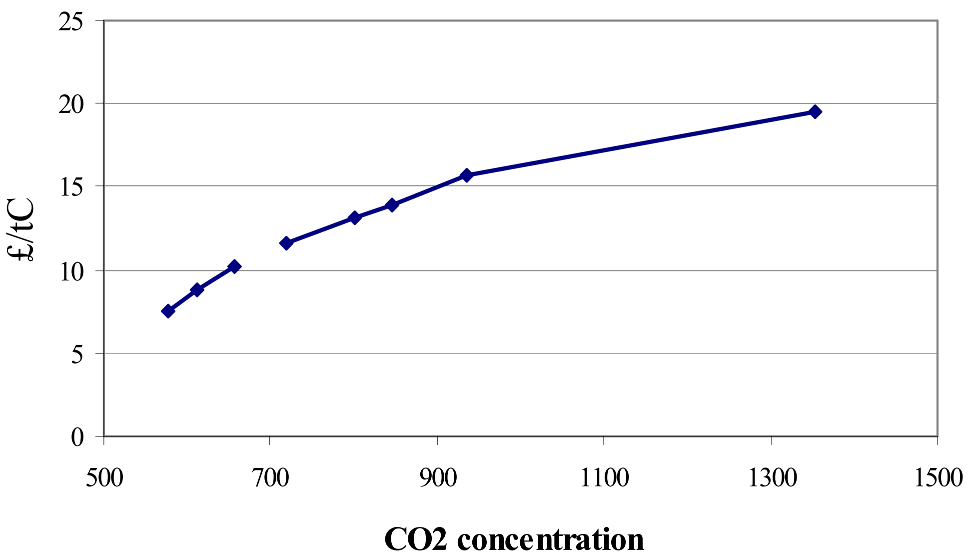
With different future scenarios, the SCC values are likely to change, for example on the path towards a 2050 scenario we would expect lower SCC values in future year (though this was not found with the PAGE analysis above). The study has also assessed the possible SCC values from FUND under different future scenarios, consistent with different emissions paths and global post-Kyoto policies. The table below shows the marginal damage costs of carbon dioxide emissions in the period 2000-2009 for the business as usual scenario and various policy scenarios. The scenarios are ranked according to the their maximum CO_2 concentration in the atmosphere.

The table and figure below show the marginal damage costs of carbon dioxide emissions in the period 2000-2009 for Greenbook declining scheme but without equity weighting, for the business as usual scenario and various policy scenarios. The scenarios are ranked according to the their maximum CO_2 concentration in the atmosphere. This analysis has only been undertaken using the FUND best estimate for current emissions – it has not been completed for future time periods, with the full Monte Carlo analysis (to generate median and mean values), as this would require detailed additional modelling work. This analysis is highlighted as a priority for future work.

Marginal SCC under different policy scenarios (CO_2 concentrations) from FUND, current emissions, no equity weighting. Best Guess.

$MaxCO_2$	1352	934	846	800	720	682	658	611	577
SCC £/tC	19.6	15.7	13.9	13.1	11.6	9.7	10.1	8.8	7.5

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent



effects.

Marginal SCC under different policy scenarios (CO_2 concentrations) from FUND, current emissions, no equity weighting. Best Guess

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.

The UK target is based on 550 ppm scenario (carbon dioxide concentrations in the atmosphere at no more than 550 ppm). This is close to the CO_2 concentration on the far left of the graph. This could be considered to be consistent with the concept that progress towards 550 ppm stabilisation (and lower temperature changes) would prevent much of the major potential damages of climate change, leading to lower marginal SCC values. However, as FUND does not include any of these major events, any socially contingent effects, and excludes many bounded risks, this is not really conclusive. Note the graph above only relates to current emissions, it would be expected to change for emissions in future years.

Marginal SCC under different policy scenarios (CO2 concentrations) from FUND, current emissions, no equity weighting. Best Guess

			$95/tC			
MaxCO2	**0%**	**1%**	**3%**	**Weitzman**	**Gollier**	**Greenbook**
BaU 1352	65.6	13.3	-2.3	23.5	1812.1	22.7
934	54.2	9.3	-3.2	18.5	1759.4	18.2
846	51.4	8.1	-3.5	17.2	1725.3	16.1
800	49.1	7.3	-3.7	16.2	1694.7	15.2
720	44.4	5.9	-3.9	14.3	1620.5	13.5
682	42.1	4.6	-4.5	13.1	1578.6	11.2
658	39.9	4.6	-4.2	12.4	1537.2	11.8
611	35.6	3.3	-4.5	10.7	1451.3	10.2
577	31.6	2.2	-4.7	9.0	1362.0	8.7

			£2000/tC			
MaxCO2	**0%**	**1%**	**3%**	**Weitzman**	**Gollier**	**Greenbook**
1352	56.6	11.4	-2.0	20.3	1563.2	19.6
934	46.8	8.0	-2.8	16.0	1517.8	15.7
846	44.3	7.0	-3.0	14.8	1488.4	13.9
800	42.3	6.3	-3.2	14.0	1462.0	13.1
720	38.3	5.1	-3.4	12.3	1397.9	11.6
682	36.3	4.0	-3.8	11.3	1361.9	9.7
658	34.4	3.9	-3.6	10.7	1326.1	10.1
611	30.7	2.9	-3.8	9.2	1252.0	8.8
577	27.2	1.9	-4.0	7.8	1175.0	7.5

The FUND model results exclude some bounded risks, and exclude major climatic system events and socially contingent effects.