

The social cost of carbon: Valuation estimates and their use in UK policy

Paul Watkiss

Paul Watkiss Associates, Oxford, UK. *

Thomas E. Downing

Stockholm Environment Institute, Oxford, UK. †

Abstract

There is an increasing interest in the economics of climate change, and the marginal damage costs of emissions, known as the Social Cost of Carbon (SCC). In 2002, the UK Government recommended an SCC for policy appraisal. A recent review of this SCC was commissioned and summarised in this paper. The authors conclude that SCC estimates span at least three orders of magnitude, reflecting uncertainties in climate change and choices of key parameters/variables (discount rate, equity weighting and risk aversion). Estimates also vary due to their coverage, and a risk matrix was developed to compare climate change effects (predictable to major events) against impacts (market, non-market and socially contingent). From several lines of evidence, the current lower SCC value is considered a reasonable lower benchmark for a global decision committed to reducing the threat of dangerous climate change. An upper benchmark was more difficult to deduce, though the risk of high values was considered significant. It is currently impossible to provide a central value with confidence. The study also reviewed the use of the SCC in policy, from project appraisal to long-term climate policy, and used stakeholder interviews to elicit views. A wide diversity of responses was found: whilst most considered some values are needed for policy appraisal, nearly all had reservations for long-term policy. From this, the authors propose a two tier approach. The economic benefits of climate change should be considered when setting long-term policy, but a wider framework is needed (i.e. than cost-benefit analysis). This should include a disaggregated analysis of economic winners and losers by region and sector, and key impact indicators such as health and ecosystems. It should also consider the full risk matrix (i.e. non-marginal/irreversible effects). Once long-term policy is set, shadow prices for appraisal across Government are useful, provided they are consistent with the long-term goal, and are applied consistently.

*Corresponding Author. E-mail: paul.watkiss@btinternet.com

†E-mail: tom.downing@sei.se

Keywords: Social Cost of Carbon, SCC, economics of climate change, UK climate change policy, marginal social costs, climate change valuation

1 Introduction

Traditionally the policy debate on climate change has focused on the costs of mitigation, but there is an increasing interest in the economic costs (the social costs) of climate change. In the UK Government, these are known as the Social Cost of Carbon (SCC). The Social Cost of Carbon—in this policy context—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 ([GES, 2002](#)) recommended an illustrative marginal global SCC estimate of £70/tonne of carbon (tC), within a range of £35 to £140/tC, for use in policy appraisal across Government (all three estimates rising at £1/tC per year from the year 2000). These SCC values have been used widely in regulatory impact appraisal and in the consideration of environmental taxes and charges. The GES paper also recommended that these values should be subject to periodic review. The GES paper sparked a response, with many commentators questioning the values (e.g., [Pearce, 2003](#); [House of Lords, 2005](#)).

This debate over the state-of-the-art in estimates of the SCC, and its use in Government policy making, led to two parallel review projects, commissioned in 2004. The first review looked at the underlying SCC values and uncertainty ([Downing et al., 2005](#)), whilst the second looked at how best to use these values in policy ([Watkiss et al., 2006](#)). This paper summarises the output from these papers, and the lead authors' views on the findings and implications. It also puts these findings in the context of the subsequent Stern Review on the Economics of Climate Change ([Stern et al., 2006](#))¹.

2 SCC Estimates

The analysis of SCC values investigated three lines of evidence: an updated literature review of values; a knowledge elicitation of experts; and modelling with two of the leading Integrated Assessment Models (FUND and PAGE)².

¹In July 2005, the Stern Review was commissioned by the Chancellor of the Exchequer, reporting to both the Chancellor and to the Prime Minister, as a contribution to assessing the evidence and building understanding of the economics of climate change. The two SCC reviews were finalized and published after Stern had been commissioned, and therefore formed an input into the Stern Review, which itself was published in late 2006. More so than the original GES paper, the Stern review led to a vigorous critique (e.g., [Nordhaus, forthcoming](#); [Tol, 2006](#); [Yohe, 2006](#), and many others).

²A number of other lines of evidence were also investigated. A number of MSc Theses by David Anthoff (2004, see also [Anthoff et al. 2006a](#)), Megan Ceronsky (2004, see also [Ceronsky et al. 2005a,b](#)), Jiehan Guo (2004, see also [Guo et al. 2006](#)) and Ada Li (2004), supervised by Cameron Hepburn, University of Oxford, provided input looking at extreme events, dis-

The literature review was an update of the Tol (2005) paper, which looked at marginal social cost values from 28 studies in the literature, providing 103 estimates. The Tol paper reported that if all studies were combined, the mode was \$2/tC, the median \$14/tC, the mean \$93/tC, and the 95 percentile \$350/tC. Excluding the studies that were not peer reviewed, the mean was \$50/tC³ (for any discount rate) and this is reflected in the paper conclusions, which cites a maximum value of \$50/tC⁴ (for observed discount rates)—significantly below the central illustrative SCC values of £70/tC. Further work by Tol (2005) has shown a general decrease in the marginal social cost values over time, particularly since the year 2000, due to consideration of explicit socio-economic reference scenarios (generally of wealthier futures), inclusion of benefits as well as impacts, and notably due to autonomous adaptation⁵. However, work by Downing & Watkiss (2003) has raised the issue of study coverage in comparing SCC values, and this was advanced during the studies.

The SCC values were compared for their coverage against a risk matrix (Figure 1), in relation to

1. The uncertainty of climate change impacts, covering:
 - Impacts that can be predicted with relative confidence and where the confidence in the direction of effect is certain (e.g. average temperature);
 - Impacts where prediction is more uncertain, and where models often give different levels of impacts, or even predictions of a different sign (positive/negative), as with for example regional estimates of levels of precipitation, or frequency or magnitude of extreme events;
 - Impacts where prediction is highly uncertain, notably around the major ‘tipping points’ commonly identified (major climate discontinuities or irreversibilities, such as the West Antarctic ice sheet, methane hydrates, etc, as in (Schellnhuber et al 2005).
2. The uncertainty in valuation, covering:
 - Market effects (e.g., estimates captured through markets such as energy and agriculture);
 - Non-market effects (e.g., estimates for health and ecosystems which rely on other economic approaches, as advanced through the environmental economics literature);

counting, risk aversion and ambiguity aversion. The study also included the development of a multi-agent model of the Sahel.

³Note the values cited are mostly in the year of the study, i.e. they are not increased to consistent year 2000 or year 2005 prices.

⁴The author, Richard Tol, concludes that ‘using standard assumptions about discounting and aggregation, the marginal damage costs of carbon dioxide emissions are unlikely to exceed \$50/tC, and are probably much smaller’

⁵It should be noted that such trends may change in future analysis. Two recent findings are that climate sensitivity and the likelihood that severe impacts increases at lower temperature changes may be higher than previously expected (Schellnhuber & et al., 2005).



		Uncertainty in Valuation 		
		Market	Non Market	(Socially Contingent)
Uncertainty in Predicting Climate Change 	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 1: The Social Cost of Carbon Risk Matrix (Downing & Watkiss, 2003; Downing et al., 2005; Watkiss et al., 2006)

- A third category of non-market effects—labeled socially contingent effects—defined as large scale dynamics related to human values and equity that are very poorly represented in damage estimates based on marginal cost values, e.g. regional conflict, famine, poverty.

The policy paper (Watkiss et al., 2006) mapped the existing literature studies onto this matrix to examine the coverage, shown in Figure 2. It was found that most studies/models cover only limited climate effects such as temperature change, and generally only value market damages (e.g. agriculture and energy). Very few studies cover any non-market damages, locally-specific precipitation effects, or the risk of extreme weather (floods, storms, etc). Almost none cover socially contingent effects and major/catastrophic events. Of course, much of the variation in the SCC estimates in the literature arises because different model estimates of the SCC include different coverage.

More importantly, the risk matrix coverage shows the uncertainty in the SCC values concerns not only the ‘true’ value of impacts in the models, but also uncertainty about impacts that have not yet been quantified and valued. An immediate conclusion is that the SCC values in the literature are therefore a sub-total of the full SCC—though we do not know by how much (because the probability and consequences of much of the boxes in the matrix are not known). While the missing categories are likely to include both positive and negative effects, the results of expert interviews (discussed later) suggest that the missing effects are likely to have net damages, which could be potentially very large. There is some emerging work that is expanding the analysis of the matrix (e.g., Anthoff et al., 2006b; Ericson et al., 2006) but this remains a

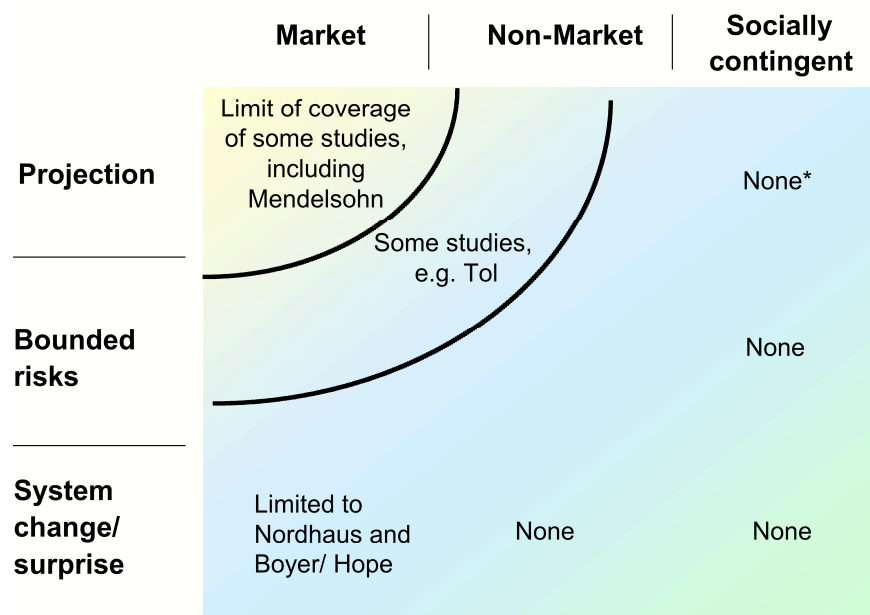


Figure 2: The Coverage of SCC Studies Against the Risk Matrix (Watkiss et al., 2006) (* Some sectoral and/or regional studies exist for socially contingent effects for ‘projections’ (and limited analysis of ‘bounded risk’), but they are limited to impacts, and do not extend to economic costs.)

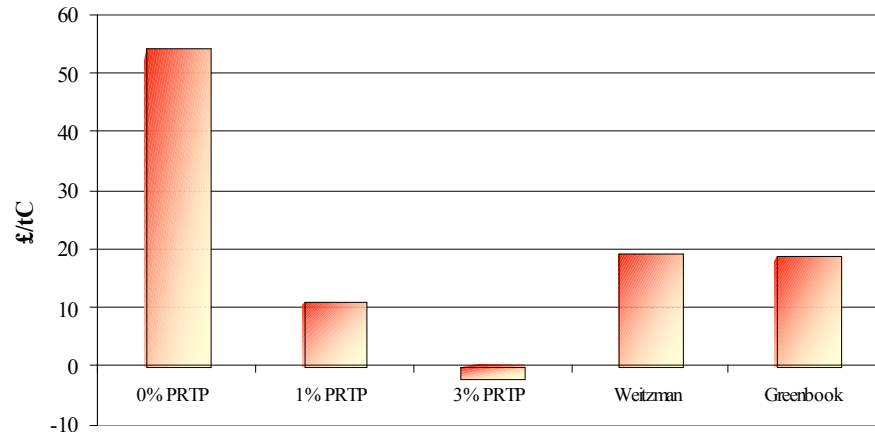


Figure 3: Example of how SCC estimates vary in FUND (Best Guess setting) with discount rate

research priority⁶.

As part of the review work on the SCC estimates, the study reviewed and assessed the key parameters that affect estimates (Downing et al., 2005, based on the underlying work feeding into this study⁷). It is clear 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 input or decision perspectives, most importantly:

- *Discount rate.* Clearly the choice of discount rate has a very large effect on any values, because most impacts of climate change occur in the future. Higher discount rates lead to lower values. As an illustration, in FUND, as an example of importance of the effect, a discount rate of 1% Pure Rate of Time Preference (PRTP) produces estimates that are on the order of 1/5th of the SCC calculated with a PRTP of 0% (whilst a 3% PRTP can lead to net benefits). The Green Book declining discount rate scheme produced estimates between 0 and 1% PRTP (see Figure 3 for an examples from a central FUND run)⁸.

⁶The exact net effects of the missing categories remain unknown, especially in relation to complex socially contingent effects. For instance, while are studies that show population dislocations and abandonment in response to some climate change variables such as drought (e.g., deMenocal, 2001), conversely there are also studies which show greater frequency of wars during cool periods as a resulting scarcity of resources (e.g., Zhang et al., 2007).

⁷by Anthoff (2004); Ceronsky (2004); Guo (2004); Li (2004)

⁸Most impact assessment modelling studies present results in terms of the pure rate of time preference (PRTP). The social rate of time preference, which is typically used in conventional project/policy CBA in Government 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. The use of PRTP in IAMs 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.

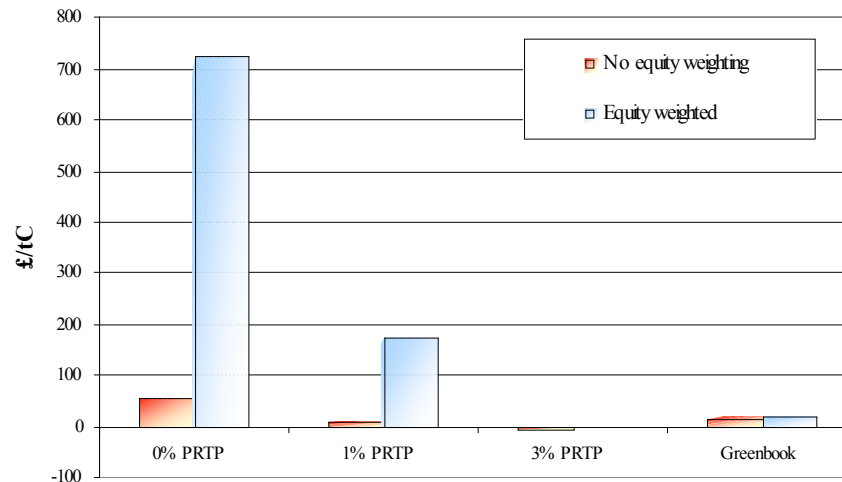


Figure 4: Example of how SCC estimates vary in FUND (Best Guess setting) with equity

- The *study-time horizon*. Aggregate models suggest that net impacts of climate change may be positive in the short term, but turn negative for more severe climate change (even without major events). Extending the time horizon, even with discounting, can substantially increase the SCC for current emissions (note different discounting assumptions can make this even more important). Constraining the time-scale (e.g., to 100 years) will conversely lead to lower values.
- The approach to weighting impacts in different regions (*equity weighting*). Most impacts in the medium term occur in developing countries, and so the decision on whether to use compensation values or adjust estimates using a form of distributional weighting (equity weighting) has a significantly bearing on the results. Use of equity weights increases the SCC values, but there have been concerns raised over their use when compared to other international policy (e.g. in the UK, see [Pearce 2003](#); and also recent work by [Anthoff et al. 2006a](#)). With a PRTP of 0%, and equity weighting, the FUND model analysis showed an increase in the SCC by a factor of 5 to 15, depending on the way equity weights are calculated (see [Figure 4](#) for an example from a central FUND run). Even with higher discount rates, the increase might be a factor of 2 to 10.
- The reporting of the *central tendency* (specifically whether mean or median values are cited as the central estimate). Both the mean and the median have been used as a measure of central tendency for different SCC estimates. For skewed distributions they give substantially different results even with the same underlying data. As the SCC estimates are

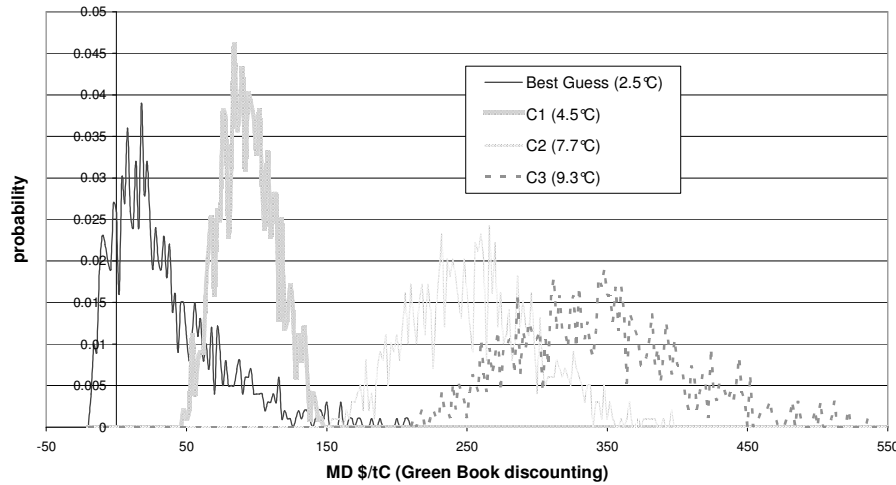


Figure 5: Distribution of the SCC in FUND with four climate sensitivities (Ceronsky, 2004).

right skewed (mean > median), than the choice of central value can increase or decrease the values (e.g. models/studies which report median values give lower estimates than those that report mean values as the central estimate—see the reported values quoted above from the Tol meta-analysis (2004a) of \$14 median and \$93 mean).

- *Climate sensitivity*, i.e., the equilibrium warming expected with a doubling of CO₂ concentrations. The Third Assessment Report of the IPCC concluded that the range was 1.5 to 4.5°C with a best guess of 2.5°C⁹. This can dramatically affect the SCC values, and the effects are increased with some of the more recent higher values (e.g., Stainforth et al., 2005; Frame et al., 2005). As an illustration (Ceronsky, 2004, see Figure 5), the SCC using FUND was found to be 5–6 times higher at 4.5°C than at 2.5°C, and a further factor of 3 to 7 (e.g., comparing 9.3°C to 4.5°C).

Each of these five variables can significantly influence the SCC values, leading to differences in values that are orders of magnitude different. There is no consensus on which parameter variables to use (though there are many alternative views expressed, which vary with the use of a prescriptive or descriptive approach). What is important is that the choice of specific parameters can explain the difference between the most recent Government SCC¹⁰ estimates in

⁹Note since the SCC studies, the Intergovernmental Panel on Climate Change Assessment Report 4 (2007) concludes that the ‘best guess’ is 3°C, with a range from 2 to 4.5°C

¹⁰Page 287 (chapter 13) of the Stern review quotes a marginal social cost for the baseline of \$85/tCO₂—which is broadly equivalent to \$310/tC—at least double the central illustrative GES value of £70/tC, and cite that ‘cost of climate change is now expected to be larger than many earlier studies suggest’.

the UK (Stern et al., 2006) which arrived at a value several times the existing UK SCC and the wider literature (such as Tol, 2005), even though the Stern analysis uses much the same models and damage functions (see Yohe, 2006). As a summary, the Stern Review adopted a global rather than a national perspective, with substantial aversion to risk, and consideration of intertemporal and geographical equity. This translated to the use of a very low discount rate (0.1% PRTP), use of a form of equity weighting, use of mean values, and consideration of higher climate sensitivity based on more recent evidence.

3 Knowledge Elicitation

To further explore the effect of climate and decision factors, the project polled 14 experts for responses to some 30 prescribed scenarios of climate change, coverage of impacts sectors, and decision choices (such as discount rate). The experts included well-known advocates for a high SCC as well as for low SCC values. Each expert was asked to rate their confidence in each response. The responses were not benchmarked in any way—the interviewer did not prompt the respondent to anchor the range or the mid-point. The experts received the results with an opportunity to comment on the conclusions—but this was not an iterative exercise nor was it designed to achieve a consensus among the experts. Of the nearly 450 scenario-responses, fully 70% had a confidence rating of very low or low. None of the scenarios were judged a confidence of very high and only 3% had a high confidence.

The major determinant of the experts' estimates of the SCC was the climate sensitivity (Table 1). Experts reporting generally low estimates (e.g., L1) produced estimates exceeding £35/tC, but only for high climate scenarios and usually with other decision factors. In the middle to high group of experts (e.g., M1 and X2), values around £35/tC occurred for many climate scenarios, and were quite common for middle to high scenarios. A decision tree of the scenario responses found the importance of aversion to risk (from the range of climate sensitivities), with intermediary contributions from the range of impacts included (e.g., market and non-market, socially contingent), adaptation (as a reduction in impacts), discount rate and decision perspective (e.g., global or local).

4 Review of SCC use in Policy

The UK Government, and its economic regulators, extensively use economic appraisal. The Treasury Green Book (HMT, 2004, 2007) provides the guidance on how to do this, and requires Government action be based on an assessment of how any proposed policy, programme or project can best promote the public interest. It specifically sets out guidance to assess whether the benefits of intervention are expected to exceed the costs. This is assessed through cost-benefit analysis (CBA), whereby all relevant costs and benefits to government and so-

Table 1: Selected estimates of the SCC from experts for a range of scenarios, £/tC. Respondents are grouped according to their responses, as low (L), medium (M) or high (X).

Respondent	Climate Scenario					
	Low		Medium		High	
	SCC	range £/tC	SCC	range £/tC	SCC	range £/tC
L1	1	8	8	17	11	66
L2	-3	7	6	29	12	111
L3	-2	1	4	21	19	190
M1	8	33	17	50	17	78
X1	8	22	33	83	56	145
X2	0	22	0	36	11	167

ciety of all options are valued, and the net benefits or costs calculated. The UK has also adopted a pro-active approach on the use of economic instruments including environmental taxes, charges and subsidies, as well as market-based instruments (HMT, 2002).

The policy project reviewed the potential use of SCC values in decision making for UK Government, based around the Treasury guidance. It found a number of key potential applications for the SCC¹¹:

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

Note the reference to project and policy appraisal can include areas directly targeted at GHG reduction, but also other policy (e.g. energy, air quality, transport, etc, for which the primary aim is not targeted towards climate change).

The study reviewed how the existing SCC values had been used across each these four application areas since the guidance was issued in 2002. It found there had been widespread use of the SCC estimates for the first three applications. A summary of examples is presented in the table below for different applications in different Government departments, agencies and regulators¹².

However, it was found that while there had been widespread use, the applications did not adopt a consistent approach. For example, some used the

¹¹An additional category—adaptation—is now also considered relevant.

¹²Note the study also found that the use of the SCC values was not always consistent, for example, some analysts had used the central illustrative value of £70/tC only, whilst some used the full range £35 to £140/tC. It also identified a limited number of relevant policy appraisals which had important effects on greenhouse gas emissions, but had not used the SCC values.

central illustrative value of £70/tC only, whilst some used the illustrative range of £35 to £140/tC. There were also a few cases where a single value at the upper or lower end of the range was used. During the interviews, the reason for this variation was explored: in some cases this reflected the view that the analyst held on the robustness of the SCC value. What is clear is that the use of different values leads to inconsistency, and this has implications for the cost-effective introduction of GHG strategies across different policy areas. Importantly it provides a key point for appraisal in the future (in the UK and elsewhere)—there is a trade off between using a range of values to reflect the likely uncertainty, compared to the use of a central value (only) to ensure consistency.

Interestingly, the review found limited use of the SCC in long-term climate change policy. The UK has adopted a long-term GHG reduction goal. This was published in the 2003 Energy White Paper (DTI, 2003), which set out the longer term framework for the UK's energy policy and accepted that the UK should put itself on a path to reducing carbon dioxide emissions by some 60% (from 1990 levels) by 2050. The white paper analysis did consider the SCC in the analysis of the necessary short-term steps towards this goal (until 2020), but the value was not used explicitly (in published material) in cost-benefit analysis of the long-term goal. This is consistent with the general finding (reflected in the study stakeholder analysis, see below) that for longer-term climate change policy, cost-benefit analysis is rarely used, and is the subject of considerable debate. The study also reviewed the use of SCC estimates in policy in other countries/organisations and found very limited current use with only a handful of examples and no routine application of such estimates.

5 Stakeholder Consultation on Policy Uses of the SCC

The policy study further undertook stakeholder consultation to elicit views on the SCC values, focusing on the choice of the key parameters (e.g. discount rate) that can affect the values (see above section), and on how the SCC should best be used in UK policy (values and preferred approaches to deal with risk and uncertainty). The study undertook stakeholder interviews and a workshop focusing on two major groups: (1) Climate change impact/valuation experts and (2) Government economists (as users). The study also had input from an expert peer review panel and steering group.

Overall, the consultation suggested that a shadow price of carbon emissions should be maintained for project and policy appraisal across UK Government, and that this value should be consistent with longer-term (climate) policy goals. The consultation also suggested that any value should be implemented consistently across all applications. There was, however, considerable resistance by some consultees to the use of the values in cost-benefit analysis for long-term climate policy, though nearly all groups recognised the need for some form of benefits analysis in this decision making context. Overall, there were three key

Table 2: Examples of the use of the SCC value across Government in the UK.

Organisation	Example Applications	Value Used and Implication
Defra	Regulatory Impact Assessment of the proposed F Gas regulations	Use of £35–£140/tC. The value used made a significant difference to the choice of options in the RIA.
	Cost-benefit analysis of UK Emission Trading Scheme Analysis of waste tax charges (review and consultation)	Used as part of an ex post consideration. Use of £35–£140/tC for review, though final policy did not proceed with waste taxes
DfT	Incorporation into New Approach to Appraisal for Road Transport infrastructure appraisal	Use of £35–£140/tC. Now incorporated in guidance and used routinely in appraisal, though the SCC is very low in relation to other cost and benefit streams (i.e. in most casts, it does not affect schemes materially).
	Incorporation into National Transport Model/Social Pricing Model	Use of £35–£140/tC, with central £70/tC. Now incorporated in model and including in all Government policy analysis.
	Analysis of aviation tax in Aviation White Paper (for consultation)	Use of £70/tC, rising by £1/tC by year to give £100/tC for 2030. Considered in consultation, but final policy did not proceed with aviation taxes
DTI	Analysis of road user charging and differential charges (consultation paper)	Used in consultation. Still being considered as part of charging regime as part of ongoing work in this area, e.g. recent Eddington review (2006).
	Energy White Paper	Use of £70/tC as a benchmark for costs of options to 2020. More recently, values have been used in the CBA of energy options in the Energy Review and Energy White Paper (2007)
ODPM	Regulatory Impact Assessment for Renewables Obligation II Proposals for Part L amendment (energy efficiency provisions) of Building Regulations	Use of 0, £70 and £140/tC
Ofgem	Energy investment appraisal (gas network extension, electricity transmission infrastructure)	Use of 0–£35/tC
EA	Assessment of Asset Management Programme 4 for Water Sector (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.

areas where the respondents had differing views. These were:

- Whether carbon shadow prices should be based on estimates of marginal abatement costs (MAC) consistent with the existing UK long-term target (60% reduction in CO₂ emissions by 2050), or whether the estimate of the marginal damage costs of carbon emissions (SCC) should be used. These views reflect different methodological viewpoints amongst stakeholders and are discussed 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 expressed concerns that the use 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. Much of the discussion here centred on whether climate change was a special application (and views differed on this point). While there was considerable support for the use of the Green Book declining scheme, which starts at 3.5% (social rate of discount) and declines to 1% over three hundred years, there was a divergent set of views on equity weighting¹³.

The first bullet point above reflects different perspectives on policy appraisal and CBA in general, but particularly on CBA for climate change policy. There were three broad groups of stakeholders. A first group which believed that cost-effectiveness should be the primary consideration when appraising lower-level policies, given that the UK Government had already set a long-term (2050) target for reducing emissions of CO₂. Such an approach should lead to the achievement of this goal at least cost. Within this group there were two lines of argument. Those who strongly felt that cost-benefit analysis had absolutely no role in long-term climate change policy and targets, and believed such policy should be set on the basis of scientific evidence, physical impacts and the precautionary principle. Some respondents in this group also raised the issue of the duty of care and human rights. Alternatively, there were those that believed that when policy is not easily based on an objective assessment of the costs and benefits (as with climate change), the process of target setting helps to reveal the weight which society puts on costs and benefits. They implicitly believe

¹³In some cases, the choice of input parameters appears to follow the consideration of the magnitude of SCC estimates, i.e., parameters are chosen to reinforce the expected SCC values.

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 is to 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 might consider a wider framework, with input from SCC and MAC estimates.

6 Additional Modelling

In working through practical case studies on policy applications, the study found that the basic SCC output from Integrated Assessment Models (IAMs) was not sufficient. There is a need for models to generate a more comprehensive suite of analysis for economic appraisal in practice, including:

- The need to consider the SCC values for emissions in different future time periods, e.g. 2010, 2020, etc, as it is not appropriate to use only a single year 2000 emission for appraisal. This reflects the fact that SCC values change over time;
- The need to consider the social costs for different greenhouse gases, not just CO₂, recognising that because of discounting, it is not appropriate to take existing values for carbon and use global warming potentials to derive social costs for other gases such as methane, and.
- The need to consider how the SCC changes with different mitigation policies, i.e. to generate values for a business as usual, but also ‘with policy’ scenarios that occur with mitigation policy.

These recommendations apply to the use of any ‘benefit’ input or values in appraisal—the SCC is not a static constant and failure to recognise this can lead to significant errors in appraisal analysis.

Some additional work was undertaken in the studies to investigate the SCC values. A set of ‘business as usual’ values for the SCC was derived using two of the leading Integrated Assessment Models:

- FUND (Climate Framework for Uncertainty, Negotiation, and Distribution model), version 2.8 (Tol, 2002*a,b*, 2004)
- PAGE2002, an updated version of the PAGE95 integrated assessment model (Plambeck et al., 1997; Plambeck & Hope, 1995, 1996).

The analysis with both models used the parameters agreed for the UK policy analysis from the steering group/expert peer review team. These were:

- Green Book declining discount rates, as recommended in UK policy¹⁴;
- Equity weighting (though there were concerns about the use of equity weights);
- Mean values (as the appropriate measure of central tendency), in line with principle of maximising expected utility and at least conveying some of the risk of unpleasant surprises (note the study also trimmed data, where necessary to remove some outliers, to provide a trimmed mean).

The above decision parameters are based (loosely) on a global decision perspective, i.e. one committed to reducing the threat of dangerous climate change, and including a modest level of aversion to extreme risks, relatively low discount rates and equity weighting. Whilst these are broadly similar to the assumptions proposed by the Stern Review (Stern et al., 2006, see also Anthoff et al. 2006*a*), Stern applied a much lower discount rate, included a higher upper bound for climate sensitivity, and also introduced some estimates for the missing elements of the risk matrix. Alternative assumptions on input parameters and assumptions would (and do!) produce very different estimates.

This analysis showed that the mean values from the IAMs are lower than the current central SCC illustrative guidance for a year 2000 emission, but that the IAM values increase much more quickly over time, and overtake the SCC values after 2030. In interpreting and comparing the values (and underlying models), it is also essential to note that these SCC estimates above still do not include consideration of the full risk matrix—they exclude socially contingent effects and major events, and also only have a partial coverage of bounded risks and non-market impacts. However, there are also issues over the discount scheme, and especially whether the equity weighting scheme is appropriate.

¹⁴Whilst the Greenbook declining discount rate scheme allows the direct application of a scheme that is part of current Government guidance, there are problems in implementing this scheme for climate change, as it is based on a Social Rate of Time Preference—a more accurate way to adopt a declining discount scheme would be to use the growth assumptions built into the models by region and then vary the Pure Rate of Time Preference.

Table 3: Illustrative outputs for the SCC over time—using the input parameters agreed for the study of declining discount rate, equity weighting, and mean values. 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. Values for FUND trim 1% of values as outliers.

£/tC	SCC Estimates—Year of Emission (Mean)						
	2000	2010	2020	2030	2040	2050	2060
Existing UK SCC							
Low	35	45	55	65	75	85	95
Central	70	80	90	100	110	120	130
High	140	150	160	170	180	190	200
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

7 Conclusions

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 (SCC) 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.

Representing understanding and uncertainty in a simple risk matrix helps to assess the coverage of existing estimates and the remaining gaps in our knowledge. Estimates of the SCC should be seen as a sample of the known damages. It seems quite likely that expanded coverage of the risks will increase estimates of the SCC, but this is impossible to determine without further analysis.

Climate uncertainties and the climate sensitivity are key factors in larger estimates of the social cost of carbon. Decision variables such as the discount rate and equity weighting also are extremely important. Even with a risk based approach, estimates of the central tendency (mean or median) can significantly affect the estimates.

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. These aspects are not covered in the current models and estimates

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

The lower existing UK SCC 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. A different set of input parameters will, however, lead to very different values—potentially much lower - or as seen more recently in the Stern review, much higher .

An upper benchmark is more difficult to deduce from the present state of knowledge (though the risk of high values is significant).

The application of the SCC in policy making remains controversial. There are major differences of opinion over the ‘correct’ input parameters to use for an SCC in relation to discount rate, equity weights, etc.—sensitivity analysis is essential in investigating the effects of these parameters. The explicit use of SCC values in cost-benefit analysis for climate change policy remains controversial, though many stakeholders now recognize the usefulness of SCC values in providing an input to decision making.

From consideration of all the study findings, we recommend that the economic benefits of climate change policy should be considered when setting long-term targets and goals. However, whilst some benefits can be directly estimated as monetary values, a wider framework is needed to take all relevant effects into account (no single method, model or tool adequately captures all of the uncertainties). Single estimates of the SCC, often portrayed as central estimate or best guess 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. In many situations, stakeholders are concerned with protecting the vulnerable (a prominent aim of the Framework Convention on Climate Change) rather than aggregate welfare across nations, sectors and populations.

The full risk matrix identified in the study (including risk of major change) should be considered, with an explicit consideration of major events (particularly for non-marginal and irreversible events) and the analysis should include extensive uncertainty and sensitivity analysis (e.g., over key decision variables such as discount rate and equity weighting). Given the status of the knowledge on economic effects for the full risk matrix, alternative decision frameworks (e.g. risk based approaches) enhance the knowledge available for such decisions.

Detailed policies follow from, and should be consistent with the long-term goals and frameworks, once agreed. For example, day-to-day policy decisions affecting policy or project appraisal, or setting levels of taxes and charges, should reflect the policy commitments. This should ensure that the (long-term) target

is achieved in a cost-effective way, and there is a need for consistency in appraisal across policy areas to achieve this, i.e. any values should be used consistently across all applications in Government.

Overall, this is a two-tier approach, with different types of analysis for long-term targets (based on a wider multi-attribute framework) and short-term economic appraisal (using shadow prices for day-to-day appraisal across Government).

More than anything, the review has identified a significant research gap in our knowledge of the economic benefits of climate change policy, which urgently need to be addressed to help inform decision making.

8 Acknowledgements

The two underlying studies were funded by Defra the UK Department for Environment, Food and the Regions. They benefited enormously from the input of David Anthoff, Ruth Butterfield, Megan Ceronsky, Jiehan Guo, Cameron Hepburn, Chris Hope, Alistair Hunt, Ada Li, Scott Moss, Anthony Nyong and Richard Tol. The work also benefited significantly from input from the project officer at Defra (Michele Pittini) and the project steering group. We stress, however, that the views expressed in this paper do not represent the views of these contributors, nor are they the views of UK Government.

9 Bibliography

- Anthoff, D. (2004), Social cost of carbon: Equity weighting, Masters thesis, Oxford University. [86](#), [90](#)
- Anthoff, D., Hepburn, C. & Tol, R. S. J. (2006a), Equity weighting and the marginal damage costs of climate change, FNU working paper, november. [86](#), [91](#), [99](#)
- Anthoff, D., Nicholls, R. J., Tol, R. S. J. & Vafeidis, A. T. (2006b), Global and regional exposure to large rises in sea-level: A sensitivity analysis, Research report prepared for the stern review. tyndall working paper 96 on the economics of climate change. [88](#)
- Ceronsky, M. (2004), Checking the price tag on catastrophe: An investigation of the sensitivity of FUND's social cost of carbon estimates to the incorporation of non-linear climate responses, Masters thesis, Oxford University. [86](#), [90](#), [92](#)
- Ceronsky, M., Anthoff, D., Hepburn, C. & Tol, R. S. J. (2005a), 'Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response', *Climatic Change*. [86](#)
- Ceronsky, M., Hepburn, C., Obersteiner, M. & Yamagata, Y. (2005b), 'Clashing strategic cultures and climate policy', *Climate Policy* **4**(4), 347–357. [86](#)

- deMenocal, P. B. (2001), 'Cultural responses to climate change during the late holocene', *Science* **292**(5517), 667–673. [90](#)
- Downing, A. D., Butterfield, R., Ceronsky, m., Grubb, M., Guo, J., Hepburn, C., Hope, C., Hunt, A., Li, A., Markandya, A., Nyong, A., Tol, R. S. J. & Watkiss, P. (2005), Scoping uncertainty in the social cost of carbon, Final project report. social cost of carbon: A closer look at uncertainty, Department of Environment, Food and Rural Affairs. <http://www.defra.gov.uk/environment/climatechange/carboncost/aeat-scc.htm>. [86](#), [88](#), [90](#)
- Downing, T. & Watkiss, P. (2003), The marginal social costs of carbon in policy making: Applications, uncertainty and a possible risk based approach, *in* 'DEFRA International Seminar on the Social Costs of Carbon'. <http://www.defra.gov.uk/environment/climatechange/carboncost/proceedings.htm>. [87](#), [88](#)
- DTI (2003), 'Our energy future—creating a low carbon economy'. [95](#)
- Ericson, J. P., Vorosmarty, C. J., Dingman, S. L., Ward, L. G. & Meybeck, M. (2006), 'Effective sea level rise and deltas: Causes of change and human dimension implications', *Global Planetary Change* **50**, 63–82. [88](#)
- Frame, D. J., Booth, B. B. B., Kettleborough, J. A., Stainforth, D. A., Gregory, J. M., Collins, M. & Allen, M. R. (2005), 'Constraining climate forecasts: The role of prior assumptions', *Geophysical Research Letters* **32**, L09702. [92](#)
- GES (2002), 'UK Government Economic Service (GES) paper estimating the social cost of carbon emissions'. http://www.hm-treasury.gov.uk/documents/taxation_work_and_welfare/taxation_and_the_environment/tax_env_GESWP140.cfm. [86](#)
- Guo, J. (2004), Discounting and the social cost of carbon, Masters thesis, Oxford University. [86](#), [90](#)
- Guo, J., Hepburn, C., Tol, R. S. J. & Anthoff, D. (2006), 'Discounting and the social cost of carbon: A closer look at uncertainty', *Environmental Science and Policy* **9**(3), 205–216. [86](#)
- HMT (2002), 'Tax and the environment: Using economic instruments'. [94](#)
- HMT (2004), 'Green book, appraisal and evaluation in central government'. http://www.hm-treasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm. [93](#)
- HMT (2007), 'Green book, appraisal and evaluation in central government'. http://www.hm-treasury.gov.uk/media/3/F/green_book_260907.pdf. [93](#)
- House of Lords (2005), Select committee on economic affairs 2nd report of session 2005–2006, The economics of climate change volume i: Report. [86](#)

- Li, A. (2004), Investigating the effect of risk and ambiguity aversion on the social cost of carbon, Masters thesis, Oxford University. 86, 90
- Nordhaus, W. D. (forthcoming), ‘The Stern review on the economics of global warming’, *Journal of Economic Literature*. http://nordhaus.econ.yale.edu/stern_050307.pdf. 86
- Pearce, D. W. (2003), ‘The social cost of carbon and its policy implications’, *Oxford Review of Economic Policy* **19**(3), 362–384. 86, 91
- Plambeck, E. & Hope, C. W. (1995), Validation and initial results for the updated PAGE model, University of Cambridge research papers in management studies, 1994–95, no. 15. 99
- Plambeck, E. & Hope, C. W. (1996), ‘PAGE95. an updated valuation of the impacts of global warming.’, *Energy Policy* **24**(9), 783–794. 99
- Plambeck, E., Hope, C. & Anderson, J. (1997), ‘The PAGE95 model: Integrating the science and economics of global warming’, *Energy Economics* **19**, 77–101. 99
- Schellnhuber, H. J. & et al. (2005), Avoiding dangerous climate change, in J. Schellnhuber, H. W. Cramer, N. Nakicenovic, T. Wigley & G. Yohe, eds, ‘?’, Cambridge University Press. 87
- Stainforth, D. A., Aina, T., Christensen, C., Collins, M., Faull, N., Frame, D. J., Kettleborough, J. A., Knight, S., Martin, A., Murphy, J. M., Piani, C., Sexton, d., Smith, L. A., Spicer, R. A., Thorpe, A. J. & Allen, M. R. (2005), ‘Uncertainty in predictions of the climate response to rising levels of greenhouse gases’, *Nature* **433**, 403–406. 92
- Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmondson, N., Garbett, S., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H. & Zenghelis, D. (2006), *Stern review on the economics of climate change*, Cambridge University Press, Cambridge. 86, 93, 99
- Tol, R. S. J. (2002a), ‘New estimates of the damage costs of climate change. part I: Benchmark estimates’, *Environmental & Resource Economics* **21**(1), 47–73. 99
- Tol, R. S. J. (2002b), ‘New estimates of the damage costs of climate change, part II. dynamic estimates’, *Environmental & Resource Economics* **21**(2), 135–160. 99
- Tol, R. S. J. (2004), The marginal damage cost of carbon dioxide emissions: An assessment of the uncertainties, Technical report, Center for marine and climate research, University of Hamburg. 99

- Tol, R. S. J. (2005), The social cost of carbon, *in* 'Presentation at the DEFRA international seminar on the social costs of carbon'. <http://socialcostofcarbon.aeat.com>. 87, 93
- Tol, R. S. J. (2006), 'The social cost of carbon. the Stern review of the economics of climate change: A comment.'. <http://www.fnu.zmw.de/fileadmin/fnu-files/reports/sternreview.pdf>. 86
- Watkiss, P., Anthoff, D., Downing, T., Hepburn, C., Hope, C., Hunt, A. & Tol, R. S. J. (2006), The social costs of carbon (SCC) review—methodological approaches for using SCC estimates in policy assessment, Final report to DEFRA. <http://www.defra.gov.uk/environment/climatechange/carboncost/aeat-scc.htm>. 86, 88, 89
- Yohe, G. (2006), 'Some thoughts on the damage estimates presented in the Stern Review—an editorial', *Integrated Assessment Journal* 6(3), 65–72. 86, 93
- Zhang, D. D., Zhang, J., Lee, H. F. & He, Y. (2007), 'Climate change and war frequency in Eastern China over the last millennium', *Human Ecology*. 90