Forestry Commission

Research Report

Forests and carbon: valuation, discounting and risk management

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Contents

Summary

- Increasing atmospheric concentrations of greenhouse gases (GHGs), of which carbon dioxide (CO_2) is the most important, is a primary cause of anthropogenic climate change. The global atmospheric CO_2 concentration has risen by over a third from pre-industrial levels of about 280 ppm in 1750 to 383 ppm in 2007, far exceeding the maximum of the natural range over the past 650 000 years of 300 ppm, and is currently rising at over 2 ppm a year. Aggregate atmospheric GHG concentrations, often measured in carbon dioxide equivalents (CO_2e), currently exceed the 430 ppm CO_2e level reported in the 2006 Stern Review, and may have to be stabilised around 450 ppm CO_2e if global warming is to be limited to below 2°C and dangerous climate change prevented.

- Placing a value on carbon is important in ensuring that effective incentives are put in place to tackle climate change. Carbon valuation is also essential in comparing the relative merits of climate mitigation and adaptation activities over time. Valuing future carbon benefits is closely linked to risk management issues because future values are influenced by risks that benefits will not arise as anticipated.

- Valuing carbon is complex and uses different approaches according to whether a societal or market perspective is taken. At present, there is little relationship between the value to society of reducing greenhouse gas emissions or sequestering carbon and the market price. This is due to low emission reduction targets being set by governments in establishing cap-and-trade schemes and shortcomings in the design and operation of such markets.

- Estimating the value of carbon from a societal perspective can be based on the marginal damage cost of emissions – also termed the social cost of carbon (SCC) – or the marginal abatement cost (MAC) of reducing emissions or sequestering carbon, or the carbon price or pollution tax required to meet a given climate stabilisation goal. Estimates of the social value of carbon are subject to wide variation, spanning at least three orders of magnitude from zero to over £1000/tC, reflecting different methods, assumptions and models, as well as uncertainty concerning climate change impacts.

- There is no internationally agreed methodology for estimating the social value of carbon. Therefore, values partly reflect national convention. Current UK government guidance for policy appraisal include central estimates for 2010 of £14/tCO_2e (£52/tC) for sectors covered by the EU Emissions trading scheme (ETS) and £52/tCO_2e (£190/tC) for non-ETS sectors, both rising over time to a peak of £308/tCO_2e (£1129/tC) in 2077 at 2009 prices, thereafter declining. Based upon estimating carbon prices consistent with national emissions reduction targets, the two sets of values reflect initially separate targets, being assumed to converge from 2030 as a more comprehensive global carbon market develops.

- Detailed consideration of UK Government guidance is beyond the scope of this paper. However, it is worth highlighting the sensitivity to the assumed GHG emissions reduction targets. The guidance is based upon target reductions of 34% compared with 1990 levels by 2020 and 80% compared by 2050, viewed as consistent with the UK's contribution to ensuring global temperature increase is limited to around 2°C and atmospheric GHG concentrations constrained to be within the 460–480 ppm CO_2e range in 2200. Were accelerating global emissions, more severe than anticipated impacts, non-negligible probabilities of catastrophic impacts, or a desire for greater certainty that critical thresholds will not be exceeded, to lead to tighter targets being adopted, estimates of the social value of carbon would need to be revised upwards.

- The present value of a future carbon reduction (i.e. what it is estimated to be worth currently) is sensitive to the discount rate assumed. The discounting protocol from the Treasury Green Book is recommended for UK policy appraisal, while use of lower discount rates (e.g. similar to those in the Stern Review) would significantly increase present values of future carbon benefits.

- Early emissions reductions allow more time to avoid 'dangerous' climate change if impacts are worse than expected,

but these benefits have not been taken into account in estimating present values of carbon. Were they accounted for, adopting a declining present value of carbon over time (as initially the case under current UK government guidance) may be preferable to a constant (or increasing) value over time.

- The magnitude of the social value of carbon has a major influence on whether carbon mitigation actions are cost effective. A low value of carbon will make relatively costly mitigation unviable. This is exacerbated by the use of higher discount rates because these result in future carbon savings being valued less. Both adoption of a relatively high discount rate and a relatively modest social value of carbon risk undervaluing potential contributions of forestry to climate mitigation.

- The development of carbon trading in recent years has resulted in carbon commanding a market price. In practice, a wide range of market prices exists. Prices in voluntary carbon markets worldwide in 2008 ranged from around \$1/tCO_2e to around \$47/tCO_2e (\$4/tC–\$182/tC), in part highlighting the importance of differences of quality and type. Prices may increase as more stringent climate change policy targets are introduced, but this will also depend upon a range of other factors, including any changes in coverage of national emission reduction commitments.

- Establishing a framework that places a value on carbon and thereby gives financial incentives for businesses and households to incorporate climate change impacts of their activities into their decisions is of key importance for the Government. However, mechanisms that value and provide incentives to sustain and enhance forest carbon stocks are currently very weak both within the UK and at international level. At an international level, forestry has been excluded from current trading mechanisms under the Kyoto Protocol although activities to reduce deforestation and degradation (REDD) are forming part of the negotiations to agree a framework after 2012. The EU Emissions trading scheme (ETS) currently excludes forestry. At a national level, to date there has been little explicit assistance for providing forestry carbon benefits despite the potential to play a greater role in helping meet UK emissions reduction targets.

- The Government's Quality Assurance Scheme for Carbon Offsetting (DECC, 2009c) focuses on internationally-compliant mechanisms under the Kyoto Protocol Clean Development Mechanism (CDM) and Joint Implementation (JI) scheme, and phase II of the EU ETS. It, therefore, does not apply to forestry projects at this time. Current government proposals on carbon units and carbon accounting similarly cover only internationally-compliant credits. Exclusion of forest carbon units from voluntary market projects stems partly from forestry being covered by mandatory reporting of emissions from land use and land use change (LULUCF) activities under the Kyoto Protocol.

- In-depth consideration of carbon quality assurance is beyond the scope of this paper. However, it is important to note that some voluntary carbon standards aim to provide as high a level of assurance as Kyoto compliant credits.

- Any voluntary carbon units issued by sectors covered by binding national or international carbon reduction commitments give rise to potential double-counting problems unless they provide additional carbon benefits to those covered by national reporting. At present no mechanism exists to ensure the additionality of any voluntary carbon units issued by the UK forestry sector by excluding them from national reporting, or allowing equivalent carbon credits to be retired. To avoid any need in using the term 'offset' to distinguish benefits that are additional from those that are not, in this paper the term carbon 'benefit' is used as a generic term to cover all cases. Similarly, as 'credit' is sometimes restricted to denoting entitlements to benefits derived from regulatory trading mechanisms or offsets, the term carbon 'unit' is used as a generic term applying to any carbon benefit.

- Voluntary carbon projects have a potentially important role in helping the UK meet its emissions reduction targets. Several approaches to comparing benefits across time and to risk management are possible in developing a UK code of good conduct for forestry carbon projects.

- Discounting is the standard approach to comparing benefits across time, and is widely used in government and the private sector. It is also a valuation tool that could be used to account for risks that future carbon benefits do not arise as anticipated. However, discounting has not been used explicitly by carbon standards in either comparing benefits across time or risk management. An approach to comparing future carbon benefits over time could simply be based upon the discounting protocol and uprating recommended in UK government guidance on valuing carbon. However, assuming a decline followed by an increase in the present value of carbon benefits could lead to time-inconsistency problems (i.e. decisions that appear best at present are not optimal when considered from the perspective of a later date).

- Maintaining a buffer may be a more practical option to implement than discounting in managing risks and uncertainties, avoiding potential confusion in establishing discounting protocols if future benefits are also to be discounted for time and changing circumstances.

- Issuing temporary carbon units is likely to remain an important approach in certain segments of the carbon market to help manage non-permanence risks (as well as potentially in quantifying the carbon substitution benefits of using timber instead of more energy-intensive materials). A transparent method for comparing the value of carbon units of different duration is likely to be useful, possibly based upon a tonne-year, rather than a tonne, of carbon as the unit of comparison (and discounted as appropriate).

- Due to delayed carbon sequestration benefits and high up-front investment costs, the bulk of forestry carbon sold in voluntary carbon markets may be expected to continue to be for ex-ante units (before carbon benefits are quantified and verified). Developing a code of good practice for forestry carbon projects that covers both ex-post and ex-ante forestry carbon is likely to be important to help underpin the quality of emission reduction claims and increase consumer confidence.

- Establishing a robust framework that values forestry carbon will be important if the forestry sector is to be encouraged to play a greater role in helping to meet national commitments for carbon emission reductions, and if significant opportunities for climate change mitigation by the sector are not to be missed. Developing a Woodland Carbon Code for forestry carbon projects in the UK is a potentially important step in providing a surer foundation upon which such a framework could be based.

1 Introduction

Establishing a framework that values carbon – including the carbon benefits of forests – is of key importance if incentives to incorporate the climate change impacts of decisions are to be provided. How carbon is valued is a fundamental issue in any such framework, including under the Stern Review recommendation that establishing a carbon price (through tax, trading, or regulation) 'is an essential foundation for climate-change policy' (Stern, 2006, p.xviii).

The principal objectives of this report are:

1. To review methods to value carbon over time, from societal and market perspectives.

2. To examine approaches for dealing with risk, given the long timeframes that apply to forestry projects.

3. To consider approaches to carbon valuation and risk management that could be used in extending standards to forestry more generally in voluntary carbon markets in the UK.

This paper summarises key issues, while also providing a level of technical detail designed to allow it to be used as a reference document. It is a discussion paper and does not constitute a statement of policy.

Background

Reviewing different approaches to valuing carbon and discounting is timely given current development of a UK Code of Good Conduct for forestry carbon projects[1] and associated questions of how best to compare carbon benefits of projects over time. Links with assessment methods for UK carbon budgets and Carbon Impact Assessment methodologies linked to the Marginal Abatement Cost of Carbon that explicitly or implicitly include trade-offs between the timing and cost of emission reduction initiatives, could also be important.

Placing a value on ecosystem services such as carbon sequestration is widely viewed as essential in guiding public policy and private forest management decision-making.[2] Valuing carbon from a societal perspective is of direct relevance to appraising the costs and benefits to society of publicly funded forestry projects, while market prices are most relevant in appraising expected profitability of private sector projects.

As increasingly recognised at global level, forests potentially have an extremely important role to play in mitigating climate change, especially in relation to reducing tropical deforestation, which is currently the third largest source of global carbon emissions (accounting for around a fifth of total emissions). A recent high level report to the UK government, for example, has argued that developing markets for forestry carbon is of central importance to tackling climate change, arguing that this would substantially reduce the costs of greenhouse gas (GHG) emission reductions and allow more ambitious targets to be reached (Eliasch Review, 2008, p.xii).[3] However, although not a panacea,[4] market and other mechanisms that value and provide incentives to sustain and enhance forest carbon stocks are currently very weak internationally.

Instruments that provide credits for a specified amount of GHG emissions reduced, avoided, or absorbed are often termed 'carbon offsets'. By providing organisations and individuals with a means of supplementing efforts to reduce their greenhouse gas emissions,[5] 'carbon offsetting' is considered by many to constitute a useful part of an overall

1 See: www.forestry.gov.uk/forestry/infd-7m8fm2.

2 While the standard approach in economics is to assume complete comparability of costs and benefits, this tends to overlook the disputed nature of value judgements implicit in methods used to value carbon and non-market impacts such as loss of life, habitat destruction and biodiversity loss. For some, preventing avoidable anthropogenic global warming is essentially an issue of environmental justice, with benefits associated with greenhouse gas-emitting activities considered fundamentally non-comparable with harms inflicted by failing to address climate change, including violations of basic human rights. Spash (1994) notes that doing harm is not in general cancelled out by doing good, with climate change likened by Shue (1999) to a situation in which someone obtains pleasure from burying bombs under a footpath knowing that they would explode and injure someone in the future, whereas preventable effects that would result in physical harm must be prevented, not merely compensated for. However, an environmental justice approach may be compatible with existing international objectives to stabilise atmospheric GHGs at levels necessary to avoid 'dangerous' climate change.

3 Eliasch Review (2008, pp.xi–xii) notes 'without tackling forest loss, it is highly unlikely that we could achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that avoids the worst effects of climate change.'

4 For a broader discussion of development of payments for ecosystem services including significant institutional barriers in some developing coun

5 A drive towards becoming 'carbon neutral' is a principal driver of demand for offsets by many organisations, although for some they may be viewed as usefully providing a means of going further to become 'carbon positive'.tries, see: Valatin & Coull (2008).

climate change strategy. This is generally the case providing organisations and individuals act to reduce their own emissions as the priority and do not treat offsetting as a substitute,[6] and that the offsets provide additional carbon benefits to those expected to occur anyway. This fits with the position that carbon offsets are of value only when used in conjunction with, rather than as a substitute for, emissions reductions. However, where projects provide carbon benefits that are accounted for under existing national emission reduction commitments, they cannot be considered additional benefits to those covered by associated national reporting.[7] Many projects in industrialised countries fall into this category, including most in the UK forestry sector.

To avoid any need associated with using the term 'offset' to distinguish benefits that are additional from those that are not,[8] in this paper the term carbon 'benefits' is used as a generic term to cover all cases. Similarly, as 'credit' is sometimes restricted to denoting entitlements to benefits derived from regulatory trading mechanisms or carbon offsets providing benefits that are additional, here the term carbon 'unit' is used as a generic term applying to entitlements to any carbon benefit.[9]

In the UK there are currently at least 18 providers of UK forestry carbon units (Table I, Appendix A). Some of these also provide carbon units for overseas projects. In total, there are over 20 UK-based providers of overseas forestry carbon units at present, mainly providing for projects in developing countries (Table II, Appendix A). In addition, several overseas-based providers of overseas forestry carbon units have UK offices,[10] while many other overseas organisations market forestry carbon units over the internet and may include UK firms and households among their customers.[11]

With the exception of the few projects targeted at bioenergy production, carbon sequestration has been the primary focus of forestry carbon projects to date.[12] The focus of this paper is valuation and discounting approaches applied to carbon sequestration benefits.

Different activities and projects are characterised by differences in quality and the timing of carbon benefits, and by different levels of risk that benefits may fail to materialise or be sustained. As a result, valuation, discounting and risk management are important issues when comparing expected carbon benefits.

Confusion about different standards,[13] and approaches, and concerns about the quality of units and the veracity of carbon reduction claims, are widely considered to be major obstacles to sustained development of carbon markets. Carbon trading is undertaken both in statutory 'compliance markets' and in largely unregulated 'voluntary markets'. Lack of regulatory standards applying to voluntary carbon units is viewed by some as exposing consumers to unacceptably high risks of fraud,[14] with some fears expressed that poor quality could undermine consumer confidence to such an extent that the entire market could collapse.

The UK Government's Quality Assurance Scheme for Carbon Offsetting (DECC, 2009c), launched by the Department of Energy and Climate Change, currently covers only Kyoto credits (Certified Emission Reductions, and Emission Reduction Units)[15] and phase II EU ETS credits (EUAs).[16]

[6] Offsetting remains controversial, opposed by some on grounds of the questionable validity of 'neutralising' emissions by comparison with reducing emissions, or due to the perceived motivation of offsetters. Offsets have been argued by some to be like 'putting lipstick on a pig', or selling medieval 'indulgences' doing little more than salving corporate or individual consciences, or considered little more than a cynical public relations or marketing exercise (see: Ewing, 2008).

[7] Note that this is the case irrespective of whether such activities would have been expected to have gone ahead in the absence of finance through voluntary carbon markets (which is a different aspect of additionality).

[8] See separate discussion paper on the multi-faceted concept of additionality (Valatin, 2010).

[9] Credit is also used in this paper for entitlements under regulatory trading mechanisms.

[10] Examples include EcoSecurities, an Irish-based company reported to have played an important role in developing forestry carbon projects (www.ecosecurities.com); Evolution Markets, a US-based company reported to be the world's highest volume environmental broker (www.evomarkets.com); and Climate Wedge, a Finnish-based company (www.climatewedge.com).

[11] Forestry carbon providers based in other EU countries include the Face Foundation, a Dutch-based non-profit foundation (www.stichtingface.nl), Futuro Forestal, a German-based company (www.futuroforestal.com), and Klimafa, a Hungarian-based company (www.Klimafa.com).

[12] Some carbon accounting protocols extend to soil carbon and other aspects. Where significant carbon substitution benefits associated with using wood products instead of more energy-intensive products (e.g. concrete or steel), or with substituting for fossil fuels are significant, these could be valued in a similar way to carbon sequestration benefits (even if subject to a further layer of complexity associated with multiple end-uses, and different risks).

[13] Including different types of VERs (see: Annex II).

[14] On this, and for examples of other problems of offset quality in practice, see: Davies (2007).

[15] Forestry credits tCERs and lCERs can be covered if the provider demonstrates a method by which they are guaranteed to be renewed or replaced on expiry (DECC, 2009c, p.6).

[16] See section 2 for a description of these types of credit.

However, in 2008 the then Secretary of State issued a challenge to the industry to develop a standard for Voluntary Emission Reductions (VERs) that could be incorporated into the code in the future.[17] As only two forestry projects have been approved under the Clean Development Mechanism (CDM) out of a total approved of almost one thousand eight hundred projects to date,[18] with associated credits reportedly yet to be issued,[19] and there have been no forestry projects approved under the JI mechanism to date,[20] while the EU ETS currently excludes forestry,[21] associated forestry carbon credits do not exist at present. The Government's Quality Assurance Scheme for carbon offsetting does not therefore currently apply to forestry.[22]

Structure

This report focuses on different elements of forestry carbon valuation, discounting and risk management. Differences between public and private perspectives are identified.

Section 2 considers approaches to estimating the value of current carbon benefits. Briefly describing different types of carbon units, different quantification methods, and sources of quality differences, approaches to estimating the social value of carbon, and factors influencing the market value of carbon are discussed. The potential influence of expected future market values on current values is also noted.

Section 3 considers approaches to estimating the value of future carbon benefits and comparing carbon values over time. Explicitly or implicitly, comparisons between periods involve discounting to allow for the passage of time and for changing circumstances. The discussion of the social value of carbon over time draws upon discounting approaches adopted in the Green Book (HM Treasury, 2003), the Stern Review (Stern, 2006), and UK Government guidance on valuing Carbon (Price *et al.*, 2007, DECC, 2009b, DECC, 2010 a,b).

Section 4 discusses approaches to valuing future carbon benefits that relate to management of risk and uncertainty, including non-permanence issues. The discussion distinguishes between approaches used in valuing existing ex-post carbon benefits that have already occurred, and ex-ante (future) carbon benefits.

Section 5 concludes, including a brief discussion of policy-relevant issues for the UK.

The appendices include further reference material. This includes lists of UK-based carbon unit providers for UK and for overseas forestry projects (Appendix A), a summary of approaches to discounting in the Green Book, Stern Review and current UK Government guidance on valuing carbon (Appendix B), a survey of risk management approaches under different voluntary standards (Appendix C), and a glossary of key terms, abbreviations and carbon units (Appendix D).

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[17] See: www.defra.gov.uk/environment/climatechange/uk/carbonoffset/codeofpractice.htm
[18] See: http://cdm.unfccc.int/Statistics/Registration/RegisteredProjByScopePieChart.html (accessed 12/3/09).
[19] Hamilton (2008) reports that no tCERs or lCERs have been issued to date or are likely to be issued in the immediate future. (However, the manager of the World Bank's BioCarbon Fund is reported as saying that 340,000 credits are expected to be issued by 2012 from the Pearl River project in China – the only afforestation/reforestation to be approved under the CDM so far – and with several million tCERs in total potentially issued by 2012 if projections in the project design documents submitted are realised).
[20] As of March 2009. (See: http://ji.unfccc.int/JI_Projects/ProjectInfo.html).
[21] See: Article 11a(3)(b) relating to exclusion of Kyoto credits from LULUCF activities introduced under the 'Linking Directive' 2004/101/EC into the 'Emissions Trading' Directive 2003/87/EC.
[22] Forestry projects are specifically mentioned in relation to non-permanence of carbon sinks, with the question posed (DEFRA, 2008, Q6, p.12): 'How might an offset provider selling forestry credits best demonstrate and guarantee that the credits will be renewed or replaced?'

2 Carbon valuation

From an economic perspective, it is often considered most efficient for the market price of carbon to equal the value to society of reducing emissions by one unit. The underlying economic perspective that abatement should occur up to a point where the benefits of further emissions reductions are balanced by the costs of further abatement is characterised by the Stern Review (2006, p.311) as a necessary condition for well functioning markets to reduce GHG emissions efficiently. Establishment of a framework that places a value on carbon and thereby gives financial incentives for businesses and households to incorporate climate change impacts of their activities into their decisions, is considered in the UK, for example, to be a key role for Government (DTI, 2006).[23] However, in practice as yet there has been little relationship between the value to society of reducing greenhouse gas emissions or sequestering carbon and the market price. This mismatch is due to low emission reduction targets being set, market failures arising from information imperfections, the public good nature of emission reductions,[24] and other factors. In general, the market value of carbon savings may be expected to be lower than the social value as a consequence of failure of markets to fully take into account the benefits to society.[25]

Several quality issues influence both the social and the market value of carbon benefits. These include measurement issues such as how carbon savings are quantified,[26] additionality (including tests used to ensure benefits claimed are additional to those that would have arisen anyway under a 'business as usual' scenario), leakage (whether emissions inadvertently increased elsewhere), and permanence (whether reductions are permanent or temporary). They also include verifiability (including the rigour applied in quantifying baseline emissions and subsequent reductions), and double-counting (whether reductions have already been counted). The timing and duration of carbon benefits (including whether carbon units are issued ex-ante or ex-post),[27] the level of country risks (including perceived stability of existing property rights systems), and the extent to which carbon projects offer ancillary benefits (e.g. biodiversity, landscape amenity, water quality, and other impacts), can also be significant quality issues.

Social value of carbon

Various approaches exist to valuing carbon from a societal perspective. The principal ones are the marginal damage costs of carbon emissions – also termed the 'social cost of carbon' (SCC),[28] the marginal abatement cost (MAC) of reducing emissions or sequestering carbon, and the carbon price or pollution tax required to meet a given climate stabilisation goal. The Shadow Price of Carbon (SPC)[29] is sometimes defined as the pollution tax that equates the SCC and the MAC (Clarkson and Deyes, 2002),[30] and sometimes conceptualised as equivalent to the SCC in the absence of other distortions (Stern Review, 2006).[31] If a regulatory framework exists limiting emissions to the socially desired level, market prices can also provide a guide to the social value of carbon.

[23] www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1.

[24] i.e. benefits are often characterised as `non-rival' (one person's enjoyment does not detract from enjoyment by others) and `non-excludable' (it is not feasible, or too costly, to prevent others enjoying them).

[25] This will also depend upon regulation, as over-stringent emissions reduction targets might instead lead to the market value exceeding the social value.

[26] Richards and Stokes (2004) note different ways of measuring a tonne of carbon sequestered. These include the flow summation method which adds total carbon sequestered irrespective of when it occurs (treating late sequestration as equivalent to early sequestration – implying no net gain in carbon over a rotation where wood is harvested and only carbon sequestered is included), the average storage method which considers sequestration over a full rotation (undefined in the case of indefinite rotations), and the discounting method which applies a discount rate to future sequestration. (The resulting summary statistic under the latter method can be termed 'present tons equivalent' or 'PTE'). Although the expected pattern and magnitude of carbon sequestration may be the most accurate way of describing carbon sequestration projects, it does not allow easy comparison of different options (Richards and Stokes, 2004).

[27] Counting future carbon sequestration towards offsetting current emissions is considered by some to be bad practice. E.g. Ewing (2008, p.16) argues that 'Any claims of immediate emission reductions through offsetting where credits are sold forward are clear cases of "greenwashing". '

[28] The SCC is defined in the Stern Review (2006, p.287), for example, as 'the impact of emitting an extra unit of carbon at any particular time on the present value (at that time) of expected wellbeing or utility. '

[29] The concept of a shadow price in economics is used to refer to the opportunity cost of devoting an extra unit of a particular factor of production to a given project or activity (c.f. Price, 1989), or more generally, to the impact of relaxing a constraint in an optimisation problem by one unit.

[30] Clarkson and Deyes (2002) state that most studies estimating the social cost of carbon use an inter-temporal optimisation approach that aims to estimate socially optimum levels of emissions through time from the intersection of marginal abatement cost and marginal social damage cost curves.

[31] Stern (2006, section 13.9, footnote 16, p.301) states 'The social cost of carbon can also be thought of as the shadow price of carbon if there are no other distortions in the economy, apart from the greenhouse-gas externality, affected by emissions. ' However, in the context of exhaustible resources and scarcity rents associated with fossil fuels, the Stern Review (2006, p.318) notes that the most appropriate tax rate will reflect wider market dynamics and not just the social cost of carbon.

Due to different methodologies, models and underlying assumptions used (e.g. concerning global population growth and technologies available to reduce emissions in the second half of the century), estimates of the social value of carbon are subject to wide variation. For example, SCC estimates, implicitly reflecting the price the world has to pay for each tonne of carbon dioxide emitted if no action is taken (Stern Review, 2006, p.301), span at least three orders of magnitude from zero to over £1000/tC (Downing *et al.*, 2005). The wide range is partly due to uncertainties about the extent of climate change and its impacts,[32] and because SCC estimates depend upon different underlying assumptions about discounting (Tol, 2009) and equity weighting (Watkiss *et al.*, 2006), and beliefs about the trajectory and ultimate concentration of greenhouse gases. For stabilisation around 450–550ppm CO_2e, for example, the Stern Review (2006, p.304) suggests that estimates of the current SCC may be around a third of the level for a business as usual (BAU) scenario.[33]

In the absence of a standardised internationally agreed methodology, approaches to valuing carbon vary both between countries and over time, as well as between sectors in some cases. For example, Watkiss *et al.* (2006, p.10) report that the European Commission and European Investment Bank have used values of around £60/tC to £145/tC (at 2000 prices),[34] the World Bank a value of about £14/tC (with a range of £4/tC to £28/tC),[35] and the Dutch Government approximately £6/tC (2001 prices).[36] A high level French committee recently recommended adopting a carbon price of €32/tCO_2e (equivalent to around £103/tC)[37] in 2010 (2008 prices) in appraising public projects.[38] Current UK government guidance for policy appraisal (DECC, 2009a,b, 2010) include central estimates for 2010 (at 2009 prices) of £22/tCO_2e (equivalent to £79/tC) for sectors covered by the EU ETS and £52/tCO_2e (£190/tC) for non-ETS sectors (Table IV, Appendix B).[39] This replaces previous UK government guidance (Price *et al.*, 2007) recommending use of a Shadow Price of Carbon based upon estimates of the SCC in the Stern Review (2006) of £26.50/tCO_2e (£97/tC) for 2008,[40] with a range of +20%/-10% used for sensitivity analysis.[41]

Market value of carbon

Market prices reflect quality differences, and supply and demand conditions, underlying institutional factors including regulatory frameworks within which markets operate, and transactions costs. Carbon markets can be classified as one of two types.

Firstly 'compliance markets', which cover the bulk of transactions worldwide, are associated with national or international regulatory frameworks limiting greenhouse gas emissions, often imposing an upper limit ('cap') on emissions. In these markets, only specified 'compliance credits' can be traded. The Kyoto Protocol, for example, provides for international trading in four main kinds of compliance credit. Assigned Amount Units (AAUs) represent initial credits assigned under Article 3.7 to industrialised countries and transition economies listed in Annex I of the Protocol, and can be traded among those countries that agreed legally-binding emissions reductions (listed in Annex B of the Protocol).[42] Certified Emissions Reductions (CERs) are issued under Article 12 for Clean Development Mechanism

32 E.g. Great Britain Parliament (2007, p.24) notes 'It has long been argued that monetisation of climate change damage, such as loss of ecosystems and large scale population displacement, cannot be assessed because an upper limit of the cost is so difficult to establish.'

33 \$25-\$30 per tonne of CO_2e respectively (at 2000 prices), as opposed to \$85/tCO_2 for the central BAU case.

34 €70/C – €170/tC at 1995 prices (Watkiss *et al.*, 2006, p.10).

35 \$5/tC – \$40/tC with a central value of \$20/tC (Watkiss *et al.*, 2006, p.10).

36 €8.8/tC. Watkiss *et al.* (2006, p.10) note that particularly in energy appraisals the European Investment Bank has also used values of around £4/tC to £87/tC (€5/C to €125/tC).

37 The conversion factor from CO_2e to C is 3.67 (i.e. 44/12). The exchange rate as at 31/8/09 of £1=€1.13 is used for conversion from euros to pounds sterling.

38 The estimated values rise to €56/tCO_2e (£181/tC) in 2020, €100/tCO_2e (£323/tC) in 2030 and €200/tCO_2e (£646/tC) in 2050. See: Quinet et. al. (2009, Table 1, p.11).

39 Both values are assumed to rise over time to £200/tCO_2e (£733/tC) in 2050 (2009 prices), being assumed to converge from 2030 as a more comprehensive global carbon market develops. A range of +/-50% is mainly used for sensitivity analysis with a narrower range initially used for values applying to EU ETS sectors. (The low and high estimates of the traded price of carbon are £12/tCO_2e and £27/tCO_2e respectively in 2009).

40 These estimates are considered consistent with stabilisation at the top end of the 450–550ppm CO_2e range (the range within which the optimum stabilisation goal was considered to lie by the Stern Review). 550ppm CO_2e is not considered either the most appropriate or most likely target to be reached, but adopting a higher SCC than that consistent with stabilisation at 450ppm CO_2e is argued to be prudent, as the latter might lead to too little mitigation (See: Price *et al.*, 2007, p.6). However, Stern (2009, p.94) states '..I think the Stern Review assumptions led to an under-estimation of the costs of inaction '.

41 This in turn replaced previous guidance recommending use of a Social Cost of Carbon of £70/tC for 2000, with sensitivity analysis using the range of £35 to £140/tC (DEFRA, 2006).

42 Annex I countries agreed a non-binding commitment to reduce their emissions to 1990 levels by 2000. For the most part Annex I and Annex B countries are the same. (However, Aukland *et al.*, 2002, p.39) note that Belarus and Turkey are Annex I but not Annex B countries, while Croatia, Liechtenstein, Monaco and Slovenia are Annex B but not Annex I countries). AAUs are often sold in conjunction with Green Investment Schemes to address additionality concerns (CCC, 2008, p.147).

project, allowing Annex I countries to offset part of their emissions reductions targets through investment in emission reduction/sustainable development projects in non-Annex I countries, with forestry projects a special case for which temporary five-year (tCERs) or longer-term (lCERs) credits are issued. Emission Reduction Units (ERUs) are issued under Articles 6 for Joint Implementation Mechanism projects between Annex I countries. Removal Units (RMUs) are credits issued under Articles 3.3 and 3.4 for net removals from land-use, land-use change and forestry activities within Annex I countries that can be traded among Annex B.[43] Other kinds of compliance credit include EU Allowances (EUAs) issued under the EU ETS (which accounted for over two-thirds of all compliance credits sold worldwide in 2007),[44] and those issued under national schemes such as tradable abatement certificates (NGACs) under the New South Wales Greenhouse Gas Abatement scheme, and New Zealand units under the New Zealand Emissions Trading Scheme.[45] The total volume of carbon credits traded in compliance markets worldwide is estimated to have grown by over 40% from 2007 to 2008, exceeding 4000 $MtCO_2e$ and valued at around US$120 000 m in 2008 (Hamilton *et al.*, 2009, Capoor and Ambrosi, 2009).[46] This compares with an expansion of over 60% between 2006 and 2007 (Hamilton *et al.*, 2008), much of the latter growth associated with development of portfolio-based guaranteed Certified Emissions Reductions (gCERs).[47] Regulatory factors affecting quality, demand,[48] and supply are key factors affecting market prices, especially for compliance credits (as illustrated, for example, by the dramatic fall in prices for EUAs under phase I of the EU ETS once the generous nature of initial allocations became clear).[49] The main buyers of compliance credits include governments meeting international commitments under the Kyoto Protocol, EU companies covered by the EU ETS, US multinational, asset managers (including carbon fund and hedge fund investors), and intermediaries, including trading companies and banks (Capoor and Ambrosi, 2008).

Secondly ‘voluntary carbon’ markets provide carbon benefits to businesses, individuals and households acting of their own volition (e.g. seeking to reduce their carbon footprint). In addition to limited trading in compliance credits,[50] they encompass all trading in carbon units issued outside statutory frameworks,[51] which cannot be traded in compliance markets. Globally, the total volume of carbon traded in voluntary carbon markets remains small compared to the volume traded in compliance markets, but is estimated to have roughly doubled from 2006 to 2007, and from 2007 to 2008, reaching an estimated 123$MtCO_2e$ valued at US$705m in 2008 (Hamilton *et al.*, 2009). Voluntary carbon units fall into three main categories. Project-based units verified by a third party, the project developer, or carbon unit provider include Verified Emissions Reductions (VERs).[52] Allowance-based carbon units created under the Chicago Climate Exchange and European Climate Exchange voluntary cap-and-trade scheme are termed Carbon Financial Instruments (CFIs). A range of carbon units for projects not subject to verification also exist (Ewing, 2008).[53]

Few compliance credits for forestry carbon exist at present (as has already been noted in relation to Kyoto Protocol flexibility mechanisms and current exclusion under the EU ETS).[54] There is little information currently available on market values for CDM and JI forestry carbon credits (tCERs, lCERs, and ERUs).[55] Prices for forestry credits could be expected to differ significantly from the average for all Kyoto-compliant credits due to the limited duration of temporary Certified Emission Reductions (tCERs) and long-term Certified Emission Reductions (lCERs) issued for CDM

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43 See: http://unfccc.int/kyoto_protocol/items/2830.php and http://unfccc.int/kyoto_protocol/registry_systems/registry_functions/items/4066.php.

44 The total volume of EUAs transacted in 2007 (comprised almost entirely of phase II allowances and derivative contracts) is estimated at over 2000$MtCO_2e$ valued at over US$50 000m (Capoor and Ambrosi (2008).

45 Two emerging US compliance markets are the Regional Greenhouse Gas Initiative (see: www.rggi.org/offsets) and the Western Climate Initiative (see: www.westernclimateinitiative.org/).

46 Hamilton *et al.* (2009, p.6) estimate the total value of transactions at US$119 000m, with estimates in Capoor and Ambrosi (2009, p.3) of in excess of US$126,000m for all carbon markets compared to around US$700m for the Chicago Climate Exchange and other voluntary markets combined implying a total for regulated markets of over US$125 000m.

47 See: Capoor and Ambrosi (2008, p.3).

48 E.g. proposals by the Committee on Climate Change to limit use of offsets in meeting UK emission targets (CCC, 2008) could be expected affect the demand for carbon units.

49 Prices reportedly fell from €30 in April 2006 (Capoor and Ambrosi, 2007, Figure 1, p.12) to €0.01 in mid 2007 (Peter Elsasser, pers com). See also: Elsasser, 2008, Figure 3, p.19 (based upon market data from www.eex.de).

50 CERs are estimated to have accounted for 14% and ERUs under 0.5% of all carbon units transacted in voluntary OTC markets worldwide in 2007 (Hamilton *et al.*, 2008, p.47).

51 Elsewhere these are often termed ‘voluntary credits’.

52 Note: VER is also sometimes used as a generic term for all Voluntary Emissions Reductions (i.e. whether independently verified or not).

53 E.g. see: Tables I and II (Appendix A).

54 New Zealand Units (NZUs) could prove to be an exception, with forestry the first sector covered by the New Zealand Emissions Trading Scheme (New Zealand Ministry of Agriculture and Forestry, 2010).

55 Probably some information on prices for forward delivery of credits exists.

forestry projects,[56] and potentially also due to the existence of ancillary benefits offered by forestry projects. According to Baalman and Schlamadinger (2008, p.8), both tCERs and lCERs are estimated by market participants to be worth around 25% of the value of standard CERs.

Voluntary forestry carbon, by contrast, accounts for a significant share of the project-based units traded in voluntary carbon markets worldwide, if an apparently declining proportion of the total. For carbon units sold in voluntary 'OTC' carbon markets worldwide (covering all except those under the Chicago Climate Exchange), Hamilton *et al.* (2009, Table 3, p.44) report that forestry projects accounted for 10% of the total volume transacted in 2008 (compared to 15% and 37% of all carbon units sold in 2007 and 2006, respectively). Total forestry carbon units sold covered an estimated 5.2 $MtCO_2e$ in 2008 (up from 4.3$MtCO_2e$ in 2007), a sixth of which were for avoided deforestation projects (Hamilton *et al.*, 2009, p.44). Weighted average prices for carbon units across the value chain[57] were estimated to be $6.4/$tCO_2e$ – $7.5/$tCO_2e$ for afforestation and reforestation, $7.7/$tCO_2e$ for forest management, and $6.3/$tCO_2e$ for avoided deforestation projects in 2008, and all above the average of $5.7/$tCO_2e$ for all carbon units sold in voluntary OTC carbon markets in 2008 (Hamilton *et al.*, 2009, p.9).

Prices for forestry carbon units transacted in voluntary markets may help provide some indication of likely prices for Kyoto-compliant forestry credits. However, due to relatively stringent verification procedures and being based upon ex-post rather than ex-ante crediting of carbon benefits, Kyoto-compliant forestry credits are likely to achieve prices well above the average for all forestry carbon units sold. For example, estimated average prices in 2008 for CERs and ERUs for all project types of $20/$tCO_2e$ were more than double the average of $6/$tCO_2e$ for all types of carbon units sold in voluntary carbon markets (Hamilton *et al.*, 2009, p.6, 27).[58]

The market value of carbon depends upon the type of carbon unit, and prevailing supply and demand conditions. This is illustrated by the mean market prices for different categories of carbon units in 2007 in Table 1 from a recent World Bank report. (Marked differences in average prices similarly exist for carbon units certified under different voluntary market standards).[59]

Focusing upon averages in Table 1 masks a wide spread of market prices. In 2008, for instance, carbon prices are reported to have ranged from $1.2/$tCO_2e$ to $46.9/$tCO_2e$ (Hamilton *et al.* 2009, p.9), with prices for forestry carbon units covering a similar range from around $2/$tCO_2e$ to about $46/$tCO_2e$.[62] Only a relatively small proportion of price differentials are explained by variations between different levels of the supply chain (project developer, intermediary, retailer, etc).[63] Capoor and Ambrosi (2007) note the importance of the specific terms of contract for project-based carbon units, including any upfront payments in cases of forward delivery arrangements.[64]

Table 1 Mean carbon prices in 2007 (US $ at current prices).

Type	Share of units sold (%)	Price ($/$tCO_2e$)	Price ($/tC)
Primary CERs	18.5	13	49
Secondary CERs	8.0	23	83
ERUs	1.4	16	60
Other project-based units[60]	1.4	6	23
All project based units	29.3	16	57
EUAs[61]	69.1	24	89
NGACs	0.8	9	33
CFIs	0.8	3	11
All Allowance based units	70.7	24	88
All units		21	79

Source: volumes and values taken from Capoor and Ambrosi (2008, Table 1, p.1).
Notes: primary transactions are where the original owner or issuer sells the credits. Secondary transactions are where the seller is not the original owner or issuer.

56 Market observers reportedly consider World Bank price estimates of $3/$tCO_2e$ to $4/$tCO_2e$ for tCERs on the high side (Hamilton, 2008).
57 i.e. not just including prices charged by carbon unit retailers.
58 Illustrating difficulties in obtaining consistent price information, Hamilton *et al.* (2008, Table 3, p.54) compares estimated price ranges for different carbon unit types with those from another recent study, showing quite large differences. For example for CERs Hamilton *et al.* (2008) report a price range of $8/$tCO_2e$ to $29/$tCO_2e$, compared to those in Kollmuss *et al.* (2008) of $19/$tCO_2e$ to $41/$tCO_2e$. (Note also that prices for secondary CERs were 60% higher than those for primary CERs in 2008 – see: Hamilton *et al.*, 2009, p.6, p.27).
59 E.g. Hamilton *et al.* (2009, Figure 29, p.72) cite average price levels for carbon units certified under the CarbonFix Standard of $18.4/$tCO_2e$ in 2007 compared to $5.5/$tCO_2e$ for those certified under the Voluntary Carbon Standard, and $3.8/$tCO_2e$ for those certified under the American Carbon Registry Standard in 2008.
60 This includes project-based voluntary carbon transactions.
61 This includes spot, options, and futures trades. Spot trades accounted for 2% of the volume and 1% of the total value in 2007 due to the low price of Phase I EUAs (Capoor and Ambrosi, 2008, p.7).
62 In 2007, minimum and maximum market prices for carbon units sold in voluntary OTC markets spanned over two orders of magnitude from $1.8/$tCO_2e$ to around $300/$tCO_2e$ in 2007. However, Hamilton *et al.* (2008) note that the highest price recorded (for Gold-standard certified wind farm carbon units) was anomalous.
63 Hamilton *et al.* (2008, Figure 8, p.30) shows average prices for carbon units sold by project developers in voluntary OTC markets of $5.0/$tCO_2e$ compared to $11.3/$tCO_2e$ for those sold by retailers in 2007. A narrower range is reported in 2008, prices, with the average for carbon units sold by project developers of $5.1/$tCO_2e$ compared to $8.9/$tCO_2e$ for those sold by retailers (Hamilton *et al.* 2009, Figure 8, p.36).

Demand for voluntary carbon units (and therefore the price level) is affected by regulatory factors including potential double-counting issues associated with reporting under public carbon reduction commitments. In some countries (e.g. the Netherlands), the sale of voluntary carbon units to foreign entities is banned unless an equivalent number of compliance credits are retired.[65] According to Hamilton *et al.* (2009), the precipitous drop in total EU voluntary carbon benefits purchased from 2.3 $mtCO_2e$ in 2007 to 0.2 $mtCO_2e$ in 2008 was partly due to concerns about double-counting reductions associated with also being covered by national reporting under the Kyoto Protocol.

Both the expected value of future carbon benefits, and approaches to managing risks that anticipated future carbon benefits may not arise, can influence current market prices. These issues are considered further in the two following sections.

[64] CER prices, for example, are reported to have ranged from around US$6 to US$25 in 2006 (Capoor and Ambrosi, 2007, Figure 8, p.31). In some cases financial institutions may provide loans against expected proceeds from forward delivery contracts (Capoor and Ambrosi, 2008, p.33). While legally-binding Emission Reduction Purchase Agreements (ERPAs) between project developers and credit purchasers can be established at any point in a project, such arrangements have reportedly been uncommon (Neeff and Henders, 2007).

[65] Similarly, under some voluntary carbon standards units are only issued for projects in countries with mandatory emissions reduction targets where an equivalent amount of allowances are retired (Gold Standard, 2008, p.20), or the emissions reductions or removals are excluded from being counted towards the statutory targets (VCS, 2008b, p.12).

3 Discounting

Discounting is the method conventionally used to compare costs and benefits occurring in different time periods. Explicitly or implicitly, it is characterised by applying a discount factor to adjust for the passage of time,[66] aimed at estimating an equivalent present value.[67] Procedures that also allow for changing circumstances over time are sometimes termed 'quasi-discounting',[68] but for current purposes are also considered a form of discounting.

Discounting may be justified on a variety of grounds.[69] The view that people act as though they have a 'time preference' and apply a discount factor that places more weight on current benefits than on future ones is often considered an accurate descriptive model of much human behaviour. For example, for investors the rate of return on alternative investments provides a measure of the opportunity cost of undertaking a given project. They may use this rate to discount expected future revenue flows in comparing projects. Risk aversion may also provide a justification for discounting future revenue flows where benefits accruing later are considered more risky or less certain than those which occur sooner. Discounting for changing circumstances may also be justified on the basis of 'diminishing marginal utility' where individuals or society expects to become more wealthy over time.

The two following subsections examine use of discounting for time and changing circumstances in relation to the social value of carbon and the market value of carbon. Valuation of future carbon benefits is especially pertinent to considering afforestation projects as carbon benefits are spread unevenly over a long period of time.[70]

Social value of carbon

Discounting from a societal perspective is in general linked conceptually to the rate of Social Time Preference. Based upon the idea that society generally attaches a higher value to goods and services now than in the future, the rate of Social Time Preference (r) is often characterised as comprising three elements. These are the rate at which future consumption is discounted compared to current consumption if no change in consumption level is expected (ρ), the expected rate of growth of per capita consumption (g), and the elasticity of the marginal utility of consumption (μ).[71] The Green Book (HM Treasury, 2003, p.97), for example, defines the rate of Social Time Preference[72] as:[73]

$$r = \rho + \mu g$$

There exists considerable consensus on constituent elements of the social discount rate, but far less agreement about the magnitude of the different elements or the overall rate.[74] Approaches both to estimating and to discounting the social value of carbon vary between countries. Illustrative of social values of carbon for 2020, 2030 and 2050 associated with achieving a global climate stabilisation target of 550ppm CO_2e are given in Table 2 from a recent US Climate Change Science Program report (Clarke *et al.*, 2007) based upon a carbon price/pollution tax approach and from previous UK government guidance (Price *et al.*, 2007) based upon SCC estimates from the Stern Review (2006).[75]

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66 In the case of a constant discount rate, the discount factor is equal to the reciprocal of one plus the discount rate all to the power of the number of time periods elapsing before the cost or benefit accrues.

67 C.f. Price (1993, p.4) defines discounting as 'any process of revaluing a future event, condition, service, or product, to give a present equivalent (present value).'

68 E.g. Price (1993, p.4) defines quasi discounting as 'a similar, but more flexible process: it may take account of changing quantities, qualities and probabilities over time', noting (p.333) that '...declining future consumption would probably justify a negative quasi-discount rate'.

69 For an in depth treatment of different justifications and their shortcomings, see: Price (1993), who concludes (p.344) '...discounting does not tell the correct story about future values. The track of values through time is not generally a negative exponential'.

70 Reduced emissions from deforestation and degradation (REDD) projects can provide more immediate and uniform benefits.

71 Future increases in consumption are weighted less where consumers are assumed to become richer over time, with discounting necessary to avoid redistribution from the relatively poor current generation to the relatively rich future generation (Angelsen, 1991). Equivalently, the discount rate can be formulated in terms of a coefficient of relative risk aversion (Weitzman, 2007).

72 Note that as the consumption-invariant discount rate (ρ) is argued to depend on both a pure rate of time preference (δ), which can be conceptualised as a discount rate on utility, and the risk of catastrophe that future returns are eliminated or radically and unpredictably altered (L), it is not independent of risk and uncertainty.

73 For ρ = δ this is the Frank Ramsey equation which applies in a deterministic context (Weitzman, 2007).

74 Price (1993, p.330) notes, however, two different views on compatibility with sustainability. One is that they are complementary with discounting assuring efficient allocation of investment funds, the other is that sustainability 'is the ideological opposite of discounting: discounting seems an excellent and assured way of compromising the ability of future generations to meet their own needs! The two concepts are incompatible, so one or the other must be chosen.'

Table 2 Social value of carbon estimates for stabilisation around 550 ppm CO_2e (£/tC at 2007 prices).

Estimate year	US models (carbon price/tax)			UK models (shadow price of carbon)		
	MERGE	MiniCAM	IGSM	Low (-10%)	Central	High (+20%)
2020	6	11	57	109	121	145
2030	10	20	86	132	147	176
2050	28	53	187	197	219	262

Sources: US Climate Change Science Program (Clark *et al.*, 2007); UK Government (Defra) (Price *et al.*, 2007, Table 2).
Notes: Estimates in Price *et al.* (2007) in £/tCO_2 converted to £/tC and estimates in Clarke *et al.* (2007) in $/tC converted to £/tC at £=$1.309 exchange rate adopted by Price *et al.* (2007, p.20) from the Stern Review.

Estimated carbon values in Table 2 imply that, taking account purely of changing circumstances associated with increasing damage costs or efficiency requirements of equalising marginal abatement costs between periods, any given carbon saving would be between 1.8 (in the case of the UK) and 4.6 times (in the case of the MiniCAM estimates) more valuable in 2050 than in 2020. The differences in the changes in estimated values partly reflect methodological differences in approaches used to uprate values over time. The estimates from the US Climate Change Science Program (Clarke *et al.*, 2007, p.89), for example, are based either on solving for the cost-minimizing allocation of emissions reductions over time (under MERGE), or assuming a constant 4% increase in the carbon price over time reflecting the assumed economy-wide rate of return (under IGSM) or the rate of interest plus the average rate of carbon removal from the atmosphere by natural systems (under MiniCAM). The estimates from the MERGE and MiniCAM models are both based upon minimising the discounted cost of abatement across periods, and therefore depend upon applying a discount rate to future costs and benefits to take account of time, although no account is given of the precise discount rate used.[76] The above UK values simply assumed an annual 2% increase in real terms[77] to allow for increasing damage to the environment of GHG emissions (Price *et al.*, 2007).[78]

Once discounting for time is also taken into account, the overall effect can be a declining, constant or increasing social value of carbon over time. The effect of applying the discounting protocol from the Treasury Green Book (starting at 3.5% for the first 30 years) to the increasing social values of carbon recommended in current UK government guidelines on valuing carbon in policy appraisals (DECC, 2009b, 2010),[79] for example, is shown in Table 3 for selected years using 2010 as the base year.[80] This illustrates how once discounting for time is taken into account, the present value of future carbon benefits (and costs) initially declines (up to 2020 in the case of sectors covered by the EU ETS and up to 2030 in other sectors), before increasing again until the mid 2050s, declining again thereafter. (Table IV, Appendix B provides values for intervening years).

Table 3 UK social values of carbon (£/tCO_2e at 2009 prices).

Year	Sectors covered by EU ETS			Sectors not covered by EU ETS		
	Central price of carbon	Discounted price of carbon	Index (2010 discounted price =100)	Central price of carbon	Discounted price of carbon	Index (2010 discounted price =100)
2010	14	14	100	52	52	100
2020	16	12	82	60	43	82
2030	70	35	250	70	35	68
2040	135	48	341	135	48	93
2050	200	53	376	200	53	103
2060	266	52	372	266	52	102
2070	301	44	313	301	44	85
2080	306	33	237	306	33	65
2090	292	24	173	292	24	47
2100	268	17	124	268	17	34

Sources: DECC (2010a, 2010b, Table 3, pp.42–43)[81], HM Treasury (2003).

[75] Revised UK guidance on carbon valuation was issued in July 2009 (Table 3 below and Table IV in Appendix B), with use of the previous approach now limited to appraisal of overall frameworks for emissions reductions such as the Climate Change Act (DECC, 2009b, p.83).

[76] E.g. the stated justification for applying an annual 4% increase in the price of carbon in the IGSM model is simply 'an entity faced with a carbon constraint and a decision to reduce emissions now or later would compare the expected return on that emissions reduction investment with the rate of return elsewhere in the economy' (Clarke *et al.*, 2007, p.89).

[77] In nominal terms increasing the value by an additional 2% pa to allow for inflation is recommended.

[78] Damage caused by a unit of emissions increases as the atmospheric concentration of greenhouse gases increases.

[79] Note that the carbon values are expected to be revised annually (DECC, 2010, p.4).

[80] For consistency with published estimates (DECC, 2010), values are given at 2009 prices.

[81] Discounted values and indices are based upon the more precise values in spreadsheets at: www.decc.gov.uk/en/content/cms/statistics/analysts_group/analysts_group.aspx.

Lack of international consensus currently about the appropriate social discount rates to apply in comparing carbon benefits over time is partly due to different expectations about future growth rates of the economy, and the circumstances of different groups (with a negative discount rate generally considered appropriate for any groups expected to experience declining per capita consumption). Approaches can also vary depending upon the purposes for which discounting is used and underlying ethical positions. Previous UK government guidelines on valuing carbon, for example, recommended use of lower discount rates for assessing 'non-marginal decisions' concerning current willingness to pay to avoid climate change impacts based upon the inter-generational equity perspective adopted in the Stern Review (Price *et al.*, 2007, p.14).[82] The approach in the Stern Review is unusual in treating the social discount rate as endogenous (Dietz, 2007), and dependent upon the expected rate of growth of the global economy.[83]

Market value of carbon

Future carbon prices are of particular relevance in appraising private sector forestry projects delivering carbon benefits some years ahead, but as in any market, reliably forecasting future values is difficult. In general carbon prices may be expected to rise due to tighter restrictions on emissions, but future prices are subject to significant uncertainties, not least associated with changes in underlying institutional frameworks (e.g. global abatement targets and post-2012 arrangements once the Kyoto Protocol expires) and in linked trading frameworks such as the EU ETS.[84] Some studies provide forecasts of price levels in the short term,[85] but forecasts vary considerably depending upon underlying assumptions about the evolution of the economy and emissions, mandatory restrictions, and other factors. Springer (2004, Table 1, p.612), for example, reports carbon price forecasts from 16 models for 2010 of between US\$3/tCO_2–US\$74/tCO_2. Similarly, the UK Committee on Climate Change has considered low, central and high price projections of €5/tCO_2, €16/tCO_2 and €60/tCO_2 in 2020 based upon different assumptions regarding reference case emissions, global agreement, and trading constraints using the Office of Climate Change GLOCAF model (CCC, 2008, p.162).

Illustrating the importance of regulatory influences, previous UK government forecasts of prices for EU Allowances under the EU ETS are shown in Table 4, highlighting differences between values of phase II and phase III credits.[86]

Table 4 Forecast EUAs prices and discounted prices (£/tCO_2 at 2008 prices).

Year	Type	Price of carbon	Discounted price	Index of discounted price
2008	Phase II (2008–12) credits	16.3	16.3	100.0
2009		16.7	16.5	101.3
2010		17.2	16.7	102.8
2011		17.7	17.0	104.4
2012		18.4	17.3	106.6
2013	Phase III (2013–20) credits	26.6	24.7	152.1
2014		27.3	25.0	153.6
2015		28.0	25.2	155.2
2016		28.7	25.5	156.8
2017		29.4	25.7	158.3
2018		30.1	26.0	160.0
2019		30.9	26.3	161.6
2020		31.6	26.5	163.2

Sources: DECC (2008b, Tables 15 and 16).
Notes: discounted estimates based upon Green Book discount rate (3.5%). Phase III prices assume a 20% EU emissions reduction target.[87]

Existing market prices can provide useful indicators of market participants' expectations of future prices. To the extent that futures markets exist, for example, current prices for forward delivery of carbon units[88] can be viewed as encapsulating the discounted expected future market values of market participants.[89] In cases where the timing of future carbon benefits is specified, market prices for ex-ante carbon units for benefits anticipated to accrue in future

[82] Adopting a low social discount rate has also been argued to be justified by uncertainty concerning climate change impacts (see: Price and Willis, 1993, and arguments in Appendix B concerning the Stern Review approach by Weitzman, 2007).

[83] Dietz (2007, p.7) argues '...the social discount rate is neither constant nor certain: it depends if nothing else on future consumption growth. Moreover, if we assume climate change itself possesses the capacity to depress consumption growth on a global scale, then the choice of social discount rate is not exogenous to the choice of climate-change policy.'

[84] E.g. Gupta *et al.* (2007, p.779) report that the peak in prices for CERs in early 2006 coincided with a peak in prices for EUAs.

[85] Springer and Varilek, 2004, for example, forecast CER prices in 2010 to be under US\$10/ tCO_2 after peaking at over €20/tCO_2 in early 2006.

[86] This contrasts with the smooth transition in the traded price of carbon between 2012–2013 recommended under current UK Government advice on valuing carbon (see: Table IV in Appendix B).

[87] A so-called 'EU 20% world'. Forecasts consistent with a 30% EU emissions reduction target are also being estimated (see: DECC, 2008b, 9.16).

[88] 'Forward delivery' is conceptualised as involving a binding agreement between the provider and buyer to deliver carbon units at a specified future date and price (Kollmuss *et al.*, 2008, p.46).

[89] Average forward CER prices in 2007, for example, are reported to have been around €10, compared to spot prices for issued CERs of €16–17 (Capoor and Ambrosi, 2007, p.3).

years can also reflect discounted expected values. In addition, current market prices for temporary carbon units which must be replaced on expiry will also necessarily in part reflect expected future market values of carbon units at the time of replacement. While several commercial organisations provide information on existing carbon prices and forecasts,[90] little information appears to be available specifically on expected future market values of forestry carbon units. As with other carbon units, future prices might be expected to rise as more stringent targets are introduced, but with the precise trajectory can be expected to depend upon a variety of factors, including market confidence in the environmental integrity of carbon benefits, development of abatement technologies, regulatory factors and national carbon accounting rules.

Extending standards

Discounting, as we have seen, is the standard approach to comparing benefits across time. Various approaches might be used in extending quality assurance standards to facilitate comparisons of the value of carbon benefits accruing in different time periods.

One approach to discounting future carbon benefits would simply be to follow the combined discounting protocol and uprating recommended in UK government guidance on valuing carbon for use in policy appraisal as illustrated in Table 3 above (see also Appendix B). Application of a social value of carbon which in present value terms initially declines over time, before increasing again, such as that from current UK government guidance for policy appraisal, could lead to time inconsistency problems, however, if the optimum decision appears always to be to delay forest planting.

Alternatively, for a market perspective rather than a societal one, discounting could be based upon information available on prevailing values for future benefits in the carbon markets. This is likely to require more in-depth monitoring of market transactions than is undertaken at present and would have the disadvantage that potentially it could be open to manipulation by market participants.

Were effects of allowing for time and changing circumstances expected to roughly balance, a far simpler alternative would be not to discount, but assume a fixed present value of carbon irrespective of the date. Existing carbon standards that do not differentiate between the value of carbon benefits accruing at different dates implicitly adopt this approach. A fixed social value would also have the advantage of helping avoid perverse incentives to delay activities (often associated with changing discount rates over time).

Benefits of early emissions reductions in allowing greater flexibility in choosing subsequent mitigation activities to meet a given climate target, and more time to implement policies to avoid 'dangerous' climate change if future impacts turn out to be worse than expected,[91] have not been taken into account in estimating the social value of carbon.[92] Their inclusion could imply that assuming a declining social value of carbon in real terms (as initially the case in current UK government guidance, for example) is preferable to adopting a constant (or increasing) carbon value over time.

[90] E.g. www.pointcarbon.com, www.carbonpositive.net, www.ccfe.com.

[91] In the context of accelerating emissions and more serious than anticipated impacts, Ekins (2009, p.1), for example, notes that 'This process of acceleration narrows the window for effective policy to prevent the worst effects of climate change.'

[92] Related issues are discussed by Weitzman (2007), who suggests that the impact of high uncertainty could be incorporated by assuming a low discount rate (Appendix B). However, as adopting a low discount rate increases the value of future benefits compared to present benefits, it reduces incentives for deriving early climate change mitigation benefits compared to later ones. An approach more consistent with providing incentives for early emissions reductions might be to consider the greater flexibility provided in tackling climate change explicitly as a benefit, possibly as a form of quasi-option value.

4 Risk and uncertainty management

Risks and uncertainties facing carbon projects range from generic country risks that may face any type of project, to regulatory risks affecting particular types of carbon units, to forestry-specific risks associated with 'non-permanence' and potential climate change impacts. Although not a view universally accepted,[93] non-permanence risks, which include risks of fire or other events[94] releasing carbon stored back into the atmosphere,[95] are generally considered primarily to affect forestry and other land use sector projects.[96] Risk management is especially pertinent to forestry projects where ex-ante carbon units for projected benefits are issued.

A range of approaches exists to managing risks and uncertainties associated with carbon benefits, including discounting, insurance,[97] risk spreading and portfolio management techniques,[98] and specific guarantees to replanting forests destroyed by fire or other causes, and replacing associated carbon units. These approaches could be considered applicable primarily to ex-ante carbon units (for which carbon benefits are yet to accrue). They are applicable to a lesser extent to forward delivery of ex-post carbon units, tending to be of least relevance to existing ex-post carbon units (including CERs) issued after carbon benefits have been quantified and verified (thereby reducing non-permanence risks).

The extent to which management of risks and uncertainties occurs may be expected to influence the value of carbon units, but the focus in the current section is on how risks and uncertainties are taken into account in valuing carbon. Three main approaches are considered. These are discounting, maintaining a buffer, and issuing temporary units.

Discounting

A standard approach to risk management common in most markets is to discount future benefits depending upon the level of expected risks in order to create a comparable risk-adjusted basis for comparing returns. For instance, a benefit associated with a 10% risk that it will fail to materialise may be considered worth 90% of the value of risk-free option to a risk-neutral investor.[99]

An example of the use of a risk-adjusted social discount rate is the UK Committee on Climate Change's adoption of a 10% real discount rate for climate mitigation measures associated with high uncertainty (e.g. new nuclear power stations), compared to a 3.5% rate for measures where returns are considered reasonably certain (CCC, 2008, p.118). An example of discounting market values of carbon is the large price spread between prices for EUAs and CERs for the period after 2012 (the latter being considered more risky than the former in part as use within the EU ETS has been made contingent upon a new international agreement to replace the Kyoto Protocol being established).[100] Other

[93] E.g. Herzog *et al.* (2003, p.306) argue that permanence issues apply to virtually all carbon mitigation options, essentially being 'a function of the policy regime'. For example, in the absence of globally binding emissions restrictions, avoiding burning fossil fuel today could lead to an increase future use by increasing the availability and reducing the future price (not, as often argued, permanently reducing atmospheric greenhouse gas concentrations).

[94] Potential outbreaks of pests (such as the current mountain pine beetle infestation in British Columbia which is estimated to have affected 14.5m ha and killed 620m m^3 of timber – see: www.for.gov.bc.ca/hfp/mountain_pine_beetle/facts.htm) and wind storms are also non-permanence risks to the extent that they are associated with an increased release of carbon to the atmosphere. For an overview of approaches to managing abiotic risks in general in forestry, and wind risks in particular, see: Gardiner and Quine (2000).

[95] Permanence is a term that is sometimes used to also cover issues arising from changes in carbon benefits over time more generally (e.g. as a stable state is approached, net carbon sequestration rates of forest sinks will tend to zero in the long run), and issues associated with the temporal specification or duration of carbon units (Kim *et al.*, 2008).

[96] Precisely what are meant by 'permanent' and 'non-permanent' varies. However, simply assuming above a particular threshold period to be permanent (e.g. assuming storage of at least a century along the lines of the 100-year horizon assumed in constructing Global Warming Potential indices under the Kyoto Protocol) is argued to lack economic or other rationale, and to have potentially undesirable consequences in practice (Richards and Stokes, 2004).

[97] Capoor and Ambrosi (2007, p.35) report that insurance products developed by the World Bank's Multilateral Investment Guarantee Agency and others have not been popular with project developers and asset managers, being viewed as expensive.

[98] E.g. Capoor and Ambrosi (2008, p.22) note requirements on regulated financial entities to use 'value-at-risk' techniques, using statistical analysis of historical price data and volatilities to estimate the probability of portfolio losses. Capoor and Ambrosi (2007, p.35) report that portfolio management through project selection and geographical diversification appears the most popular approach to managing delivery risk.

[99] Valuation depends upon attitudes to risk, and will depend upon the extent to which investors are risk-averse. For a critique of risk discounting, see: Price (1993, ch.12).

[100] The price spread between future EUAs and high quality forward primary CERs (reportedly almost €13) also reflects regulatory and issuance risks (Capoor and Ambrosi, 2008, p.33).

examples reported include prices for anticipated CERs from projects at an early stage of regulatory and operational preparation (which at around €8–€10 in 2007 were discounted by of the order of 40–50% compared to CERs already issued), and discount rates applied by fund managers to expected deliveries of CERs of at least 15–50% (Capoor and Ambrosi, 2008, p.32,47,20). To take account of risks of carbon losses from forest fires, a generic method of estimating a discounted market value of carbon is proposed by Hurteau *et al.* (2009), who report it implies that a carbon unit from a fire-prone ponderosa pine forest in the southwest US is worth 30% of one from a California redwood forest.

Maintaining a buffer

Maintaining a 'buffer' has similarities to insurance,[101] but is an approach taken by sellers (principally issuers) of carbon units rather than purchasers. A proportion of carbon units are withheld from the market in order to cover risks that some anticipated benefits will not arise. In contrast to discounting, which generally serves to reduce the value of carbon units, the approach tends to increase their value to a level approaching that associated with a risk free project in which carbon benefits are certain.[102]

An example of a government adopting this approach is Costa Rica. It has used a buffer approach in offering emission reduction units from its Protected Areas Project, with the proportion of units withheld in the buffer varying between stands according to the perceived level of risk (Chomitz, 2000).

Several voluntary carbon market certification schemes also take non-permanence of forestry projects into account in part by maintaining a buffer of units to allow for potential losses due to fire and other risks. The proportion of total units retained for this purpose varies, related in some cases to perceived differences in levels of risk (Table 5), and generally being based upon expert judgement.

Issuing temporary carbon units

Issuing temporary carbon units involves placing a fixed duration on units issued to limit risks that carbon benefits will not be permanent (or as long lasting as anticipated). Like discounting, this tends to reduce the value of each carbon unit issued. In general, the market price of a temporary carbon unit could be expected to equal the difference between the current price of a permanent unit and the discounted expected price of a permanent unit at the time of the temporary unit's expiry (Chomitz, 2000),[103] with no temporary units issued where prices are expected to rise faster than the discount rate.

Unlike discounting and maintaining a buffer, issuing temporary carbon units is an approach which can apply equally to ex-post and ex-ante carbon units. This approach is applied, for example, to units issued for CDM forestry projects which can be of two types (the choice being left to the project developer). Firstly, temporary Certified Emission Reductions (tCERs) are short-term credits issued for a single 5-year period and on expiry have to be replaced by other tCERs, permanent CERs, ERUs, AAUs, RMUs (they cannot be

Table 5 Standards incorporating a Buffer in managing non-permanence risks.

Standard	Buffer
American Carbon Registry Forest Carbon Project Standard	Unspecified proportions (jointly determined by independent verifier and Registry)
CarbonFix Standard	30% of the certified units initially allocated to a buffer fund, a quarter of these being used to provide insurance
Climate, Community and Biodiversity Standard	Unspecified proportion
Plan Vivio Standard	Unspecified proportion
Voluntary Carbon Standard	10%–60% (depending whether 'low', medium' or 'high' risk category and project type)
VER+ Standard	At least 20%

Sources: websites for each standard (see: Appendix C).

[101] E.g. Chomitz (2000, p.16) refers to it (in the context of Costa Rica) as a form of 'self-insurance'.
[102] Each unit sold becomes more valuable simply because purchasers in effect obtain benefits associated with more than a single unit.
[103] E.g. if a discount rate of 10% is applied and carbon prices are expected to grow at 5% pa, a temporary unit would be worth 22% of a permanent one over a 5-year period (Chomitz, 2000, p.16). The existence of transactions costs could further reduce the value of temporary units.

replaced by lCERs). Secondly, long-term Certified Emission Reductions (lCERs) are longer-term credits of variable duration, being issued for the period remaining until the end of the project and on expiry have to be replaced by permanent CERs, ERUs, AAUs or RMUs (they cannot be replaced by other lCERs or by tCERs).[104]

Issuing temporary carbon units also applies to forestry carbon benefits under some voluntary carbon market standards. For example, under the VER+ standard (based largely upon CDM and JI standards but covering a wider range of activities, including afforestation, reforestation, avoided deforestation, and improved forest management projects) carbon units for forestry projects have a maximum of duration of 50 years.[105]

Issuing temporary carbon units could potentially be an important approach in attempts to extend the quantification of carbon benefits of forestry projects to cover temporary carbon substitution benefits associated with using timber instead of more energy-intensive materials.

Extending standards

Each of the main approaches to risk management discussed above might be used in extending quality assurance standards. Possible approaches in each case are briefly considered below.

If discounting future carbon benefits to allow for risks and uncertainties were adopted, this might be based upon an approach suggested by Chomitz (2000, p.15) of mandating a centrally-designated task force to determine appropriate project type and region-specific discount rates, and revised over time to take project experience and changing country risks into account. Just as some projects are excluded as too risky under some voluntary standards, there could be cases where projects or country circumstances are considered so risky that completely neglecting future benefits and allowing only ex-post carbon units is appropriate.

Maintaining a buffer may be considered a more practical option to implement than discounting to avoid potential confusion in establishing discounting protocols if future benefits are also to be discounted for time and changing circumstances. The size of the buffer may continue to be stipulated under individual voluntary standards, but approval would be required by a centrally-designated body to be considered adequate and accepted under any code of conduct.[106] As climate change impacts are more uncertain the further in the future, the appropriate size for a buffer could depend upon the time profile of expected future carbon benefits. Using a buffer in managing risks and uncertainties is similar to some international carbon accounting requirements applying at inter-government level.[107]

Given the importance of regular monitoring and verification of carbon sequestration benefits in underpinning market confidence in forestry carbon units, issuing temporary carbon units is likely to remain an important approach adopted in certain segments of the carbon market to help manage non-permanence risks. To the extent that the duration of carbon units reflects the preferences of market participants, this does not appear to require standardisation. However, in the absence of mandatory requirements to replace temporary carbon units when they expire, establishing a transparent method for comparing the value of carbon units of different duration is likely to be useful, possibly using a tonne-year, rather than a tonne, of carbon or carbon dioxide as the unit of comparison (and discounted as appropriate).

Where discounting to allow for time and changing circumstances is also used, the use of a constant discount rate rather than changing (e.g. declining) discount rates would simplify comparisons between carbon units of different duration. The approach (which could entail a form of discounting the value of temporary compared to more permanent benefits) may require a centrally-designated body to establish principles determining relative values, or could rely upon relative market values (although this is likely to require in-depth monitoring of market transactions and potentially be open to manipulation by market participants).

[104] A pre-requisite for issuing tCERs and lCERs is the prior verification of carbon storage by projects every 5 years. Unlike tCERs (which cover a single 5-year period), lCERs have to be replaced if project verification shows lower carbon storage (e.g. due to thinning, fire or other causes) than the level for which credits have already been issued (Neeff and Henders, 2007). Lack of fungibility between tCERs and lCERs (and also limited fungibility with other CERs), may be regarded as disadvantaging investment in carbon forestry projects compared to other mitigation activities under the CDM.

[105] www.netinform.de/KE/Beratung/Service_Ver.aspx. 'Plan Vivio Certificates' issued by BioClimate Research and Development cover carbon benefits over a 100-year period (See: www.planvivo.org), which may be considered by some more akin to permanent units.

[106] Potentially, national or international buffers of forestry carbon units might also be established to help pool risks and reduce project costs. The Eliasch Review (2008, p.187), for example, recommends creation of national forest carbon reserve accounts along the lines of the buffer approach used at project level under the VCS.

[107] Parties to the Kyoto Protocol are required to hold minimum levels of ERUs, CERs, AAUs and RMUs ('commitment period reserves') in their national registries to reduce the risk they could 'oversell' units, and subsequently be unable to meet their emissions targets. (See: http://unfccc.int/kyoto_protocol/mechanisms/emissions_trading/items/2731.php).

5 Conclusions

As the review has shown, a variety of approaches to valuing carbon exist. Approaches differ according to whether a societal or market perspective is taken. While this review has focused on carbon alone, the value of carbon units can be enhanced by their capacity to deliver additional benefits such as nature conservation and poverty reduction.

Estimates of the social value of carbon are sensitive to the underlying methodology and assumptions adopted. They are also affected by discount rates applied which help determine whether present values of future carbon benefits rise, remain constant, or fall over time. In the absence of an internationally agreed methodology, the social value of carbon considered appropriate in appraising public forestry carbon projects is likely to depend upon national convention. As we have seen (Table 3 above – see also Appendix B), current UK government guidance on valuing carbon for policy appraisal (DECC, 2009a,b) implies that present values of carbon initially fall, before increasing again.

Detailed consideration of current UK government guidance on valuing carbon for policy appraisal is beyond the scope of this paper, but it is worth highlighting the sensitivity of the estimates to GHG stabilisation targets (and underlying atmospheric concentrations and associated global temperature increase assumed), as well as discounting protocols. The guidance is based upon target GHG emissions reductions of 34% compared to 1990 levels by 2020 as part of the European Commission's Climate and Energy Package, and of 80% compared to 1990 levels by 2050 meeting commitments under the UK Climate Change Act (DECC, 2009b, p.26, p.31). It aims to be consistent with the UK's contribution to limiting global temperature increase in 2100 to around 2°C above pre-industrial levels[108] and constraining atmospheric GHG concentrations to be within the 460–480ppm CO_2e range in 2200 (DECC, 2009b, p.32).[109] Were accelerating global emissions (GCP, 2008, Canadell *et al.*, 2007)[110] more severe than anticipated impacts (Ekins, 2009), recognition of non-negligible risks of catastrophic impacts[111] or of optimism bias,[112] or a desire for greater certainty critical thresholds will not be exceeded (Johnson, 2009) to lead to tighter targets,[113] estimates of the social value of carbon would need to be revised upwards. Adopting higher social values of carbon to account for the possibility of the UK's preferred maximum level of atmospheric concentrations of GHGs being exceeded appears to some more consistent with the Precautionary Principle[114] prior to a binding agreement on limiting global emissions being reached. In cases where the carbon value recommended is below the social cost of carbon (the case of the 'traded price' up to 2022 – see DECC, 2009b, Annex 4, p.119), potential ethical issues could arise if this leads to

[108] The central estimate is reported to be based upon a 50/50 probability of temperature rise of around 2°C in 2100 and a less than 1% probability of temperature rise over 4°C (DECC 2009b, p.21). Stabilisation at 450ppm CO_2e is thought to be associated with an approximately 54% (26%–77%) probability of a greater than 2°C temperature rise at equilibrium, while stabilisation at 350ppm is associated with an approximately 7% (0%–31%) probability of a greater than 2°C temperature rise (DECC 2009b, Table 3.2, p.20).

[109] However, noting that we will probably be at 450ppm CO_2e within ten years, Stern (2009, p.26) argues that 'Given that we are already at 430ppm, we have probably missed the chance of keeping emissions below 450ppm. Limiting temperature increases, with high probability, to 2°C – which is often advocated on the grounds that anything higher would be dangerous – is a goal that is unlikely to be achievable, unless we discover and implement ways of extracting GHGs from the atmosphere on a large scale. At 500ppm CO_2e, the chances of exceeding 2°C are over 95%.'

[110] The growth rate in global CO_2 emissions is reported to have increased from 1.3% pa in the 1990s to 3.3% pa in the period 2000–2006 (Canadell *et al.*, 2007), a rise by a third to 2.2ppm a year in 2007 compared to the average (1.5ppm a year) for the previous 20 years, giving a total atmospheric CO_2 concentration of 383ppm in 2007 (GCP, 2008), far exceeding the maximum of the natural range over the past 650,000 years of 300ppm (IPCC, 2007). The Global Carbon Project reports emissions growth during 2000–2007 was higher than that assumed under the IPCC's most fossil fuel intensive scenario (www.globalcarbonproject.org/carbontrends/index.htm). Noting recent developments in climate science and analysis of potential impacts also imply lower emissions targets are appropriate, CCC(2008, Figure 1.1, p.11) shows actual emissions exceeded scenarios A2, B1 and B2 from the IPCC(2000) Special Report on Emissions Scenarios (while lying below those for scenario A1B).

[111] Although essentially unknowable, drawing on probability density functions from scientific papers covered by the IPCC (2007, Table 9.3), Weitzman (2009) speculates that there may be a 5% probability of a greater than 10°C change in mean global surface temperature in around the next 200 years and a 1% probability of a greater than 20°C change compared to pre-industrial revolution levels. In either case, it is argued that such rapid warming would lead to mass extinctions and biosphere ecosystem disintegration, destroying life on Earth as we know it. According to Stern (2009, p.26), an atmospheric concentration of 750ppm CO_2e by 2100 might be a conservative estimate of the consequences of 'business as usual' emissions', a level which Hadley Centre models suggest may be associated with a 9% probability of exceeding a 7°C temperature increase (See: Stern Review, 2006, Box 8.1, p.220).

[112] Ekins (2009, p.1) argues 'Just as scientists have under-estimated the scientific impacts of climate change, policy makers have tended to over-estimate the effectiveness of policies they have put in place to address it. It is essential that any new appraisal method should seek to take account of and compensate [for] this tendency towards a dual excess of optimism.'

[113] The 2°C goal is not universally accepted in the scientific community. In evidence to the House of Commons Environmental Audit Committee, for example, James Hansen of the NASA Goddard Institute for Space Studies stated that 1°C is a more appropriate target and that atmospheric CO_2 needs to be stabilised at around 350ppm (i.e. at a lower level that that currently) – see: ENDS Report No.47, p.63 (Dec 2008).

adoption of policies that sanction higher emissions than would be the case if the SCC had been used (Hamilton, 2009).[115]

UK government guidance recommends using the discounting protocol from the Green Book (HM Treasury, 2003.)[116] rather than lower discount rates consistent with the approach in the Stern Review.[117] If lower discount rates were adopted, present values of future carbon benefits would increase.[118]

Establishing a relatively modest social value of carbon increases the likelihood that policies and projects associated with higher emissions will be approved, making it more difficult to achieve the assumed stabilisation level (Great Britain Parliament, 2008, Stanton and Ackerman, 2008).[119] Both adoption of a relatively high discount rate and a relatively modest social value of carbon risk undervaluing potential contributions of forestry to climate mitigation.

As the review has illustrated, a wide range of market values for carbon exist, with prices varying between different types and qualities of carbon units. Especially for compliance credits, prices are strongly influenced by regulatory factors that affect supply and demand, and also influence the current market value of future carbon benefits.

Establishing a framework that places a value on carbon and thereby gives financial incentives for businesses and households to incorporate climate change impacts of their activities into their decisions is viewed of key importance by the UK Government (DTI, 2006). However, mechanisms that value and provide incentives to sustain and enhance forest carbon stocks are currently very weak both within the UK and at international level. As noted above, credits for forestry carbon have yet to be issued under the Kyoto Protocol flexibility mechanisms, while forest carbon is currently excluded from the EU ETS. Furthermore, focused upon internationally compliant credits, the Government's Quality Assurance Scheme for Carbon Offsetting (DECC, 2009c), does not currently apply to forestry projects, and if adopted, the approach proposed in the recent Department of Energy and Climate Change Consultation on carbon units and carbon accounting (DECC, 2008a) will similarly exclude voluntary forestry carbon. In the latter case there is a lack of confidence in the capacity of VERs to offer the needed level of assurance concerning issues such as additionality and transparency in a context where the quality, credibility and cost of carbon benefits are very variable, and carbon units are viewed as not having been subject to the same rigour of certification and verification as Kyoto compliant credits (DECC, 2008a, p.17). Exclusion of voluntary forest carbon stems from forestry being covered by mandatory reporting of emissions from land use and land use change (LULUCF) activities under the Kyoto Protocol.

In-depth consideration of approaches used by different voluntary carbon market standards to assure quality including additionality and transparency is beyond the scope of this paper. However, it is important to note that some voluntary carbon standards (e.g. VER+, VOS) explicitly aim to provide as high a level of assurance as Kyoto

114 This Principle (to which the Government is committed under the 1992 Rio Declaration on Environment and Development and European Resolution of 2000) seeks to 'make a decision that seeks to avoid serious damage if things go wrong' (United Kingdom Interdepartmental Liaison Group on Risk Assessment, 2002, p.5). While a variety of formulations of the Principle exist, the Rio Declaration states 'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.' (Principle 15 – see: www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163). Ekins (2009, p.1) argues for 'strong and precautionary policy', noting that 'extrapolating from a global agreement on climate change to a global trajectory of carbon emissions and atmospheric concentrations and temperature changes'... will be as uncertain a process as estimating the impacts of climate change that will result.' According to Ackerman (2009, p1) '...determination of overall targets for greenhouse gas reduction should be ...based upon a precautionary response to catastrophic worst-case risks, not calculations of the social cost of carbon.'

115 Hamilton (2009, p.1) notes '...there is a risk that the UK government would be publicly proceeding with projects that are harmful to the global environment.'

116 Note that use of hyperbolic (declining) discount rates can lead to time inconsistency in decision-making (e.g. see: Price, 2004).

117 Expert reviews of the previous DEFRA guidance suggests that the underlying justification is neither fully understood nor accepted. Bowen (2007) notes that use of the standard 3.5% discount rate '...may be convenient, but it does not follow from the logic of the Stern Review's non-marginal expected utility analysis.' Stanton and Ackerman (2008, p.14) argue use of the standard discount rate is based upon the view that the lower rate in the Stern Review '...is valid everywhere but applicable nowhere.' Grounds for assuming a linear 2% annual increase in the SPC have also been questioned (Helm, 2007, Watkiss, 2007, Stanton and Ackerman, 2008).

118 However, where uncertainty concerning future impacts of climate change on forests is particularly great, a higher discount rate may be appropriate in valuing the future carbon benefits of forests, implying a reduction in their present values.

119 Great Britain Parliament (2008, p.19) notes of previous DEFRA guidance: '...by assuming that action will be taken to ensure that the effects of climate change will be relatively mild, the paper concludes that the costs of climate change are relatively low. In doing this, however, it is setting a relatively low carbon price to be plugged into all Government decision-making today. The risk is that this will fail to discourage the approval of policies and projects that will lead to a growth in carbon emissions—and thus help to make it more difficult to achieve the stabilisation target that the paper assumes will be met.' Noting the exclusion of some social costs, Great Britain Parliament (2008, p.18) argues 'The strict monetary value given for the SPC will undoubtedly be an undervaluation.'

compliant credits, with a few (e.g. Gold Standard)[120] aiming for higher standards in certain respects, while concerns about the additionality of some Kyoto compliant credits (AAUs) has led to their sales often being underpinned by other instruments. Lack of confidence in the capacity of any voluntary carbon standards to offer at least as high a level of assurance as Kyoto and EU ETS compliant credits regarding issues such as additionality and transparency may therefore appear misplaced. (Appendix C provides details on voluntary market standards applying to forestry projects in relation to valuation and risk management issues).

However, any sale of voluntary carbon units by sectors covered by binding national or international emission reduction commitments give rise to potential double-counting problems unless they can be demonstrated to provide additional carbon benefits to those covered by national reporting. At present no mechanism exists to ensure the additionality of any voluntary carbon units issued by the UK forestry sector by excluding them from national reporting, or allowing equivalent compliance credits to be retired.[121] Nonetheless the voluntary carbon market has a potentially important role in developing projects that help meet national emission reduction targets.

In order to underpin the quality of claims to carbon sequestration benefits, the Forestry Commission is currently developing a UK code of good conduct for forestry carbon projects.[122] Several approaches would be feasible in establishing a framework allowing carbon benefits to be compared across time, and in managing risks and uncertainties. Potential approaches based upon discounting, maintaining a buffer, and issuing temporary carbon units have been briefly discussed in sections 2 and 3.

Due partly to delayed carbon sequestration benefits and high up-front investment costs, the bulk of forestry units sold in voluntary carbon markets may be expected to continue to be issued ex-ante before carbon benefits have been quantified and verified.[123] Limiting the code of good conduct to ex-post carbon units reduces risks that carbon benefits fail to materialise, but could have a detrimental impact on incentives to undertake carbon sequestration projects.

Establishing a robust framework that values forestry carbon will be important if the forestry sector is to be encouraged to play a greater role in helping to meet national carbon emission reduction commitments, and if significant opportunities for climate change mitigation by the sector are not to be missed. Developing the Code of Good Conduct for forestry carbon projects in the UK is a potentially important step in providing a surer foundation upon which such a framework could be based.

[120] The Gold Standard does not cover forestry, however. The CCB standard, which does, encompasses a wider range of benefits (e.g. species conservation) and can be combined with other standards.
[121] For fuller discussion of carbon additionality issues, see: Valatin (2010).
[122] i.e. recognising that in general any carbon units sold by the UK forestry sector contribute to meeting national targets, rather than being additional to those covered by national reporting under the Kyoto Protocol.
[123] However, to the extent that carbon prices are expected to rise over time (e.g. due to the introduction of more stringent targets), this will tend to increase the viability and comparative attractiveness of issuing carbon units ex-post.

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Appendix A UK-based forestry carbon unit providers

UK-based providers of forestry carbon units are listed[124] in Tables I and II below for UK and overseas projects respectively.[125]

Table I UK providers of carbon units from UK forestry projects (as at early 2009).

Organisation	Website	Type of organisation	Type(s) of project	Primary market(s)	Types of carbon unit
Borders Forest Trust	www.bordersforesttrust.org	Charity	CF	Firms	Unverified
Carbon Footprint	www.carbonfootprint.com	Company	R, LPT	Firms, Households	Verified
Carbon Forestry	www.carbonforestry.co.uk	Company	T	Firms, Households	Unverified
Carbon Leaf	www.carbonleaf.co.uk	Company	T	Households	Unverified
Carbon Offset Scotland	www.carbon-offset-scotland.com	Company	T	Households	Unverified
Carbon Responsible	www.carbonresponsible.com	Company	T	Firms, Households	Verified
Co2balance	www.co2balance.uk.com	Company	A, HN	Firms, Households	Verified (max 90% sold)
Erase my Footprint	www.erasemyfootprint.com	Company	A	Households	Unverified
Forest Carbon	www.forest-carbon.co.uk	Company	A	Firms	Unverified
Future Forests	www.futureforests.co.uk	Company	T, R	Households	Unverified
Grow a Forest	www.growaforest.com	Non-profit Company	A	Households	Unverified
Moor Trees	www.moortrees.org	Charity	A	Households	Unverified
Project Climate	http://projectclimate.org	Company	A	Firms	Verified
The CarbonNeutral Company	www.carbonneutral.com	Company	T, F	Firms, Households	Verified
The C-Change Trust	www.thec-changetrust.com	Charity	A, CF, HN	Firms, Households	Verified
Treeflights	www.treeflights.com	Company	A, R	Households	Unverified
Trees for Cities	www.treesforcities.org	Charity	U, CF	Households	Unverified
Woodland Trust	www.woodlandtrust.org.uk	Charity	A	Firms	Unverified

Sources: Ewing (2008), and carbon unit providers' websites.[126]
Notes: A = Afforestation (planting trees where none previously); CF = Community Forestry; F = Forestry (unspecified); HN = development of habitat networks; LPT = 'Low profile' tree planting (hedgerows, school grounds, etc); NW = 'native' woodland (establishment and restoration); R = Reforestation/Restoration (planting trees in previously forested areas); T = Tree planting (unspecified); U = Urban tree planting.

[124] Although thought to be comprehensive, no claim to completeness is made.
[125] Note that listing does not in any way imply endorsement.
[126] Where verification is not mentioned on the website, units are assumed to be unverified.

Table II UK providers of carbon units for overseas forestry (as at early 2009).

Organisation	Website	Type of organisation	Types of project	Location(s) of projects	Primary market(s)	Types of carbon unit
C level	www.Clevel.co.uk	Company	RR	Uganda	Firms, Households	VERs
Carbon Footprint	www.carbonfootprint.com	Company	R, LPT	Kenya	Firms, Households	VERs
Carbon Me	www.carbonme.org	Company	CF, R	LDCs incl. Ethiopia	Households	Unverified
Carbon Positive	www.carbonpositive.net/	Company	R	LDCs incl Brazil & Indonesia	Firms, Households	VERs (+CERs in the future)
Climate Stewards	www.climatestewards.net/	Charity	T	Ghana & other LDCs	Households	VERs
Climate Warehouse	www.climatewarehouse.com	Company	F	Worldwide	Firms	VERs and CERs
Co2balance	www.co2balance.uk.com	Company	A, HN	France	Firms, Households	VERs (max 90% sold)
Cool Earth	www.coolearth.org	Charity	D	Brazil, Peru & Ecuador	Firms, Households, Schools	VERs
Correct Carbon	www.correctcarbon.co.uk	Company	R	Panama	Households	VERs
Envirotrade	www.envirotrade.co.uk	Company	R, Ag	Mozambique, Bhutan & other LDCs	Firms, Households	VERs
Flying Forest	www.FlyingForest.org	Company	T	Namibia, S. Africa, Zambia	Households	Unverified
Greenstone Carbon Management	www.greenstonecarbon.com	Company	A, R	Worldwide	Firms	VERs and CERs
GroPower	www.GroPower.net	Company	J	Philippines	Households	VERs
Mycarbondebt	www.mycarbondebt.com	Company	T	India, Tanzania	Households	VERs
Plan Vivo	www.planvivo.org	Non-profit Foundation	CF/Ag	Mexico, Uganda, Mozambique	Firms	VERs
Ripple Africa	www.rippleafrica.org	Charity	T, R	Malawi	Households	VERs
The CarbonNeutral Company	www.carbonneutral.com	Company	T, F	Worldwide	Firms, Households	VERs and CERs
Treeflights	www.treeflights.com	Company	A, R	Peru	Households	Unverified
Trees for Cities	www.treesforcities.org	Charity	U, CF	Peru, Ethiopia, Kenya	Households	Unverified
World Land Trust – Carbon Balanced	www.carbonbalanced.org	Charity	D, R, RR, HN	Ecuador, Paraguay, Brazil	Firms, Households	VERs and CERs

Sources: Ewing (2008), and carbon unit providers' websites.
Notes: A = Afforestation; Ag = Agroforestry; CF = Community Forestry; D = Avoided deforestation; F = Forestry (unspecified); HN = development of Habitat Networks; J = Jatropha tree planting to use seeds for biofuel (fossil fuel substitution); LPT = 'Low profile' tree planting (hedgerows, school grounds, etc); R = Reforestation/Restoration; RR = Rainforest reforestation; T = Tree planting; U = Urban tree planting; LDCs = 'Less Developed Countries'.

Appendix B Discounting

The Green Book

The Green Book baseline estimate of the rate of Social Time Preference ($r=3.5\%$) is reported to be derived from evidence suggesting that the consumption-invariant discount rate (ρ) is around 1.5%, the elasticity of the marginal utility of consumption (μ) is about 1, and the expected rate of growth of per capita consumption (g) is around 2% pa (HM Treasury, 2003, p.98). In cases where appraisal depends significantly on discounting effects in the very long term, uncertainty about the future provides the main rationale for Green Book recommendations that the following declining discount rates be adopted:

Table III Treasury Green Book discount rates.

Years	0-30	31-75	76-125	126-200	201-300	301+
Rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

Source: (HM Treasury, 2003, Table 6.1, p.99).

The Stern Review

Viewing each future generation as having the same claim to ethical consideration as the current generation, the Stern Review (p.31) notes that 'assessing impacts over a very long time period emphasises the problem that future generations are not fully represented in current discussion.' Considering adoption of a positive pure rate of time preference (δ) ethically indefensible in the context of climate change, the approach to discounting adopted in the Stern Review assumes a low consumption-invariant discount rate ($\rho=0.1$) associated purely with uncertainty about the existence of future generations given possible exogenous shocks (e.g. catastrophe caused by a meteorite).[127] Viewing discounting as appropriate in comparing marginal perturbations around a growth path but not in making comparisons across different paths, the Stern Review (p.52) argues against adopting a single constant discount rate. It notes that if inequality and uncertainty were to rise over time this would generally reduce the discount rate, and that different rates may be expected to apply to different groups and types of goods.[128]

Use of a low discount rate in the Stern Review has been subject to much debate. Nordhaus (2007, p.689, p.701), for instance, argues that 'If we substitute more conventional discount rates used in other global warming analyses, by governments, by consumers, or by businesses, the Review's dramatic results disappear. The Review's unambiguous conclusions about the need for extreme immediate action will not survive the substitution of assumptions that are consistent with today's marketplace real interest rates and savings rates.' By contrast, Weitzman (2007) is more supportive of a low discount rate, but for reasons that differ from those in the Review. According to him, in contrast to values adopted for the consumption-invariant discount rate of $\rho=0.1\%$, a growth rate of $g=1.3\%$, and a marginal utility of consumption of $\mu=1$,[129] giving a discount rate of 1.4%,[130] a more reasonable estimate for each of the three elements is 2%, which would imply a discount rate in a deterministic framework of 6%.[131] However, once uncertainty about the scale and likelihood of catastrophic outcomes is included, the discount rate may be close to that assumed in the Stern Review. For example, for a correlation coefficient between increased output from climate mitigation investment projects and returns to the economy as a whole (β) of $\beta=0.5$, based upon a historical risk-free interest rate of 1% and economy-wide rate of return of 7%, the relevant discount rate for comparisons with a century hence is 1.7%.[132]

[127] However, even this high a level of consumption-invariant discount rate (ρ) is recognised by the Stern Review (p.47) as apparently implying an implausibly high (10%) chance of humanity's extinction by the end of the century.

[128] The Stern Review (p.52) notes 'For example, if conventional consumption is growing but the environment is deteriorating, then the discount rate for consumption would be positive but for the environment it would be negative. Similarly, if the consumption of one group is rising but another is falling, then the discount rate would be positive for the former but negative for the latter.'

[129] Stern (2006, p.46) argues that 'In this context it is essentially a value judgement. If for example $\eta=1$, then we would value an increment in consumption occurring when utility was 2c as half as valuable as if it occurred when consumption was c.'

[130] However, Bowen (2007) states '...the Stern Review argument was that there does not exist a single discount rate that can be used to make non-marginal decisions under uncertainty.'

[131] The discount rate is characterised as an equilibrium price of capital.

[132] Such a 'midrange effect' is considered not implausible given that climate change impacts are expected to be highly unevenly spread between regions and sectors.

Formally incorporating uncertainty about the likelihood and magnitude of potential catastrophic outcomes of climate change poses significant challenges for economic analysis (Weitzman 2007).[133] not least as there are probably 'unknown unknowns' (Tol, 2009).[134]

UK government guidance on carbon

In contrast to the Stern Review, UK Government guidance on valuing carbon covers individual policies and projects ('marginal' decisions) rather than willingness to pay for avoiding future climate change impacts per sae ('non-marginal' decisions), with Treasury Green Book discount rates therefore argued to be appropriate rather than the lower discount rate adopted in the Stern Review.[135] Social values of carbon from the most recent guidance (DECC, 2009a, Table 1; DECC, 2009b, Annex 4, p.119) and discounted values are shown in Table IV.

Table IV UK social values of carbon and discounted values 2010–2055 (£/tCO_2e at 2009 prices).

Year	'Traded' price of carbon (sectors covered by EU ETS)					'Non-traded' price of carbon (sectors not covered by EU ETS)				
	Low	Central	High	Central discounted	Index	Low	Central	High	Central discounted	Index
2010	7	14	18	14	100	26	52	78	52	100
2011	7	14	18	14	98	26	52	79	51	98
2012	8	15	18	14	96	27	53	80	50	96
2013	8	15	19	13	94	27	54	81	49	94
2014	8	15	19	13	92	27	55	82	48	92
2015	8	15	19	13	90	28	56	84	47	91
2016	8	15	20	13	89	28	57	85	46	89
2017	8	16	20	12	87	29	57	86	45	87
2018	8	16	20	12	85	29	58	87	44	86
2019	8	16	20	12	84	30	59	89	43	84
2020	9	16	21	12	82	30	60	90	43	82
2021	11	22	29	15	105	31	61	92	42	81
2022	14	27	38	18	127	31	62	93	41	79
2023	16	32	46	21	147	32	63	95	40	78
2024	19	38	54	23	166	32	64	96	40	76
2025	22	43	63	26	183	33	65	98	39	75
2026	24	49	71	28	198	33	66	99	38	74
2027	27	54	80	30	213	34	67	101	37	72
2028	30	59	88	32	226	34	68	102	37	71
2029	32	65	97	34	238	35	69	104	36	69
2030	35	70	105	35	250	35	70	105	35	68
2031	38	77	115	37	263	38	77	115	37	72
2032	42	83	125	39	276	42	83	125	39	75
2033	45	90	134	41	288	45	90	134	41	78
2034	48	96	144	42	298	48	96	144	42	81
2035	51	103	154	43	308	51	103	154	43	84
2036	55	109	164	45	316	55	109	164	45	86
2037	58	116	173	46	324	58	116	173	46	88
2038	61	122	183	47	330	61	122	183	47	90
2039	64	129	193	47	336	64	129	193	47	92
2040	68	135	203	48	341	68	135	203	48	93
2041	71	142	212	49	347	71	142	212	49	95
2042	74	148	222	50	352	74	148	222	50	96
2043	77	155	232	50	357	77	155	232	50	97
2044	81	161	242	51	361	81	161	242	51	99
2045	84	168	251	51	365	84	168	251	51	100
2046	87	174	261	52	368	87	174	261	52	100
2047	90	181	271	52	371	90	181	271	52	101
2048	94	187	281	53	373	94	187	281	53	102
2049	97	194	290	53	375	97	194	290	53	102

[133] Noting the importance of whether the problem is characterised essentially as catastrophe insurance or consumption smoothing, Weitzman (2007, p.723) argues 'The overarching problem is that we lack a commonly accepted usable economic framework for dealing with these kinds of thick-tailed disasters, whose probability distributions are inherently difficult to estimate (which is why the tails must be thick in the first place).' See also: Weitzman (2009).

[134] With estimates only covering impacts that have been quantified and valued, Tol (2009, p.46) further argues '...climate change may spring nasty surprises. Such risks justify greenhouse gas emission reduction beyond that recommended by a cost benefit analysis under quantified risk. The size of the appropriate `uncertainty premium' is in some sense a political decision.'

[135] According to Price *et al.* (2007, p.15) the shadow price of carbon approach previously recommended 'reconciles the need to reflect the non-marginal nature of the decision to avoid dangerous climate change with the marginal nature of individual projects and policies.'

Table IV cont. UK social Values of Carbon and Discounted Values 2056–2100 (£/tCO_2e at 2009 prices).

Year	'Traded' price of carbon (sectors covered by EU ETS)					'Non-traded' price of carbon (sectors not covered by EU ETS)				
	Low	Central	High	Central discounted	Index	Low	Central	High	Central discounted	Index
2050	100	200	300	53	376	100	200	300	53	103
2051	103	207	312	53	378	103	207	312	53	103
2052	105	214	323	53	379	105	214	323	53	103
2053	107	221	335	54	380	107	221	335	54	104
2054	109	228	346	54	380	109	228	346	54	104
2055	111	234	357	54	380	111	234	357	54	104
2056	113	241	369	54	380	113	241	369	54	104
2057	115	248	380	53	378	115	248	380	53	103
2058	117	254	391	53	377	117	254	391	53	103
2059	118	260	402	53	375	118	260	402	53	102
2060	120	266	412	52	372	120	266	412	52	102
2061	121	271	421	52	368	121	271	421	52	100
2062	121	276	430	51	364	121	276	430	51	99
2063	122	280	438	51	358	122	280	438	51	98
2064	122	284	446	50	353	122	284	446	50	96
2065	122	288	453	49	347	122	288	453	49	95
2066	122	291	460	48	341	122	291	460	48	93
2067	122	294	466	47	334	122	294	466	47	91
2068	122	297	472	46	328	122	297	472	46	89
2069	121	299	477	45	321	121	299	477	45	87
2070	120	301	482	44	313	120	301	482	44	85
2071	120	303	486	43	306	120	303	486	43	83
2072	119	305	490	42	299	119	305	490	42	82
2073	118	306	494	41	291	118	306	494	41	79
2074	117	307	497	40	284	117	307	497	40	77
2075	115	308	500	39	276	115	308	500	39	75
2076	114	308	502	38	268	114	308	502	38	73
2077	112	308	503	37	261	112	308	503	37	71
2078	111	307	504	36	253	111	307	504	36	69
2079	109	307	505	35	245	109	307	505	35	67
2080	107	306	504	33	237	107	306	504	33	65
2081	105	306	506	32	230	105	306	506	32	63
2082	104	305	506	31	223	104	305	506	31	61
2083	102	304	506	30	215	102	304	506	30	59
2084	100	303	506	29	208	100	303	506	29	57
2085	98	302	506	28	202	98	302	506	28	55
2086	96	300	504	28	196	96	300	504	28	53
2087	94	298	503	27	190	94	298	503	27	52
2088	92	297	501	26	184	92	297	501	26	50
2089	90	294	499	25	178	90	294	499	25	49
2090	88	292	497	24	173	88	292	497	24	47
2091	86	291	495	24	167	86	291	495	24	46
2092	84	289	494	23	162	84	289	494	23	44
2093	82	286	491	22	157	82	286	491	22	43
2094	79	284	488	21	152	79	284	488	21	41
2095	77	281	485	21	147	77	281	485	21	40
2096	75	279	482	20	142	75	279	482	20	39
2097	73	276	480	19	137	73	276	480	19	37
2098	71	274	476	19	133	71	274	476	19	36
2099	69	271	473	18	128	69	271	473	18	35
2100	67	268	469	17	124	67	268	469	17	34

Sources: DECC (2010a, 2010b, Table 3, pp.42–43),[136] Treasury (2003).

[136] Discounted values and indices are based upon the more precise values in spreadsheets at: www.decc.gov.uk/en/content/cms/statistics/analysts_group/analysts_group.aspx

Appendix C Voluntary carbon market standards

In addition to those developed by carbon unit providers for their own use,[137] a variety of standards apply in the voluntary market to forestry carbon. These include:

American Carbon Registry Forest Carbon Project Standard (ACRFCPS)

The American Carbon Registry, a non-profit enterprise of Winrock International originally established in 1997, launched the ACRFCPS in 2009 covering ex-post carbon units. Non-permanence risks can be addressed using one of three mechanisms. These are by contributing to a Registry buffer (with the size of contribution determined using a risk assessment by the verifier and Registry), by an insurance policy guaranteeing a replacement price for carbon units, or by using non-forestry carbon units that meet Registry standards. Where the buffer option is selected, an assessment by an independent verifier is required every 5 years to ensure that a sufficient buffer is maintained.[138]

CarbonFix Standard

CarbonFix, a NGO established in Germany in 1999 to promote forestry as a tool for climate protection, launched its carbon standard in 2007. Just covering afforestation and reforestation projects,[139] ex-ante carbon units are issued based upon projected carbon sequestration (above a baseline and net of project emissions and leakage). These are termed $VER_{Futures}$. Risks of non-permanence are addressed partly by commitments to replanting areas after being destroyed (e.g. forest fires) or obtaining replacement $VER_{Futures}$, and partly through a buffer fund (30% of the certified units are initially allocated to this, of which a quarter are used to provide insurance).[140] In addition, evidence must be provided of management, financial, technical, and protective capacities, and of secured land tenure.[141]

Climate, Community and Biodiversity Standard (CCBS)

The Climate, Community and Biodiversity Alliance (CCBA), a global partnership of NGOs and companies formed in 2003 with the aim of leveraging policies and markets to promote forest conservation, restoration and agroforestry through high quality carbon projects delivering climate, biodiversity and community benefits, first drafted the CCBS in 2004. The standard requires legal safeguards (e.g. conservation easements) be used to ensure carbon benefits are maintained permanently, or insurance provided for any potential loss of expected carbon benefits. Non-permanence can be addressed partly through retaining a proportion of the total carbon units as a buffer (Merger and Williams, 2008).[142] The second version of the standard, launched in December 2008, notes that focusing upon social and environmental benefits and sustainability is important in reducing non-permanence risks.[143]

Forest Carbon Standard

The Forest Carbon Standard was created by Forest Carbon Ltd, a company based in northern England. Non-permanence is addressed by retaining more than half of the total estimated carbon units as a buffer.[144] There is also a contractual commitment to replacing trees lost for any reason.[145]

Green-e

Launched in 2007 by the Center for Resource Solutions, a non-profit organisation based in San Francisco, the stan-

[137] E.g. Climate Care, and the CarbonNeutral Company.
[138] See: Winrock International (2009). American Carbon Registry Forest Carbon Project Standard, Version 1, March, www.americancarbonregistry.org/carbon-accounting/standards.
[139] It covers areas which were not forests 10 years before a project started, or since the beginning of 1990, and excludes projects in wetlands or protected areas. (see: www.carbonfix.info/About_Us/Association.html?PHPSESSID=189915774d281eca595bf3ce5fa631f1).
[140] See: CarbonFix (2008). CarbonFix Standard version 2.1, www.carbonfix.info/CarbonFix_Standard/Standard.html?PHPSESSID=189915774d281eca595bf3ce5fa631f1, p.19.
[141] Op. cit. pp.17–18.
[142] E.g. retaining 10% of carbon units as a buffer was considered acceptable for the Project Climate afforestation project at Apley, Lincolnshire (see: www.climate-standards.org/projects/index.html). According to Merger and Williams (2008), CCBA recommends that 10% of carbon units are withheld from compliance markets, either retired, or sold through the voluntary market.
[143] See: www.climate-standards.org/standards/thestandards.html (p.7).
[144] The carbon units traded are based upon estimated stem timber only (see: www.forest-carbon.co.uk/#/creditssequestration/4531028872).
[145] An additional protection in the UK context is the requirement to replace trees under the terms of statutory felling licences (see: www.forestXcarbon.co.uk/#/theforestcarbonstandard/4531698205).

dard currently covers US projects. It stipulates that explicit, transparent and credible arrangements must be put in place to prevent reversibility or non-permanence of GHG emission reductions.[146]

Greenhouse Friendly

Established by the Australian Government, this standard covers forest sink abatement projects in Australia. These projects must be maintained for at least 70 years and include risk management (e.g. commitments to purchase alternative carbon units to balance any loss) and restoration (e.g. commitment to replant) provisions.[147]

Plan Vivio

Established by BioClimate Research and Development with the aim of reliable sequestration of carbon over the long term in economically viable, and socially and environmentally responsible projects, carbon units issued under this standard are termed 'Plan Vivio Certificates', and cover carbon benefits for forestry projects over a 100-year period. Non-permanence is fostered through community-led planning of activities and is partly addressed through retaining a proportion of the total carbon units as a buffer. Trees felled at the end of a harvest rotation have to be replanted.[148]

Voluntary Carbon Standard (VCS)

Launched in 2006/7 by the Climate Group, the International Emissions Trading Association, and the World Business Council for Sustainable Development, the VCS covers three forestry carbon categories, Afforestation, Reforestation and Revegetation, Improved Forest Management, and Reducing Emissions from Deforestation.[149] Projects involving Agriculture, Forestry, and Other Land Uses (AFOLU) have to identify potential adverse environmental and socio-economic impacts, and take steps to mitigate them, prior to carbon units (Voluntary Carbon Units – VCUs) being issued. A risk assessment also has to be undertaken. This includes consideration of project risks (unclear land tenure, financial, technical, or management failure), economic risk (raising opportunity cost of land endangering project viability), regulatory and social risk (of political or social instability) and natural disturbance risks (of fire, pests and diseases, extreme climatic events such as flooding, drought and high winds), and geological risks (e.g. volcanic eruptions, earthquakes, landslides). Risks of non-permanence are addressed by maintaining a buffer reserve of non-tradable carbon units, held in a single pooled buffer reserve for all projects. Projects are characterised as being of low, medium, high, or unacceptably high risk, with buffers for the first three categories set at progressively higher levels (see: Table V).[150]

Carbon units are issued for the period over which net GHG removals will be verified. For forestry projects this is between 20 and 100 years (Newcombe *et al.*, 2008, p.17). CDM, JI and California Climate Action Registry (CCAR) programmes have been recognised as meeting VCS standards.[151]

VER+

Launched in 2007 by Tüv Süd, a verification organisation based in Munich, the VER+ standard is based upon CDM and JI standards, and covers afforestation and reforestation,

Table V Non-tradable carbon unit buffers for forestry projects under the VCS.

Risk class	Type of project				
	Afforestation, reforestation, and revegetation	Improved Forest management	Avoided planned deforestation	Avoided unplanned frontier deforestation and degradation	Avoided unplanned mosaic deforestation and degradation
Low	10–20%	10–15%	10%	10%	10%
Medium	20–40%	15–40%	10–20%	10–25%	10–30%
High	40–60%	40–60%	20–30%	25–35%	30–40%

Source: VCS (2008a, Tables 3,7,9, p.6,9,10).

[146] www.green-e.org/getcert_ghg.shtml.
[147] See: www.climatechange.gov.au/greenhousefriendly/publications/gf-guidelines.html.
[148] Projects were originally conceived and developed in 1994 as part of a DFID-funded research project in southern Mexico. A revised standard is currently under development. BR&D has links to Edinburgh Centre for Carbon Management and has now renamed the Plan Vivo Foundation. (See: www.planvivo.org/?page_id=733).
[149] www.v-c-s.org/afl.html.
[150] NB any projects associated with unacceptably high risks (e.g. due to uncertain tenure and no established user rights) are rejected. The minimum buffer has been increased from the 5% level stipulated in Newcombe *et al.* (2007).
[151] www.v-c-s.org/programs.html.

forest conservation (avoided deforestation / degradation), and improved forest management projects. To address risks of non-permanence, a 'conservative buffer' approach is applied, with the buffer set at not less than 20% of net removals or emissions reductions.[152] Although they may be extended subsequently, carbon units expire at the end of the latest United Nations Framework Convention on Climate Change (UNFCCC) commitment period (currently end of 2012). Carbon units for forestry projects have a maximum of duration of 50 years. Projects registered under the CDM or approved under JI may apply for VER+ verification of emissions reductions prior to UNFCCC registration, but do not give rise to any additional carbon units once CERs or ERUs are granted. All VER+ carbon units (including those withheld as part of the buffer) are tracked on the BlueRegistry, established primarily to ensure that the same carbon units are not sold to more than one buyer.[153]

Voluntary Offset Standard (VOS)

Established by European Carbon Investor Services (ECIS),[154] the VOS covers CERs and ERUs, and also VERs based upon CDM and JI standards.[155]

[152] www.netinform.de/KE/Beratung/Service_Ver.aspx.
[153] www.netinform.de/BlueRegistry/LoginPage.aspx.
[154] Now International Carbon Investors & Services (ICIS), see: www.carboninvestors.org/home.
[155] It excludes some categories such as nuclear power, and activities covered by greenhouse gas emissions trading allowances (except ERUs associated with activities in EU countries that comply with avoidance of double counting).

Appendix D Glossary, abbreviations & carbon units

Additionality: Net GHG emissions savings or sequestration benefits above those that would have arisen anyway in the absence of the given activity or project within specified boundary (distinguished from 'leakage' outside this boundary).[156]

Allowance-based Carbon: Carbon units issued under a cap-and-trade scheme.

Cap-and-trade scheme: An emissions trading scheme whereby a central body sets an overall limit ('cap') on the maximum total emissions of a pollutant and allocates tradable permits to emit the pollutant consistent with the overall cap.

Carbon offset: An instrument which provides for the impact of emitting a tonne of CO_2 to be negated or diminished by avoiding the release of a tonne elsewhere, or absorbing a tonne of CO_2 that otherwise would have remained in the atmosphere.[157]

Carbon unit: A unit of carbon benefit (often measured as a tonne of carbon dioxide equivalent).

Compliance credit: A carbon unit derived from a national or international regulatory framework limiting GHG emissions.

Compliance market: A market established by a national or international regulatory framework limiting GHG emissions, often under a cap-and-trade scheme.

Double-counting: Emissions reductions or sequestration benefits that have already been counted (e.g. towards meeting national GHG reduction targets).

Forward delivery: A binding agreement between a provider and a buyer to deliver carbon units at a specified future date and price.[158]

Fungibility: The extent to which a carbon unit is exchangeable.[159]

Non-permanence: Loss or reversal of carbon benefits due to fire or other risks.

Project-based carbon: Carbon units issued for emissions reduction or sequestration projects.

Present value: The current worth of a future benefit (or cost) or flow of benefits (or costs).

Quasi-option value: The value of future information made available through the preservation of a resource.[160]

Shadow price: The impact of relaxing a constraint in an optimisation problem by one unit.

Voluntary market: A market established independently (voluntarily) of mandatory national and international regulatory frameworks limiting GHG emissions.

Voluntary 'OTC' market: Any voluntary market apart from that under the Chicago Climate Exchange.

[156] Tests and methodologies are subject of a separate discussion paper (Valatin, 2010).
[157] See definition at: www.usask.ca/agriculture/caedac/dbases/glossary.htm
[158] See: Kollmuss *et al.* (2008, p.46)
[159] See definition at: www.thefreedictionary.com/fungibility.
[160] See definition at: http://biodiversity-chm.eea.europa.eu/nyglossary_terms/Q/quasi-option_value.

AAU Assigned Amount Unit
ACRFCPS: American Carbon Registry Forest Carbon Project Standard
A/R Afforestation/reforestation
CCBA Climate, Community and Biodiversity Alliance
CCBS Climate, Community and Biodiversity Standard
CDM Clean Development Mechanism
CER Certified Emissions Reduction
CFI Carbon Financial Instrument
CO_2 Carbon dioxide
CO_2e Carbon dioxide equivalent
DECC Department of Energy and Climate Change
Defra Department for Environment, Food and Rural Affairs
ERT Emissions Reduction Tonne
ERU Emission Reduction Unit
ETS Emissions trading scheme
EUA European Union Allowance
gCER Guaranteed Certified Emissions Reduction
GHG Greenhouse gas
lCER Long-term Certified Emissions Reduction
IPCC Intergovernmental Panel on Climate Change
JI Joint Implementation
LULUCF Land use and land use change
MAC Marginal abatement cost
NGAC New South Wales Greenhouse Abatement Certificate
OTC 'Over the counter' voluntary market transactions (all except Chicago Climate Exchange)
ppm parts per million
REDD Reduced deforestation and degradation
RMU Removal Unit
SCC Social cost of carbon
SPC Shadow Price of Carbon
tCER Temporary Certified Emissions Reduction
UK United Kingdom
UNFCCC United Nations Framework Convention on Climate Change
VCS Voluntary Carbon Standard
VCU Voluntary Carbon Unit
VER Voluntary or Verified Emissions Reductions
$VER_{Futures}$ Verified Emission Reduction Futures
VOS Voluntary Offset Standard

Carbon units[161]

Table VI Kyoto carbon units

Unit	Full name	Issuer	Description	Kyoto Protocol Article(s)
AAU	Assigned Amount Unit	National registry	Initial assigned amount of each Annex B Party	3.7
RMU	Removal Unit	National registry	Net removals from LULUCF activities	3.3, 3.4
ERU	Emission Reduction Unit	National registry	Converted from AAUs or RMUs on the basis of JI projects	
CER	Certified Emissions Reduction	CDM registry	Emission reductions certified for CDM projects	12
tCER	Temporary Certified Emissions Reduction	CDM registry	Emission removals certified for A/R CDM projects (to be replaced at end of the second commitment period)	12
lCER	Long-term Certified Emissions Reduction	CDM registry	Emission removals certified for A/R CDM projects (to be replaced at end of the project's crediting period or in event of storage reversal or non-submission of a certification report)	12

Source: http://unfccc.int/kyoto_protocol/registry_systems/registry_functions/items/4066.php

Table VII Other compliance units

Unit	Full name	Issuer	Emissions trading scheme
EUA	European Union Allowance	National registry	EU Emissions Trading Scheme
NGAC	NSW Greenhouse Abatement Certificate	Government of New South Wales	New South Wales Greenhouse Gas Abatement Scheme

Table VIII Voluntary carbon units

Unit	Full name	Issuer
CFI	Carbon Financial Instrument	Chicago Climate Exchange and European Climate Exchange
ERT	Emissions Reduction Tonne	American Carbon Registry Forest Carbon Project Standard
Plan Vivio Certificate	Plan Vivio Certificate	Plan Vivio
VCU	Voluntary Carbon Unit	Voluntary Carbon Standard
VER	Voluntary (or Verified) Emissions Reduction	All voluntary carbon standards (or all those issuing independently verified carbon units)
VERFutures	Verified Emission Reduction Futures	CarbonFix

[161] Although believed to cover the main types, no claim to completeness is made.

Carbon valuation, discounting and risk management are important in ensuring that effective incentives are put in place to tackle climate change, and in comparing the relative merits of climate mitigation activities over time. Approaches applied in different contexts, including in relation to permanence issues, are reviewed in this report in order to help inform the development by the Forestry Commission of a Code of Conduct for forestry carbon projects in the UK. An overview of current UK Government guidance on valuing carbon for policy appraisals is provided and the implications of adopting the UK Treasury's declining discount rate protocol recommended in the Green Book discussed. It is noted that at present, there is little relationship between the value to society of reducing greenhouse gas emissions or sequestering carbon and the market price.

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