Forestry Commission

Research Note

Comparing the cost-effectiveness of forestry options for climate change mitigation

Gregory Valatin

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Providing estimates for the cost-effectiveness of woodland creation in removing carbon dioxide from the atmosphere is a vital part of the evidence base on forestry's contribution to mitigating climate change. Different estimates of cost effectiveness exist but there have been inconsistencies in approach which can lead to confusion and misunderstanding. Therefore, it is important to understand how existing studies have been carried out in order to consider the most appropriate and consistent approaches to be used in future. This Research Note examines two recent studies which assessed the cost-effectiveness of forestry options for climate change mitigation across Great Britain. Four key elements in each study are reviewed: (1) the forestry options considered, including species planted, yield class and management (initial spacing, thinning regime, rotation length); (2) estimated carbon savings and emissions; (3) other benefits and costs; and (4) cost-effectiveness metrics. The review suggests that a primary reason for differences in cost-effectiveness estimates is different cost assumptions. However, underlying assumptions are not clearly laid out in each case, hampering direct comparison. The Note makes recommendations for further research to support future analysis and policy evaluation. Improved understanding and clarity in these areas will help to support robust and consistent approaches to estimating the cost-effectiveness of woodland planting in tackling climate change.

Introduction

Comparing the cost-effectiveness of forestry options for climate change mitigation is complicated by the different methods for computing estimates that exist. To address this matter and determine future priorities in this field, recent studies need to be examined and assessed.

This Research Report analyses two recent studies assessing the cost-effectiveness of forestry options in carbon sequestration across Great Britain (CJC Consulting, 2014; Eory *et al*., 2015). Both of these studies are summarised and the methodology each adopts is critically reviewed. Relevant gaps in research are highlighted and recommendations are made for future development. The forestry options under consideration cover a range of species, locations and forest management approaches.

The content which follows is structured to focus upon key elements: sections addressing different forestry options, carbon savings and emissions, other benefits and costs, and various cost-effectiveness metrics. These are followed by a discussion with recommendations to help guide future work in this area.

Forestry options

The number of forestry options considered and the spatial scale at which results are provided differs between the two studies, reflecting differences in their scope. The CJC Consulting study (2014) considers a wider range of forestry options and provides stand-level data before developing a Marginal Abatement Cost Curve (MACC). By contrast, Eory *et al*. (2015) focus solely on results for each of the four countries of the UK, considering a single forestry option covering 5 species in each, while also covering agricultural options.

In CJC Consulting (2014) eight main woodland creation (forestry type) options are examined (Table 1); Eory *et al*. (2015) considered four closely related options (Table 2).

In CJC Consulting (2014), forestry types are combined with option-specific tree spacings: 1.5 m for SRF; 2.5 m for farm woodland and broadleaved woodland managed for game/ biodiversity; and 1.7 m for all other options (CJC Consulting, 2014, Table 3.1). These are combined with six region-specific soil types and two previous land uses across eleven regions of

Table 1 Woodland creation options under consideration in CJC Consulting (2014).

Forestry type	Species	Country	Area (ha)[a]	Thinning	Rotation length (years)
Short rotation forestry (SRF) for energy	Red alder (100%)	England	2	No	15 or 25
		Scotland	5		
		Wales	2		
Farm woodland for mixed objectives	Sycamore/ Common alder/ Birch (65%); Douglas fir (25%)[b]	England	3	Yes (3 thinnings)	indefinite
		Scotland	2		
		Wales	3		
Broadleaved woodland for game/biodiversity	Sycamore/ Common alder/ Birch (45%); Oak (45%)	England	5	No	indefinite
		Scotland	5		
		Wales	5		
Broadleaved woodland for timber and carbon	Oak (45%); Birch (45%)	England	2	Yes[c]	100
		Scotland	5		
		Wales	2		
Upland conifer for timber	Sitka spruce (90%)	England	15	No	maximum MAI[d]
		Scotland	50		
		Wales	15		
Lowland conifer for timber	Douglas fir (90%)	England	10	Yes[c]	maximum MAI[e]
	Sitka spruce (90%)	Scotland	25	Yes (5-year cycle)	maximum MAI[f]
		Wales	10		
Continuous cover forestry for mixed objectives	Sycamore/ Beech (30%); Douglas fir (60%)	England	5	Yes	not applicable
		Scotland	25		
		Wales	5		

Adapted from CJC Consulting (2014, Tables 1.1, 3.1 and 3.3). Notes: a. 10% of area is assumed to be open space for every option except SRF; b. in two Scottish regions, Highlands and Islands as well as Grampian, Sitka spruce replaced Douglas fir as a more appropriate species; c. thinning is based on standard Forestry Commission management tables; d. the point at which the maximum Mean Annual Increment (MAI) is reached is given as 54 years for the Highlands and Islands but it isn't specified for other areas (CJC Consulting, 2014, p. 43); e. the point at which the maximum MAI is reached is given as 58 years for Yorkshire and North-East England but it isn't specified for other areas (CJC Consulting, 2014, p. 44); f. the number of years is not given.

Table 2 Woodland creation options under consideration in Eory *et al.* (2015).

Country	Species[b]	Area (ha)	Thinning
England[a]	Sycamore/Ash/Birch (60%); Oak (27%); Douglas fir (13%)	unspecified[c]	limited
Scotland[a]	Sycamore/Ash/Birch (61%); Oak (25%); Douglas fir (14%)	unspecified[c]	limited
Wales[a]	Sycamore/Ash/Birch[d] (60%); Oak (29%); Douglas fir (12%)	unspecified[c]	limited
Northern Ireland	Sycamore/Ash/Birch (60%); Oak (27%); Douglas fir (13%)	unspecified[c]	limited

Adapted from Eory *et al.* (2015, Table 100). Notes: a. higher yield classes (YC) are assumed for England and Wales than for Scotland for mixed broadleaves (YC 8 rather than YC 6) and Douglas fir (YC 14 rather than YC 10) b. draws upon the broadleaved woodland entry for game/biodiversity in Table 1 (Eory *et al.*, 2015, p.127), but because of ash dieback, it may be better to plant Common alder than ash; c. area of individual woodland is unspecified but the total area planted annually is assumed to be 16 170 ha per year based upon Forestry Commission projections – refer to Eory *et al.*, 2015, Table 99. d. the percentages for the species in Wales add up to 101% due to a rounding error in the original publication

Great Britain (CJC Consulting, 2014, Table 3.5). In addition, region- and species-specific average yield classes (YC) are used, with a total of 2–6 YC per species considered (CJC Consulting, 2014, Table 3.4). In total, 98 separate options were considered (CJC Consulting, 2014, p. 38).

In both studies the options examined relate to woodland creation. Previous studies found that this is more cost-effective than measures to change the management of existing forests (CJC Consulting, 2014, p. 8).

CJC Consulting (2014) consider options over two time periods from the assumed initial planting in 2014; these are over 36 years to 2050, and over 186 years to 2200. Two other time periods were considered (to 2030, and to 2100) but were not used in deriving estimates (CJC Consulting 2014, p. 1). Eory *et al.* (2015) focus upon cost-effectiveness over a 100-year period.

Rotation length

None of the options considered by Eory *et al.* (2015) involved forestry rotations. By contrast, five of the eight main options considered by CJC Consulting (2014) are based upon fixed rotations. Rotation lengths are assumed, rather than being based upon model optimisation, since analysing the optimal rotation length is beyond the scope of the study (CJC Consulting 2014, p. 17).

Carbon savings and emissions

Agricultural emissions

The potential for reductions in emissions associated with a switch away from agricultural land use is noted by CJC Consulting (2014, p. 23). However, no savings attributable to reductions in emissions are included due to either one of two assumptions made: that there is agricultural intensification elsewhere in the UK, or an increase in agricultural imports. Surprisingly (considering that their study includes agricultural measures), Eory *et al.* (2015) do not cover the issue of agricultural emissions. Pasture is presumed to constitute the previous land use when estimating initial soil carbon losses due to woodland planting (Eory *et al.*, 2015, p. 127).

Carbon sequestration

Rates of carbon sequestration assumed for new woodlands in Eory *et al.* (2015) are based upon Woodland Carbon Code Carbon Lookup Tables (Forestry Commission, 2015). Carbon sequestration rates in CJC Consulting (2014) are based upon Forest Research's CSORT model, with total net carbon sequestration computed as the mean cumulative net carbon saving (CJC Consulting 2014, pp. 39-45). This is similar to the calculation of the long-run average with the Woodland Carbon Code except that it is computed over a 186-year time frame, rather than over 200 years.

Soil carbon

The CJC Consulting study (2014, Table 3.6, p. 22) assumes initial soil carbon losses at planting; these range from 0 for mineral gley or post-arable loam soil, to 48 $tCO_2e\ ha^{-1}$ for organo-mineral loam post-pasture (IPCC, 2003, 2006; UNFCCC/CNUCC, 2011). Subsequent carbon losses for organo-mineral gley or loam soil types are assumed to be 4 $tCO_2e\ ha^{-1}$ each year until 2050, with gains of 3 $tCO_2e\ ha^{-1}$ each year for mineral gley or loam until 2020.

Drawing upon Forestry Commission sources, Eory *et al.* (2015, Table 101) assume mean losses of soil carbon at planting ranging from 1.8 $tCO_2e\ ha^{-1}$ in England to 20 $tCO_2e\ ha^{-1}$ in Scotland, with subsequent soil carbon sequestration based upon the method used under the United Nations Clean Development Mechanism as outlined by West (2011). The initially high loss of soil carbon for Scotland reflects an assumed 5% topsoil loss on initial planting for both organo-mineral and mineral soils (this loss is only assumed for organo-mineral soils in other parts of the UK).

Emissions from wood product decay

The emissions from timber and wood products estimated by CJC Consulting (2014) are based upon equation 12.1 in IPCC (2006), which assumes a half-life of 25 years for roundwood products and board, and 35 years for sawn timber products (CJC Consulting, 2014, p.23). Since they focus solely on forestry options with no clearfell and with limited thinning, Eory *et al.* (2015) do not cover wood products.

Carbon savings from wood products

Use of woodfuel

CJC Consulting (2014) estimated carbon substitution savings for the use of woodfuel instead of other fuels, using long-run marginal generation-based emission (LMGE) factors; the assumptions were that woodfuel is used 50% in power generation and 50% in heat generation. These estimates (based upon 2014 figures) include a net carbon saving of 0.414 tCO_2e per ton of woodchips used in power generation, and 0.743 tCO_2e per ton of woodchips used in generating heat (CJC Consulting 2014, p. 24).

Use of wood products

It is assumed by CJC Consulting (2014) that UK timber substitutes primarily for imported wood. They contend that carbon savings from the use of wood products in construction are likely to be small, because any savings associated with the use of wood products instead of other materials such as concrete and steel are likely to fall substantially over time as those industries become more energy-efficient. They also argue that carbon savings from the use of wood products in construction are likely to be small due to a lack of cross-laminated timber production in the UK (although since their study was published cross-laminated timber has begun to be manufactured in the UK). Therefore, these carbon savings are excluded when computing cost-effectiveness estimates (CJC Consulting, 2014, p. 27).

Combustion of end-of-life wood products

CJC Consulting (2014) also contend that carbon savings associated with the combustion of wood products at the end of their life cycles are both uncertain and relatively minor. It is for this reason that these savings are also excluded when computing cost-effectiveness estimates (CJC Consulting, 2014, p. 25).

Aggregate carbon benefits

CJC Consulting (2014) made estimates of aggregate abatement based on recent regional woodland creation rate patterns, and expert opinion regarding anticipated future shares of different types of woodland being created in each country. Forestry options are ordered in terms of their cost-effectiveness to create a forestry MACC.

The level of carbon savings associated with the forestry MACC are not entirely clear from a preliminary reading of the report. The Executive Summary reports total annual carbon savings associated with the MACC to the year 2200 of 3.4 $MtCO_2e$ (CJC Consulting, 2014, p. 6). However, the main text of the report states that a planting rate of around 12 750 ha per year, consisting of forestry options costing up to £100 tCO_2e^{-1}, results in an abatement of 3.3 $MtCO_2e$ (CJC Consulting, 2014, p. 51); and that all the forestry options reported result in cumulative net carbon savings of 3.664 $MtCO_2e$ (CJC Consulting, 2014, Table 6.4). Although this is of a similar magnitude to the figure reported in the Executive Summary (3.4 $MtCO_2e$) which is stated as an annual benefit, neither the carbon savings of 3.3 $MtCO_2e$ nor 3.664 $MtCO_2e$ are explicitly stated in the main text of the report as being an annual benefit.

To help interpret the estimates of aggregate carbon savings, two other items of information are needed: (1) a single planting date (2014) is reported as being used for developing the MACC in order to reduce computational complexity and ease interpretation of the results (CJC Consulting, 2014, p. 11); and (2) the mean carbon saving weighted by planted area for all the forestry options covered is 237 $tCO_2\ ha^{-1}$ (CJC Consulting, 2014, Table 6.4). One explanation which is consistent with both (1) and (2) is that the 3.664 $MtCO_2e$ value recorded in Table 6.4 represents the total cumulative carbon savings (associated from planting 15 490 ha in 2014) for the entire 186-year period up to 2200. (The area-weighted mean of 237 $tCO_2\ ha^{-1}$ is calculated by dividing 3.664 $MtCO_2e$ by the 15 490 ha planted). A second, albeit less plausible, explanation is that the 15 490 ha per year planting rate is assumed to continue annually until 2200 (resulting in a total planting area of 2.9 million ha). The 3.664 $MtCO_2e$ is therefore interpreted as an annual saving that is equivalent to the cumulative saving over the 186-year period (since it relates to the assumed rate of planting associated with each year). For each interpretation, the 3.664 $MtCO_2e$ aggregate of carbon savings is in effect also the estimated cumulative carbon savings over the 186-year period associated with planting 15 490 ha. However, taking into consideration interest in the implications of planting rates continuing into the future, the extra information provided by the second interpretation of estimating 3.664 $MtCO_2e$ as the potential annual carbon benefit (if a total of 2.9 million ha were planted) is noteworthy.

By contrast, interpreting 3.664 $MtCO_2e$ as the cumulative carbon saving over 186 years, associated with an assumed planting date of 2014 and a sustained planting rate of 15 490 ha per year until 2200 (i.e. a total area of 2.9 million ha), would be inconsistent with the carbon savings estimated per ha (CJC Consulting, 2014, Table 6.4). It would imply carbon benefits of only 1.3 tCO_2 ha^{-1}, which would be inconsistent with the estimates provided for the 88 forestry options listed in Table 6.4 (CJC Consulting, 2014, pp. 52-5) of over 60 tCO_2 ha^{-1} in each case. (The highest estimated mean retention for the period up to 2200 is 530 tCO_2 ha^{-1} for broadleaved woodland on mineral gley soil in South-East England (planted on previously arable land and managed for game and biodiversity); the maximum for the period up to 2050 is 210 tCO_2 ha^{-1} for lowland conifers on a mineral gley soil planted on arable land in the east of England).

The basis for the total annual carbon savings of 3.4 $MtCO_2e$ as reported in the Executive Summary (CJC Consulting, 2014, p. 6) is unclear. One possibility is that it relates to options costing up to £101 tCO_2^{-1} in Table 6.4, alluding to a previous study using £100 tCO_2^{-1} as a benchmark for judging cost-effectiveness; this can therefore be attributed to a rounding-up error. Another possibility is that it is simply a mistake and should actually be given as 3.664 $MtCO_2e$ (and if interpreted as being based upon a sustained planting rate of 15 490 ha per year over the entire time period, with an assumed planting date of 2014 in each case, it would then be correctly stated as an annual benefit).

In light of the time profile for carbon changes, with savings generally being lower for a shorter time span post-planting (and indeed often negative for the first few years), then low carbon savings in the first few years post-planting help explain the study's observation that 'Analysis revealed that woodland creation could make no useful contribution to meeting short-term policy targets' (CJC Consulting, 2014, p. 1). This finding is mentioned specifically in relation to the 2020 target (CJC Consulting, 2014, p. 11), although the estimates reported also suggest that the same finding is applicable to many other forestry options over the medium term until 2050 (CJC Consulting, 2014, Table 5.2).

Eory *et al*. (2015) estimate aggregate carbon benefits by multiplying the weighted average abatement rate by the area afforested. Weightings are based upon the shares of the different species and YC categories planted on different soil types in each country, with shares of mineral and organo-mineral soils based on Forestry Commission estimates. Percentages for different soil types planted in Eory *et al*. (2015, Table 101) do not add up to 100% for Scotland or Wales; also, the soil-type columns for Wales have identical headings, so the actual split is unclear in those cases (although certain similarities for some figures suggest that the percentage splits may be the same as those provided for Northern Ireland). The total annual carbon savings of 3.6 $MtCO_2e$ per year associated with planting a total of 336 000 ha up to 2035 are estimated – and imply a mean of 11 tCO_2 ha^{-1} per year. An example provided for England (Eory *et al*., 2015, Table 108) shows mean benefits per ha of similar orders of magnitude to those in CJC Consulting (2014) of 298 tCO_2 ha^{-1}, but for a time period of 100 rather than 186 years. Direct comparisons are hampered by the abatement being discounted (Eory *et al*., 2015, p. 39).

Despite apparent similarities in the orders of magnitude of aggregate carbon savings per ha, large differences in the estimated aggregate carbon benefits on a national scale between the two studies appear to be difficult to reconcile. When comparing the CJC Consulting (2014) results for 2030 ('no useful contribution') with their own estimate of 1.8 $MtCO_2e$ per year for 2030, Eory *et al*. simply note that estimates are 'sensitive to the assumptions made' (2015, p. 129).

Other benefits and costs

In contrast to the CJC Consulting (2014) study, the Eory *et al*. (2015) study does not include other benefits or costs when making cost-effectiveness estimates. They argue that if timber revenues were included then the estimates for options 40–50 years post-planting (including clear felling) would become highly sensitive to the discount rate assumed (Eory *et al*., 2015, p. 131).

Timber revenues

In the absence of forecasts for timber prices or exchange rate movements, CJC Consulting (2014) estimate future timber revenues from current timber prices by size-grade assortment based upon price-size curves. One exception to this procedure is SRF, for which a standing sale price of £50 per tonne is assumed. Separate price-size curves for conifers are estimated for England, Scotland and Wales utilising Forestry Commission standing sales prices for 2011–12 and 2012–13 (CJC Consulting, 2014, p. 29). Since no equivalent standing sales data is available for broadleaves, commercial (unpublished) data is used, and price-size curves are '...constructed from typical current prices in the Scottish borders and north of England' (CJC Consulting, 2012, p. 8, footnote 1).

Ancillary benefits

Since both studies claim they are uncertain due to their highly site- and woodland-specific nature, ancillary benefits are excluded from the cost-effectiveness estimates (CJC Consulting, 2014, p. 31). Although no attempt is made to explicitly account for them, Eory *et al*. (2015) do note a range of potential ancillary benefits including recreation, biodiversity, flood alleviation, water and air quality, as well as the potentially negative impact on food security.

Forestry costs

Both studies assume costs are specific to each region. In the CJC Consulting (2014) study, planting and forest management costs are also assumed to be option-specific.

The Eory *et al*. (2015) study assumes costs based upon Forestry Commission data (Table 3). The CJC Consulting study only provides examples of calculations for just three of the options under consideration (CJC Consulting, 2014, Table 4.6). Eory *et al*. include both private and Government administration costs; CJC Consulting do not allow for Government administration costs, but they do include a wider range of forest management costs (in addition to initial planting and fencing costs).

Table 3 Afforestation costs by country.

Country	Planting and fencing (£ ha^{-1})			Government administration (£ ha^{-1})
	Private	Grant	Total	
England	849	4246	5095	637
Scotland	653	3267	3920	490
Wales	848	4242	5090	636
Northern Ireland	480	2400	2880	360

Adapted from Eory *et al*. (2015, Table 102) based upon Forestry Commission data.

In the CJC Consulting (2014) study the highest costs are for England, partly reflecting greater establishment and opportunity costs; the lowest costs are for Scotland. (Note that the CJC Consulting study doesn't extend to Northern Ireland). Examples of costs are provided for three cases (CJC Consulting, 2014, Table 4.6). In Present Value terms, these range from £9000 ha^{-1} for upland conifers in Scotland to £31 000 ha^{-1} for broadleaved woodland managed for biodiversity and game in South West England; costs for farm woodland in Wales are approximately £13 000 ha^{-1}.

Differences in the aggregate costs assumed in both studies reflects the range of categories under consideration, as well as the sources used for making estimates. These differences in aggregate costs appear largely attributable to the higher establishment (including fencing) and wider forest management costs which are included in the CJC Consulting study.

Agricultural opportunity costs

In the majority of cases, similar estimates of agricultural opportunity costs are used in both studies (Table 4). With no available information to account for environmental or food security issues, the CJC Consulting study utilises estimates which allow for cost savings in estimating the reduction in gross margins, as well as the use of land of lower productivity (CJC Consulting, 2014, p. 35). By contrast, Eory *et al*. note that income before subsidies on most of the lower productivity land likely to be afforested may well be low or negative (Eory *et al*., 2015, p. 132).

Table 4 Agricultural opportunity costs.

Country	CJC Consulting (£ ha^{-1} per year)	Eory *et al.* (£ ha^{-1} per year)
England	220–350[a]	220
Scotland	100–120[b]	120
Wales	220	350
Northern Ireland	–	100

Notes: a. The authors contend that these opportunity costs do not include any subsidies because the Single Farm Payment is transferred separately when land is sold' (CJC Consulting 2014, footnote 128, p.35).; b. lower estimate for Highlands and Islands.

Discount rates and total costs

The CJC Consulting study (2014, Table 2.1) utilises the Treasury's Green Book discount rates, which decline stepwise from 3.5%–2% over the 186-year time period. The Eory *et al*. study (2015) adopts two fixed rates, 3.5% and 7%.

The discount rate chosen affects the Present Value of costs incurred in subsequent years. Over the 100-year period considered by Eory *et al*., discounted aggregate cost estimates (for the combined forestry and agricultural opportunity costs) range from £6100 ha^{-1} in Northern Ireland up to £15 700 ha^{-1} in Wales with a 3.5% discount rate, with lower values of £4800–11 000 ha^{-1} with a 7% discount rate.

Only a small proportion of the difference in aggregate discounted costs per hectare compared to those assumed by Eory *et al*. (2015) can be explained by the longer 186-year period adopted by CJC Consulting (2014, Table 4.6).

Cost-effectiveness

The CJC Consulting study proposes two approaches to estimating the cost-effectiveness of forestry options for climate change mitigation: (1) cost-effectiveness in physical terms, calculated by dividing the negative of the Net Present Value (NPV) of the forestry option (excluding the carbon benefits) by the total amount of carbon saved; and (2) cost-effectiveness in terms of value, computed by dividing the negative of the NPV of the forestry option (excluding the carbon benefits) by the Present Value of the carbon saved.

1. Cost-effectiveness in 'physical' terms:

$CE = -(NPV - PV\{C\})/\Delta C$

CE: Cost effectiveness (£ per tCO_2e)
NPV: Net present value of the forestry option (£)
PV{C}: Present Value of carbon benefits of option (£)
ΔC: Total carbon savings associated with option (tCO_2e)

2. Cost-effectiveness index in 'value' terms:

$I_{CE} = -(NPV - PV\{C\})/PV\{C\}$

I_{CE} = Cost effectiveness Index
NPV = Net present value of the option (£)
PV{C}: Present Value of carbon benefits of option (£)

The first of these two approaches adopts a similar indicator to that used in current UK Government guidance for estimating cost-effectiveness (DBEIS, 2014, p. 26; DBEIS, 2018, p. 25). However, UK Government guidance subtracts only the Present Value of carbon savings for the (traded or non-traded) sector under consideration, but not those carbon savings which arise in the other sector; by contrast, the Present Value of all carbon savings (across both traded and non-traded sectors) is subtracted in the CJC Consulting calculation. UK Government guidance recommends comparing the estimated cost-effectiveness indicator with a benchmark figure which varies according to both the time profile and the associated social values of carbon (e.g. those for the non-traded sector if this is where the savings mainly arise). An option is considered to be cost-effective if the estimated cost-effectiveness indicator is lower than the benchmark cost-comparator.

The benchmark cost-comparator recommended by the UK Government is equivalent to the Present Value of carbon savings divided by the total carbon savings in the sector under consideration (DBEIS, 2018, p. 26). Therefore, the benchmark figure implies that an option is cost-effective if the negative of the NPV of an option (excluding the carbon benefits) – i.e. the net cost – divided by the Present Value of the carbon saved in the sector being considered is less than one. It is for this reason that in the case of options involving carbon savings in only one sector, for example just in the non-traded sector, the second of the CJC Consulting approaches described above in which estimates are considered cost-effective if they are less than or equal to one gives equivalent results when judging their cost-effectiveness to applying UK Government guidance.

Differences with current UK Government guidance are expected in cases where woodfuel is produced as any benefits arising in the traded sector are not distinguished from benefits arising in the non-traded sector in the CJC Consulting approach. Any divergence is due to three factors: (1) the combined Present Value of carbon savings in both the traded and non-traded sectors are subtracted when calculating the NPV (excluding carbon savings). This reduces the NPV excluding the carbon benefits, which in turn increases the value of the numerator in the cost-effectiveness equation (since the numerator is the negative of the NPV value); if all other factors remain equal then this would make the CJC Consulting estimates less cost-effective; (2) both the traded and the non-traded sectors are included in the total carbon savings accounted for, which increases the level of carbon abatement under consideration (represented by the denominator in both the UK Government approach and the first of the CJC Consulting approaches described earlier). In cases where an option is associated with a positive NPV (i.e. the numerator is positive) then the magnitude of the cost-effectiveness estimate is reduced; if all other factors remain equal then this makes the CJC Consulting estimates more cost-effective; and (3) carbon savings in both the traded and non-traded sector are accounted for when calculating the present value of carbon savings (the denominator in the second of the CJC approaches described earlier). For options associated with a positive net cost, the effect of this would be to reduce the magnitude of the cost-effectiveness estimates, making them appear more cost-effective. (This is similar to including both sectors in the estimated total carbon savings, as adopted by the first of the two CJC approaches described earlier.)

In summary, for options which do not include woodfuel production, the cost-effectiveness estimates given in the CJC Consulting study (2014, Table 6.4) should be the same as those derived by applying current UK Government guidance. The same judgements about which are cost-effective also applies to options shown in Table 9.1 (CJC Consulting, 2014, Annex II): those options which are deemed to be cost-effective (those with a negative NPV-to-carbon savings ratio below 1) are highlighted in blue, and those which are not considered cost-effective (with a ratio above 1) are shown in green.

By contrast, for options including woodfuel, the results in the CJC Consulting study (2014, Tables 6.4 and 9.1) would differ from those obtained if current UK Government guidelines were applied. The overall effect of the factors associated with the different treatment of carbon savings in the traded sector cannot be easily determined given opposing influences. If woodfuel accounted for a very small proportion of the total carbon savings associated with an option, then the overall impact of adopting the CJC Consulting approach (rather than the UK Government's) would be marginal. However, woodfuel is the primary output for SRF options, and it has also contributed a major share of the carbon savings in the conifer options under consideration (CJC Consulting, 2014, p.59). Therefore, for SRF and conifer options, concordance between the CJC Consulting results and those based upon UK Government guidance is unlikely.

Cost-effectiveness estimates in the CJC Consulting study are reported for the longer time period to 2200. Estimates in the forestry MACC range from £21 tCO_2e^{-1} for lowland conifers in England to £245 tCO_2e^{-1} for broadleaved woodland managed for timber and carbon in South West England; a wider range including options not considered cost-effective is reported (CJC Consulting, 2014, Table 9.1, Annex 2). The results for the forestry MACC are summarised in Table 5.

Of the 98 forestry options under consideration, 70 are reported to be cost-effective at DBEIS social values of carbon (central estimates); 46 options will be cost-effective if the low social values of carbon are adopted (CJC Consulting, 2014, p.56). Comparing the cost-effectiveness of different options requires care since specification of the options for any given forest type varies regionally (CJC Consulting, 2014, p.45). In addition, direct comparisons are hampered by the options having been chosen to reflect different site conditions, rather than as alternatives for a particular site.

Eory *et al*. (2015, p.39) compute cost-effectiveness by dividing the negative of the NPV of the option (excluding carbon) by the discounted lifetime abatement (i.e. the sum of the discounted annual carbon savings). Estimates are provided for 2030–5 for different countries and discount rates, but not for different options. The estimates range from £16 tCO_2e^{-1} for Northern Ireland at a 7% discount rate to £51 tCO_2e^{-1} for Wales at a 3.5% discount rate (Eory *et al*., 2015, Table 104). The woodland creation options are for a species mix similar to the farm

Table 5 Net carbon sequestration and cost-effectiveness of woodland creation options.

Woodland creation	Country	Net carbon sequestration		Cost-effectiveness to 2200 (£ tCO_2e^{-1})
		to 2050 (tCO_2e)	to 2200 (tCO_2e)	
Short rotation forestry (SRF) for energy 15-year rotation	England	-35 to 91	68 to 224	188 to 366
	Scotland	-51 to -6	7 to 80	229 to 3162
	Wales	-35	68	337
Short rotation forestry (SRF) for energy 25-year rotation	England	9 to 135	195 to 351	82 to 132
	Scotland	-13 to -44	134 to 208	45 to 107
	Wales	10	201	80
Farm woodland for mixed objectives	England	42 to 164	143 to 314	48 to 96
	Scotland	0 to 66	84 to 229	40 to 108
	Wales	46	143	72
Broadleaf woodland for game and biodiversity	England	-5 to 126	320 to 530	61 to 84
	Scotland	-41 to 4	195 to 297	32 to 46
	Wales	-5	320	42
Broadleaf woodland for timber and carbon	England	6 to 159	106 to 285	140 to 245
	Scotland	-15 to 30	77 to 136	101 to 148
	Wales	6	106	167
Upland conifer for timber	England	61 to 98	284 to 337	27 to 33
	Scotland	37 to 81	244 to 304	26 to 30
	Wales	85	331	30
Lowland conifer for timber	England	67 to 210	288 to 501	21 to 46
	Scotland	39 to 72	240 to 269	27 to 28
	Wales	85	331	39
Continuous cover forestry for mixed objectives	England	49 to 196	309 to 452	50 to 88
	Scotland	-7 to 60	189 to 288	32 to 56
	Wales	66	344	46

Adapted from CJC Consulting (2014, Table 5.2); also refer to CJC Consulting (2014, Table 6.4).

woodland managed for the mixed objectives category in the CJC Consulting study (Table 1). Although the two studies are not directly comparable due to differences in the species mix and the time periods under consideration, their findings can be tentatively compared: the cost-effectiveness estimates in CJC Consulting (2014) for farm woodland managed for mixed objectives range from £40–108 tCO_2e^{-1}.

Greater cost-effectiveness (i.e. lower estimates of £ tCO_2e^{-1}) is expected for Eory *et al*. (2015) rather than CJC Consulting (2014) given the higher estimates of abatement potential and lower costs being assumed; however, the shorter time period could have the opposite effect, as could using discounted carbon savings as the denominator. If the same time period had been used, the divergence in estimates between the two studies should be larger. This is because a longer time period tends to increase the cost-effectiveness (i.e. lower estimates of £ tCO_2e^{-1}) of woodland creation for climate change mitigation as a consequence of increased carbon sequestration, with little change in the Present Value of costs. (For a comparison of cost-effectiveness estimates over two time periods within a single study, refer to CJC Consulting, 2014, Table 5.2.)

Discussion and recommendations

Estimates in both the CJC Consulting (2014) and Eory *et al*. (2015) studies suggest, that over the longer term, woodland creation is usually cost-effective in comparison to UK social values of carbon, albeit with some exceptions in the former study. Estimates in both studies suggest that woodland creation is less cost-effective than estimates made in previous studies; for example, estimates in Moran *et al*. (2008) are negative, implying that woodland creation has a positive NPV prior to the net carbon savings being accounted for. One reason for relatively high estimates is the assumption that timber prices are constant in real terms, compared to an annual increase of 2.5% in real terms (Moran *et al*., 2008); however, CJC Consulting argue that a 2.5% annual increase is unrealistic since it implies a 100-fold increase in the timber price between 2014 and 2200 (CJC Consulting, 2014, p. 56). Higher carbon substitution benefits are also assumed in Moran *et al*. (2008) in comparison to CJC Consulting (2014), with the former based upon estimates from Forest Research's carbon accounting models. Although comprehensive information on forestry costs is lacking in CJC Consulting (2014), the examples cited suggest those estimates are far higher than those made by Moran *et al*. (2008) of £1250 ha^{-1}. (For further discussion of estimates in earlier studies, refer to Valatin (2012) and Valatin and Price (2014).) The commercial sensitivity of estimates may in some instances preclude publishing more detailed information about costs, but the provision of summary information is essential for making comparisons with other studies and to allow the same approach to be adopted by other studies in the future. A primary reason why estimates in CJC Consulting (2014) suggest that woodland creation is less cost-effective than those in Eory *et al*. (2015) appears to be different cost assumptions.

The first four recommendations that follow refer primarily to future analysis and policy evaluation.

Recommendation 1: A comprehensive summary of costs and the key assumptions underpinning estimates should be provided to facilitate comparisons with previous studies and help develop future work.

A discussion of the merits of different approaches to estimating carbon savings associated with the use of woodfuel and wood products is beyond the scope of this report. Further discussion can be found in Valatin (2017). However, the approach adopted in the CJC Consulting (2014) study implies far lower estimates of these savings than those made by Forest Research's CSORT model – largely due to the exclusion of carbon substitution benefits resulting from using wood instead of more fossil-fuel intensive products such as concrete and steel. This divergence is partly related to assumptions made about the future de-carbonisation of the UK economy. The approach adopted in the CJC Consulting (2014) study differs markedly from the approach adopted for the UK's Greenhouse Gas (GHG) inventory (Griffin, Bailey and Brown, 2014); the latter is based upon the CARBINE model (http://www.forestry.gov.uk/fr/infd-633dxb), which makes similar assumptions to CSORT.

Recommendation 2: Develop an approach that consistently reflects abatement available through the use of harvested wood products and end of life disposal.

Both the CJC Consulting (2014) and the Eory *et al*. (2015) studies focus upon constructing a MACC rather than comparing forestry options, and a range of assumptions were made to reflect varying environmental conditions across Great Britain. As noted by CJC Consulting (2014, p.45), a comparison of the cost-effectiveness of different forestry options for specific land areas is hampered by the different cost and yield assumptions which underpin those options. However, future work could potentially be designed to enable explicit comparisons between at least a subset of forestry options.

Recommendation 3: Where comparing the cost-effectiveness of different options for one area of land is important, consideration should be given to options which are alternatives for the selected site(s).

Neither the CJC Consulting (2014) nor the Eory *et al*. (2015) study exactly follows DBEIS guidance in estimating cost-effectiveness. Although the difference reported in the former only relates to cases where thinning or harvesting results in woodfuel use in sectors covered by the EU's Emission Trading System and could therefore be minor, the extent to which adopting the DBEIS approach would have altered the results in these reports is unclear.

Recommendation 4: To improve comparability, consideration should be given to adopting the approach to estimating cost-effectiveness recommended by the UK Government.

Research gaps

Several research gaps were identified in the CJC Consulting (2014) study, leading to suggestions for further work on: (1) the effects of afforestation on soil emissions, especially from organo-mineral soils (CJC Consulting, 2014, p. 22)[1]; (2) carbon savings associated with using wood products instead of other materials such as concrete and steel (CJC Consulting, 2014, p. 27); (3) carbon savings associated with the combustion of wood products at the end of their life cycle (CJC Consulting, 2014, p. 25); (4) the magnitude and spatial distribution of ancillary benefits; and (5) the performance of SRF under different management systems (CJC Consulting, 2014, p. 51).

A number of evidence gaps are implicit in the CJC Consulting (2014) study, including: (1) current prices for broadleaves; (2) forecasts for future timber prices of both broadleaves and conifers (both by species and timber-size grade); (3) levels of agricultural opportunity costs accounting for environmental and food security issues; and (4) optimal rotation lengths for forestry options involving clear-felling.

Of these, levels of agricultural opportunity costs are the most critical omission because they typically comprise a large proportion of the total costs.

Recommendation 5: Further research on the agricultural opportunity costs associated with woodland creation is a priority. Research should ideally include analysis of the actual impact of woodland creation on agricultural income and land values by drawing upon data generated from farm surveys. Better information on forestry costs and spatial variations between options would also be useful.

Although not accounted for in either the CJC Consulting (2014) or the Eory *et al*. (2015) study, another critical issue is the magnitude of ancillary benefits, as well as their spatial and temporal distribution. Some research illustrates how the inclusion of ancillary benefits can lead to forestry options being cost-effective before the climate change mitigation benefits are taken into account. For example, Nisbet *et al*. (2015) reported a climate change cost-effectiveness estimate for woodland creation measures of -£2 tCO_2e^{-1} for the 'Slowing the Flow' flood risk reduction project in North Yorkshire.

Recommendation 6: To derive more comprehensive cost-effectiveness estimates of forestry options for climate change mitigation, further research on the magnitude (and the spatial and temporal distribution) of the ancillary benefits of woodland creation is a priority. This could build upon recent work by Binner *et al*. (2017). Research to include the influence of wider factors such as albedo, evapotranspiration, and volatile organic compounds affecting climate change, would also be valuable.

Work planned at Forest Research on the cost-effectiveness of forestry options for climate change mitigation is expected to follow these recommendations. Other ongoing projects at Forest Research – for instance, in relation to soil carbon and the biophysical impacts of forests on climate forcing – address specific knowledge gaps, and the results of that work will enhance the evidence base underpinning future research on the cost-effectiveness of forestry options.

1. Carbon removals by soils is also an important topic that needs further research.

References

BINNER, A., SMITH, G., BATEMAN, I., DAY, B., AGARWALA, M. and HARWOOD, A. (2017). *Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales*. Research Report. Forestry Commission, Edinburgh.

CJC CONSULTING (2012). *Study to assess investment returns in woodland creation in Great Britain*. Report to the Forestry Commission. CJC Consulting Ltd, Oxford.

CJC CONSULTING (2014). *Assessing the cost-effectiveness of woodlands in the abatement of carbon dioxide emissions*. Final Report to the Forestry Commission. CJC Consulting Ltd, Oxford.

DBEIS (2018). *Valuation of energy use and greenhouse gas. Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government*. [Internet], Department for Business, Energy and Industrial Strategy, London. [latest version available at: www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal].

DECC (2014). *Valuation of energy use and greenhouse gas (GHG) emissions. Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government*.

[Internet.] Department of Energy and Climate change, London. [http://qna.files.parliament.uk/qna-attachments/101832/original/20141001_2014_DECC_HMT_Supplementary_Appraisal_Guidance.pdf] [latest version available at: www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal].

EORY, V., MACLEOD, M., TOPP, C.F.E., REES, R.M., WEBB, J., MCVITTIE, A., WALL, E., BORTHWICK, F., WATSON, C., WATERHOUSE, A., WILTSHIRE, J., BELL, H., MORAN, D. and DEWHURST, R. (2015). *Review and update the UK Agriculture Marginal Abatement Cost Curve to assess the greenhouse gas abatement potential for the 5th carbon budget period and to 2050*. Final Report to the Committee on Climate Change. SRUC / Ricardo-AEA, Edinburgh.

FORESTRY COMMISSION (2015). *Woodland Carbon Code Carbon Lookup Tables*. Version 1.5. Forestry Commission, Edinburgh.

GRIFFIN, A, BAILEY, R. and BROWN, P. (2014). *An Introduction to the UK's Greenhouse Gas Inventory*. [Internet], Ricardo-AEA/DECC, Didcot. [www.gov.uk/government/publications/uk-greenhouse-gas-emissions-statistics-user-guidance].

IPCC (2003). *Good Practice Guidelines for Land Use, Land-Use Change and Forestry.* [Internet], Intergovernmental Panel on Climate Change. Institute for Global Environmental Strategies, Kanagawa, Japan. [www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html].

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* [Internet], Intergovernmental Panel on Climate Change. [www.ipcc-nggip.iges.or.jp/public/2006gl].

MORAN, D., MACLEOD, M., WALL, E., EORY, V., PAJOT, G., MATTHEWS, R., MCVITTIE, A., BARNES, A., REES, B., MOXEY, A., WILLIAMS, A. and SMITH, P. (2008). *UK Marginal Abatement Cost Curves for agriculture and land use, land-use change and forestry sectors out to 2022, with qualitative analysis of options to 2050*. Final Report to the Committee on Climate Change. SAC, Edinburgh.

NISBET, T., ROE, P., MARRINGTON, S., THOMAS, H., BROADMEADOW, S. and VALATIN, G. (2015). *Slowing the Flow at Pickering*. Final Report to Defra of FCERM Multi-objective Flood Management Demonstration Project RMP5455, Phase II. Defra, London.

UNFCCC/CNUCC (2011) *A/R Methodological Tool. Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*. Executive Board Report 60, Annex 12. [Internet] Clean Development Mechanisms Executive Board, United Nations Framework Convention on Climate Change. [https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-16-v1.1.0.pdf/history_view].

VALATIN, G. (2012). *Marginal abatement cost curves for UK forestry*. Research Report. Forestry Commission, Edinburgh.

VALATIN, G. (2017). *Harvested Wood Products and Carbon Substitution: approaches to incorporating them in market standards*. Forest Research, Farnham, Surrey.

VALATIN, G. and PRICE, C. (2014). How cost-effective is forestry for climate change mitigation? In: T. Fenning (ed). *Challenges and Opportunities for the World's Forests in the 21st Century*. Springer, New York. pp. 297-339.

WEST, V. (2011). *Soil Carbon and the Woodland Carbon Code*. Forestry Commission, UK.

Enquiries relating to this publication should be addressed to:

Gregory Valatin
Forest Research
Alice Holt Lodge
Farnham
Surrey, GU10 4LH
+44 (0)300 067 5699

gregory.valatin@forestry.gsi.gov.uk
www.forestry.gov.uk/forestresearch

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