Forest Research

Harvested Wood Products and Carbon Substitution:

approaches to incorporating them in market standards

Gregory Valatin

The Research Agency of the
Forestry Commission

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Summary

Launched in 2011, the Woodland Carbon Code (Forestry Commission, 2014) covers the carbon sequestration benefits of planting new woodlands. It does not currently extend to carbon storage in harvested wood products, or to carbon substitution benefits.

This report reviews existing approaches under carbon market standards to accounting for (i) the carbon storage and (ii) the carbon substitution benefits of harvested wood products (HWP). For carbon storage benefits, protocols applying to forestry projects are reviewed. For the carbon substitution benefits, protocols for renewable energy projects that cover woodfuel use are also considered.

Harvested wood products

The carbon storage benefits review focuses on four carbon standards - the American Carbon Registry Forest Carbon Project Standard (ACRFPS), the California Air Resources Board (ARB), the Climate Action Reserve (CAR), and the Verified Carbon Standard (VCS). The main findings are:

- Approaches to determining baseline emissions (the assumed trajectory of emissions in the absence of a project) vary. Compliance with wider legal requirements is the most frequent basis, being used under three standards (ARB, CAR, and VCS in some cases), with historical records, or common practice, sometimes used instead (VCS). In one case (ACRFPS), baseline emissions are set by using economic optimisation.

- In all cases a 100-year time horizon is used in accounting for the carbon benefits of harvested wood products. Wood products with a longer life-time are assumed to store carbon permanently. Those with a shorter life-time are assumed either to release the carbon stored immediately (e.g. wood co-product at sawmills), or over a fixed period (e.g. 20 years).

- In each case the project developer - generally the forest owner, receives the carbon credits.

Recommendations in considering potential for extending the Woodland Carbon Code to carbon storage benefits of HWP include:

- consider adopting a system of temporary carbon units based on the expected lifespan of different product types (softwood, hardwood, etc).

- consider adopting a simple approach that accounts for carbon storage benefits over a fixed time horizon (e.g. the longest lifespan of the different product types).

- for each product category, consider applying a simple decay function to the carbon stored.
- consider how transport emissions can best be included in estimating the net carbon savings and the extent to which incentives for local processing and use of wood products arising from inclusion of transport emissions could help increase overall carbon benefits to society.
- explore potential mechanisms to allocate carbon units for storage in wood products between woodland owners and wood users that provides incentives to increase the supply and quality of wood and the carbon storage benefits per unit of wood used.
- explore the costs and benefits of empirical monitoring of carbon storage benefits.
- consider potential double-counting issues further and how these can be minimised.

Carbon substitution

The review of approaches to accounting for carbon substitution benefits found:

- none of the protocols for forest projects currently cover carbon substitution benefits (either associated with use of wood instead of more fossil-fuel intensive materials such as concrete and steel, or as a source of energy in place of fossil fuels).
- carbon substitution benefits of woodfuel use is covered by several renewable energy project protocols – three under two voluntary carbon standards and three under the United Nations Clean Development Mechanism (CDM).

A review of the six renewable energy protocols found:

- the forests where the biomass originates are seldom taken into consideration, with only one protocol covering activities within the forest.
- greenhouse gas (GHG) savings are estimated based upon ‘emissions factors’. These represent emissions per unit of input. The factors used differ under different protocols. They include emissions per unit of energy generated for electricity and for different types of fossil fuel, and transport emissions per kilometre travelled, or fuel type.
- the protocols focus mainly on carbon dioxide (CO_2), but with accounting extending to nitrous oxide (N_2O) and methane (CH_4) in some cases
- uncertainty is relatively high in some cases, with a default of 300% uncertainty assumed for CH_4 emissions from combustion of biomass residues.

- The forms of leakage (increased GHG emissions outside the project boundary attributed to the project) accounted for include diversion of biomass from other uses, shifts in deforestation, and shifts in other activities. Those accounted for differ between the protocols, with the differences in part reflecting the different project types covered.

- the project developer running the renewable energy plant – who is generally not the forest owner, receives the carbon credits.

- none of the protocols currently account for rebound effects – perhaps because they are complex and costly to estimate, and evidence is limited. However, failure to account for these effects – particularly in relation to impacts on fossil fuel prices and overall energy use, represents a significant potential weakness in accounting for carbon substitution benefits. no evidence on empirical monitoring or other costs of accounting for carbon substitution benefits.

- existing protocols under the voluntary carbon standards are narrower in scope than those under the CDM, with two limited to use of forest residues, and one to thermal applications of woodfuel in manufacturing.

Prior to further consideration of whether to extend the Woodland Carbon Code to carbon substitution benefits, it is recommended to:

- explore existing international trade and inter-sectoral models with the aim of quantifying the magnitude of rebound and leakage effects associated with use of UK-grown wood.

Where rebound and leakage effects are considered minor, similar recommendations are made to those for carbon storage:

- explore potential mechanisms that involve sharing the carbon units issued between landowners and wood users in order to increase incentives for carbon substitution and the overall expected net benefits to society.

- explore the costs and benefits of empirical monitoring of carbon substitution benefits.

- consider potential double-counting issues further and how these can be minimised.

1. Introduction

A key factor determining the level of greenhouse gas (GHG) savings associated with a particular project or activity is which impacts are accounted for. Apart from forestry projects locking up carbon in the forest, any harvested wood products (HWP) can act as a carbon store, substitute for more fossil carbon-intensive materials such as concrete and steel, and displace fossil fuels in energy production.

The Woodland Carbon Code, launched in 2011 to help underpin woodland carbon projects in the UK, covers the carbon sequestration benefits of planting new woodlands (Forestry Commission, 2014). It does not extend to harvested wood products or carbon substitution benefits at present, so currently provides no incentive for landowners or investors to take these wider carbon benefits of forestry projects into account in planting new woodlands.

There are several potential reasons why covering a broader range of carbon benefits could be considered desirable. Incentives for planting new woodlands that focus upon increasing carbon sequestration may fail to maximise overall carbon benefits, and even may provide perverse incentives in some cases. (This could occur where incentives for carbon sequestration lead to the creation of woodlands with less wood harvesting and consequently less carbon storage in HWP and carbon substitution than otherwise would have occurred, if the reduction in these carbon savings is greater than the increased carbon sequestration accounted for in issuing carbon credits – see: Valatin, 2012). Furthermore, the wider the coverage of climate impacts taken into account, the more complete estimates of the impacts would be, and the more attractive forestry might be expected to be compared to alternative options. Product and energy substitution are also considered by many as more effective long-term climate change mitigation strategies than sequestration (e.g. Niles and Schwarze, 2001) – although this will also depend upon the rate at which energy and construction sectors become more efficient in use of fossil fuels, and any end-of-pipe carbon sequestration and storage technologies introduced.

Whether extending the Code to cover carbon impacts associated with use of harvested wood products would be worthwhile could be expected to partly depend on the precision and cost of monitoring those impacts. Once harvested, wood is subject to a range of processes and has a wide variety of end uses. The associated carbon savings depend not just upon the specific end use, material displaced and efficiency of use, but also upon wider (e.g. ‘leakage’ and ‘rebound’) effects. In addition, how extending the Code would fit with wider GHG accounting and standards in downstream sectors needs to be considered, especially in relation to any potential double-counting issues.

Aims

The overall objectives of this study are:

i) To briefly review methods in use in carbon market transactions to account for i) harvested wood products and ii) carbon displacement benefits of substituting wood for more fossil carbon intensive materials such as concrete and steel, and iii) woodfuel for fossil fuels – including approaches used to address associated uncertainties, leakage and rebound issues.

ii) To consider appropriate methodologies that might be used were the Woodland Carbon Code to be extended to harvested wood products and the associated carbon substitution benefits;

iii) To identify existing research gaps and suggest how these could be filled.

Methodology

A bibliographic and web search, and literature and methodological review were undertaken to identify and compare existing approaches in use to account for the wider carbon benefits of harvested wood products associated with forestry projects. As no carbon standards were identified that currently cover carbon substitution benefits of forestry projects associated with use of wood resulting in saving fossil fuels, the review was subsequently widened to encompass approaches to carbon substitution benefits of woodfuel use in renewable energy projects.

Structure

The next section discusses some of the key concepts and issues. Section 3 reviews approaches used under existing carbon standards to account for carbon storage in wood products. Section 4 focuses on carbon substitution benefits, reviewing approaches under renewable energy protocols accounting for carbon savings associated with substituting woodfuel for fossil fuels. The final section then discusses the main findings of the reviews and potential for incorporating the carbon benefits of harvested wood products and carbon substitution under the Woodland Carbon Code.

2. Concepts and Issues

A few key issues are briefly outlined in this section, before reviewing approaches adopted under existing carbon standards in the following sections.

Baseline and counterfactual

The baseline against which carbon benefits are assessed is critical in quantifying the climate change mitigation benefits of an activity or project. It is based upon a counterfactual scenario specifying what would occur if a project or activity did not go ahead. As the counterfactual is unobservable, its specification is necessarily uncertain and reliant upon assumptions about what would otherwise have occurred.

Noting that standard terminology is currently lacking, Matthews et al (2014a, p.4) define the counterfactual as 'the emissions that would occur if UK wood was not harvested (and utilised as specified for a particular scenario) and the services that would have been supplied by the harvested wood were provided by other means (i.e. non-wood alternatives or imported wood).' However, there may be an almost infinite number of sources of possible avoided emissions associated with a particular activity (Mensink, 2007). Thus, the breadth of impacts considered usually has to be restricted on pragmatic grounds to those considered most significant. However, the baseline can be sensitive to the breadth of impacts accounted for.

Leakage

While in some cases projects may create positive spillovers that result in a reduction in GHG emissions outside the project area – such as due to a 'demonstration effect' (IPCC, 2000, section 2.3.5.2; see also Valatin and Price, 2014), 'leakage' refers to any increased GHG emissions outside the project boundary attributable to the project. How the project boundary is defined is crucial in determining which impacts constitute leakage (as opposed to simply constituting elements of project emissions).

Projects can lead to increased emissions elsewhere for a variety of reasons. For example, leakage may arise from 'activity displacement', such as where a forest conservation project results in timber harvesting activities shifting from the project area to other areas of forest, or if afforestation of farmland leads to increased emissions from conversion of forests to land for agricultural production elsewhere. It may arise from 'demand displacement' if, for instance, a forest conservation project reducing timber production in a given area leads to demand for increased timber production elsewhere, or for increased imports resulting in deforestation elsewhere. It may arise from 'supply displacement' if, for example, a forest carbon project increases timber production that reduces the profitability of timber production in other areas, leading to deforestation and land conversion elsewhere. Alternatively, it can arise from 'investment crowding' if, for instance, forest carbon projects reduce demand for undertaking other afforestation and reforestation projects.

Leakage is also sometimes used in a more general sense to mean situations where the targeted emissions reductions or sequestration in one place lead to increased emissions or reduced sequestration elsewhere (Murray 2006). For example, falling demand for fossil fuels in countries adopting climate policies may result in lower prices and increased use in other countries ('spatial leakage'). Anticipated reduction in future returns from selling fossil fuels in countries adopting climate policies could provide incentives for suppliers to increase current production ('intertemporal leakage') - for further discussion, see: Fischer and Salant (2012).

In some cases leakage may result in climate policies – including those promoting use of woodfuel or other sources of renewable energy, having no impact on overall GHG emissions, or even lead to higher emissions (the so-called 'green paradox'). Næss-Schmidt, Hansen and Kirk (2012), for example, suggest that putting a price on carbon emissions in Nordic countries would lead to a long-run increase in global emissions due to displacement of production in key Nordic industries such as pulp and paper to other countries. Similarly, Fölster and Nyström (2010) argue that if fossil fuel saved as a consequence of harvest residue substitution is used elsewhere, the net effect could be an increase in carbon emissions due to bringing forward release of the carbon from the residues by 10-30 years, plus emissions from its extraction and transportation.

Rebound effects

Although not always confined to effects occurring at a different location, rebound effects are similar to leakage in implying carbon savings are lower than those associated with the direct impacts of a project. Indeed, some authors consider rebound effects to constitute a form of leakage. Næss-Schmidt, Hansen and Kirk (2012, p.16), for example, define ‘rebound (carbon) leakage’ as the effect of a policy (e.g. putting a price on carbon) on reducing the global energy price and stimulating energy demand and carbon emissions elsewhere. However, rebound effects generally have a different focus to leakage, often relating to energy efficiency measures, changes in relative prices and real incomes.

Increases in GHG emissions in the wider (e.g. national or global) economy associated with the introduction of resource efficiency measures (e.g. Ghosh and Blackhurst, 2014), and related time and cost savings, are frequently referred to as rebound effects. Berners-Lee and Clark (2013, p.49), for example, characterise rebound effects as ‘a metaphor describing the way in which savings from efficiency gains bounce back as additional energy use elsewhere’.

Energy efficiency measures are the focus of definitions used in current UK government guidance on policy appraisal of GHG impacts, for example. These define a ‘direct rebound’ as occurring when consumers use financial savings from more efficient use to purchase more of the same good or service, and an ‘indirect rebound’ effect as associated with expenditure of the savings on other goods or services (DECC and HMT, 2014).

Rebound effects can arise in wider contexts too. Agostini, Giuntoli and Boulamanti (2013), for example, note a number of recent studies suggesting significant rebound effects for carbon substitution, although results are controversial and disputed. Environmental taxes and reduced consumption are also considered to give rise to rebound effects (Alcott, 2008). A broad typology of forms is proposed in the Annex, covering in total over twenty different types of rebound effect.

Rebound effects are generally quantified as the proportion of the forecast GHG savings which are not realized (Gillingham, Rapson and Wagner, 2014). As with leakage, estimates in wider contexts suggest that the negative carbon impacts of a measure could, in aggregate, exceed the level of the initial carbon saving in some cases – a phenomenon sometimes referred to as the ‘Jevons paradox’ (see Annex), or ‘backfire’. For example, Chitnis et al. (2014) give a high bound estimate for UK measures reducing food waste of 106% (lower bound 66%, with lower estimated ranges for measures affecting vehicle fuel use [25-66%], and domestic energy use [0-32%]). ‘Backfire’ can arise, for example, if money saved by consumers associated with greater resource efficiency (e.g. reduced food waste) is then spent on high carbon emissions activities (e.g. holiday flights). By contrast, similar to cases of positive spillovers noted in discussing leakage, in some cases rebound effects may be negative (leading to greater than expected carbon savings)– for example if measures mandated by regulation are more costly than existing technologies.

Ownership rights

The carbon benefits associated with harvested wood products and substitution of fossil fuel use depend primarily upon processes that occur outside the forest. Decisions taken by multiple, often unrelated, parties generally influence the extent of these benefits.

Given dependence upon wider actors, the question arises as to whether the forest owner should be able to claim ownership of rights to part of the associated carbon benefits. Although they do not determine the carbon substitution benefits of the wood once it leaves the forest, if unrewarded, there is no direct incentive for forest owners to produce types of wood expected to have high potential for carbon substitution. (An indirect incentive may exist, though, to the extent that buyers are willing to pay more for such wood due to the value of the carbon substitution benefits to the wood processors or users further down the production chain). We will return to ownership issues in the Discussion section.

Harvested wood products and associated carbon substitution benefits may require not only clarifying legal rights to the carbon, but also establishing when any associated emissions that are not otherwise regulated have to be reported (Ingerson, 2011).

3. Harvested Wood Products

This section compares the approaches taken to including harvested wood products under existing carbon standards, focusing on coverage, baseline, leakage, carbon benefit quantification, and credit ownership issues. Four voluntary carbon market standards that currently cover carbon stored in harvested wood products under some of their protocols were identified and are focused upon in comparing approaches. These standards are the American Carbon Registry Forest Carbon Project Standard (ACRFPS), the California Air Resources Board (ARB), the Climate Action Reserve (CAR), and the four improved forest management methodologies under the Verified Carbon Standard (VCS). Of these, the ARB and CAR forest protocols are very similar, but not exactly the same (see: CAR, undated).

Plan Vivo (a standard which encompasses carbon and other ecosystem services) covers HWP in some cases. For example, Baker et al (2011) adopts a decay rate approach to accounting for HWP. However, due to the ad hoc nature of its coverage and lack of codified approach, this standard is excluded from the comparisons below. (Carbon market standards that currently do not cover HWP under any of their protocols include the Gold Standard – which acquired CarbonFix in 2012).

Table I below summarises aspects of harvested wood products covered under the four carbon standards focused upon.

Table I: Coverage of harvested wood products under voluntary carbon standards

	American Carbon Registry Forest Carbon Project Standard		California Air Resources Board			Climate Action Reserve Forest Project Protocol			Verified Carbon Standard			
Activities covered:	Improved Forest Management	REDD	Reforestation	Improved Forest Management	Avoided Conversion	Reforestation	Improved Forest Management	Avoided Conversion	Improved Forest Management through extension of rotation age	Conversion of low-productive forest to high-productive forest	Improved Forest Management: conversion from logged to protected forest	Improved Forest Management in temperate and boreal forests
Version	v2.1		US Forests protocol			v3.2			v1.2	v1.2	v1.2	v1.2
Date	2010/11		Oct 2011			2010			2013	2013	2013	2013
Baseline	Y	~	Y γ	Y γ	Y γ	Y γ	Y γ	Y γ	~ π	~ μ	Y	Y
Project	Y	~	Y δ	Y δ	Y δ	Y δ	Y δ	Y δ	~ π	~ μ	Y	Y
Estimated leakage	β	Δ	Y λ	Y λ	Y λ		~ ρ		~ χ	Y	~	~
In-use carbon pool	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Landfill carbon pool	Y		θ	θ	θ	θ	θ	θ				
Decomposition CO_2			Y	Y	Y	Y	Y	Y				
Decomposition CH_4			N	N	N	N	N	N				
Decomposition N_2O			N	N	N	N	N	N				
Sawmill efficiency	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Emissions from harvesting, transportation and processing wood products			N	N		N	N	N			Y	Y
Emissions from production, transportation and disposal of alternative materials to wood products			N	N		N	N	N				

Notes: Y: covered in all cases; ~: covered in some cases; N: not covered; β: accounted for if HWP production reduced below a *de minimis* threshold (>5% relative to the baseline); γ: estimated from model-based forecasts; δ: estimated from measured harvests; Δ: market effects leakage accounted for if HWP would have been produced as a result of deforestation (unless the project developer elects to replace the entire displaced supply); θ: included only in years where actual harvest is below estimated average baseline volumes; λ: net change in carbon in HWP is multiplied by 80 percent to reflect market responses to changes in wood product production; ρ: 20% leakage assumed if harvesting is below baseline level; π: can be excluded if HWP carbon stocks are increasing faster (or decreasing slower) than under baseline; μ: can be excluded if carbon stocks in HWP insignificant; χ: no leakage assumed if project reduces HWP production (relative to the baseline) by less than 5% and any temporal displacement in the total HWP production is less than 5 years; blank: no explicit mention of whether covered or not.

Baseline and underlying counterfactual

Approaches to determining the baseline (i.e. the assumed trajectory of emissions in the absence of a project) and underlying counterfactual (i.e. the scenario thought most likely if the project had not gone ahead) vary between standards. Under the ARB and CAR, the baseline for improved forest management projects is set based upon legal requirements. A legal baseline is also used for some VCS projects, whereas for others it is based upon historical records, or on common practice. By contrast, the baseline under ACRFPS is computed using an economic optimisation (see Table II).

Table II: Approaches to determining Baseline emissions

Approach:	American Carbon Registry Forest Carbon Project Standard	California Air Resources Board (improved forest management projects)	Climate Action Reserve Forest Project Protocol (improved forest management projects)	Verified Carbon Standard
i) Legal Baseline: **a)** constraints under existing timber harvest plans met (e.g. California Forest Practice Rules requirements for achieving Maximum Sustained Production of High Quality Wood Products) **b)** where specific forest management regulations (e.g. controlling the diameter of trees harvested) exist and are enforced		X	X	β
ii) Economic Baseline: The legally-permissible harvesting scenario that would maximize net present value (NPV) of wood harvested from a perpetual series of rotations	X			
iii) Historical Baseline (if forest management records for at least 20 years prior to the project commencing exist that indicate management practices have surpassed legal barriers associated with forest legislation, and surpassed financial barriers by providing above average market returns)				X
iv) Common Practice Baseline				δ

Notes: β where not iii); δ where neither iii) nor i) b);

In some cases, coverage of different impacts under the baseline partly reflects expected regulatory changes. In the case of CAR, for example, methane emissions resulting from anaerobic decomposition of forest products in landfills are excluded as it is assumed these will be largely controlled by new regulations in the near future. Other categories are excluded if not expected to be significant – such as nitrous oxide from decomposition of wood products (CAR, 2010).

Leakage

The extent to which harvested wood products are taken into consideration in accounting for potential leakage varies between the standards. They are always accounted for under ARB (as well as under one of the VCS protocols). By contrast, under the ACRFPS they are only accounted for where the production of harvested wood products over the minimum life of the project is reduced by more than a *de minimis* threshold, or (in the case of REDD projects) if wood products would have been produced and this supply is not entirely replaced by the project developer.

Carbon benefits

To the extent that a wood product decays over time, with the carbon released back into the atmosphere, the benefit of carbon storage in a specific wood product is temporary, if tending to be longer for hardwoods than softwoods. Wood products in some cases remain intact without significant decay for hundreds of years – as illustrated by original oak beams in Medieval buildings. While carbon storage in such cases might be considered semi-permanent, it can also be subject to some of the same sources of non-permanence risks (e.g. fire and insects) as the trees prior to harvesting, even if treatment to reduce these risks is often integral to processing and maintenance of wood products.

Under each of the carbon standards covering harvested wood products a simplified approach to quantifying the carbon benefits is adopted that avoids long-term monitoring. This is based upon the simpler of the two methods outlined in US Department of Energy (USDoE) technical guidelines on voluntary reporting of greenhouse gases under Section 1605b of the 1992 US Energy Policy Act (USDoE, 2006a, p.231). Carbon benefits are considered over a 100-year time-frame. Wood products with a life-time over 100 years are assumed to store carbon permanently. Wood products with a life-time under 100 years are assumed to either completely release the carbon stored immediately (e.g. in the case of wood co-product at sawmills), or over a specific (e.g. 20-year) period. Use of a 100-year time horizon is argued to be a justified simplifying assumption given that the bulk of emissions associated with harvest, processing, wood co-products and disposal occur within this time frame (ACR, 2011d). The approach contrasts to that used in national carbon accounting under the Kyoto Protocol which, subject to transparent verifiable data being available for three wood product categories (sawnwood, wood-based panels, and pulp and paperboard), is based on applying exponential decay rates to these carbon pools (e.g. IPCC, 2013, equation 2.8.5). Some recent work on assessing the cost-effectiveness of UK woodlands for climate change mitigation similarly adopts an exponential decay rate approach (CJC et al, 2014, section 3.5.5).

The approach under the California Air Resources Board (ARB, 2011) and the Climate Action Reserve Forest Project Protocol (CAR, 2010) follows the same five steps:

i) determine the amount of carbon in wood harvested that is delivered to mills;
ii) account for mill efficiencies (carbon remaining within the processed HWP);
iii) estimate average carbon storage over 100 years in in-use HWP;
iv) estimate average carbon storage over 100 years in HWP in landfills;
v) sum to give the total average carbon storage over 100 years in HWP;

The approach is adapted from the Forestry Appendix of the Technical Guidelines of the USDoE's Greenhouse Gases reporting protocol (USDoE, 2006b) which, based upon a USDA Technical Report by Smith et al. (2006), adopts a production approach to carbon accounting. Proportions of carbon assumed to remain stored after 100 years are determined using first order decay functions for different types of HWP. (i.e. the decay functions assumed are of the form: [fraction remaining=exp(-yearsxln(2)/half-life]). The calculations are based upon the half-lives shown in Table III below.

Table III: Half-lives for harvested wood products by end use

End use or product category		Half-life (years)
New residential construction	Single family	100
	Multifamily	70
	Mobile homes	12
Residential upkeep and improvement		30
New nonresidential construction	Railroad ties	12
	Railcar repair	12
	Other (non-railroad)	67
Manufacturing	Household furniture	30
	Commercial furniture	30
	Other products	12
Shipping	Wooden containers	6
	Pallets	6
	Dunnage etc	6
Other uses for lumber and panels		12
Solid wood exports		12
Paper		2.6

Source: USDoE (2006b, Table D3, p.218)

Recent data on mill efficiencies (e.g. see spreadsheet at http://www.arb.ca.gov/cc/capandtrade/protocols/usforestprojects.htm) are used to estimate the total amount of carbon transferred into HWP, with the remainder assumed to be emitted immediately to the atmosphere. Mill efficiency estimates vary between regions and types of product (hardwood/softwood and sawlog/pulpwood), and for ARB range (as at 10th April 2017) from 0.50 for softwood pulpwood to 0.74 for softwood sawlogs (both for Washington state).

The proportions of carbon of harvested wood assumed to remain sequestered 100 years after harvest in "in use" and in "landfill" under the two standards (ARB, 2011; CAR, 2010), are shown in Table IV below for different types of wood product.

Table IV: Average storage factors of harvested wood products over 100 years

	In-use	Landfill
Softwood lumber	0.463	0.298
Hardwood lumber	0.250	0.414
Softwood plywood	0.484	0.287
Oriented strandboard	0.582	0.233
Non structural panels	0.380	0.344
Miscellaneous products	0.176	0.454
Paper	0.058	0.178

See: CAR (2010, Tables C.2 and C.3 pp.121-122); ARB (2011, Tables C.2 and C.3 p.99, p.101).

Total carbon storage under the two standards is calculated as the sum of the carbon stored in HWP "In Use" and in "Landfill". However, adopting a conservative approach in the face of significant uncertainties, carbon stored in landfill is only counted in years where the amount of carbon in the wood harvested that year is below the baseline level. This means that carbon benefits of HWP are counted in only one pool in any given year: the HWP 'in use' is counted in years where the amount of carbon in the wood harvested is above the baseline level; the HWP in landfill is counted in years where the amount in the wood harvested is below the baseline level (ARB, 2011, p.93; CAR, 2010, p.119).

A similar approach is adopted for improved forest management projects under ACRFPS (ACR, 2011a,b), and under the VCS for Improved forest management in temperate and boreal forests (VCS, 2013a), and, in some cases, for US projects for Improved forest management through extension of rotation length (VCS, 2013d). Regional estimates are used for proportions of roundwood categories remaining 'in use' and in 'landfill' pools, or emitted with or without energy being reclaimed. These are based on USDoE, (2006b, Table 1.6), or, for other areas, regional analogues under VCS (VCS, 2013a, Table 3, p.24, p.38). Regional estimates from USDoE, (2006b, Table 1.6) for the proportion of carbon in softwood produced in the different US regions remaining sequestered long-term in the in-use pool or in landfill, or emitted (with or without energy recapture) are shown in Table V below.

Table V: Average disposition patterns of carbon in U.S. softwood

		In-use	Landfill	Energy	Emitted without energy
		(fractions 100 years after production)			
Northeast	Sawlog	0.095	0.223	0.338	0.344
	Pulpwood	0.006	0.084	0.510	0.400
North Central	Sawlog	0.096	0.250	0.385	0.269
	Pulpwood	0.008	0.084	0.504	0.403
Pacific Northwest (east)	All	0.116	0.221	0.312	0.351
Pacific Northwest (west)	Sawlog	0.130	0.279	0.242	0.349
	Pulpwood	0.000	0.076	0.569	0.355
Pacific Southwest	All	0.112	0.243	0.296	0.349
Rock Mountain	All	0.112	0.255	0.373	0.260
Southeast	Sawlog	0.104	0.232	0.386	0.277
	Pulpwood	0.036	0.105	0.463	0.396
South Central	Sawlog	0.110	0.224	0.340	0.325
	Pulpwood	0.048	0.114	0.451	0.387

Source: USDoE, (2006b, Table 1.6, pp.36-46).

Although similar, the two standards focus on different numbers of discrete steps. Under ACRFPS the approach is based on two steps (ACR, 2011a, p.18; ACR, 2011b, p.20):
i) calculate the annual biomass harvested by type of product (hardwood/softwood and sawlog/pulpwood), and associated carbon using the specific gravity for each species;
ii) calculate the proportion of the carbon that remains sequestered after 100 years based upon USDoE, (2006b, Table 1.6).
Under VCS three steps are used. The first is similar to ACRFPS and focuses on estimating the carbon contained in the timber harvested. The second and third steps are:
ii) determine the total carbon entering the wood products pool by product type accounting for mill efficiencies; and
iii) calculate the carbon stored in medium term and long-term wood products.

The main difference between the approach under VCS and that under other standards relates to this last step. The approach under VCS accounts for carbon stored in medium lived products (defined as those retired between 3 and 100 years of the wood being harvested), rather than assuming all the carbon apart from that in long-lived products is emitted immediately on harvest. It assumes 1/20th of the carbon is emitted in each of the first 20 years after harvest (e.g. VCS, 2013b, equation 8, p.20; VCS, 2013c, p.21; VCS, 2013d, p.36), falling to zero after 20 years (VCS, 2013a, p.38; VCS, 2013d, p.32).

Either regional data from USDoE, (2006b, Table 1.4), or local data (where available) can be used under VCS protocol for Improved forest management in temperate and boreal forests to initially apportion carbon in harvested wood between the four categories (VCS, 2013a, p.36). By contrast, approaches under ACRFPS for REDD projects (ACR, 2011c,d, p.28), and under VCS for Improved forest management converting from low productive to high productive forests (VCS, 2013b), from Logged to Protected forest (VCS, 2013c) and, in some cases, extended rotation length (VCS, 2013d), are based upon emission factors from Winjum et al (1998). These are shown in Table VI below (those for tropical countries are used for projects under the first three of these protocols).

Table VI: Annual oxidation fractions for harvested wood products by region

	Forest region		
	Boreal	Temperate	Tropical
Sawnwood	0.005	0.01	0.02
Woodbase panels	0.010	0.02	0.04
Other industrial roundwood	0.020	0.04	0.08
Paper & paperboard	0.005	0.01	0.10

Source: Winjum et al (1998, Table 2, p.276).

Based on 3-year percentage reductions calculated as three times the equivalent annual rates implied by assuming linear decay of the Winjum et al (1998) estimates, short-lived proportions assumed under VCS (2013d, p.35) are 0.12 for sawnwood, 0.06 for woodbase panels, 0.18 for other industrial roundwood, and 0.24 for paper and paperboard. These, together with the carbon in all other HWP categories, are then assumed to be oxidised immediately after the wood is harvested (VCS, 2013d, p.36).

Estimating proportions of HWP lasting 5 years or more to be 0.8 for sawnwood, 0.9 for woodbase panels, 0.7 for other industrial roundwood, and 0.6 for paper and paperboard, Winjum et al (1998, p.276) assume four-fifths of paper and paperboard lasts less than 5 years, of which half is landfilled and retains the carbon for more than 5 years. They also indicate a wood waste fraction of 19% of the biomass extracted for developed countries and 24% for developing countries (assumed to be oxidised immediately after harvest). The exact proportions of different HWP categories assumed to be stored long-term, or emitted immediately, are not stated explicitly under each of the voluntary carbon market standards.

Ownership rights

In each case the carbon benefits associated with any increase in harvested wood products are credited to the project developer (e.g. forest owner). As the project developer does not generally determine how wood harvested is used once it leaves the forest, allocating them credits for any increase in harvested wood products does not generally affect the level of the associated of carbon benefits per unit of wood, although it does provide an incentive to increase the supply of wood harvested. We will return to ownership issues in the Discussion section.

4. Carbon Substitution

None of the voluntary standard protocols reviewed applying specifically to forestry carbon projects currently cover GHG emissions reduction benefits associated with either use of wood in energy generation in place of fossil fuels, or use of wood products in place of more fossil fuel intensive materials such as concrete and steel. However, some of the voluntary standard protocols for renewable energy projects do cover carbon substitution benefits of woodfuel use.

Three voluntary standards protocols for renewable energy were identified (two under the Gold Standard and one under the Verified Carbon Standard) that cover aspects of the carbon substitution benefits associated with woodfuel use, as well as three Clean Development Mechanism (CDM) methodologies. These are the focus of comparisons discussed below.

Applicability and project boundary

The three voluntary carbon standard protocols focused upon are the Gold Standard protocols for ecologically sound fuel switching to biomass (GSa, n.d.) and for switching from fossil fuels to biomass residues in boilers (GSb, n.d.), and the VCS protocol for switching to renewable biomass for thermal applications in manufacturing. The latter include applications in brick and tile production (VCS, 2011). The CDM methodologies include two for large-scale projects – one applying to use of biomass in electricity and heat generation (CDM, 2012) and a methodology applying to use of biomass residues in electricity generation (CDM, 2013), and a methodology for small-scale projects using biomass in heat generation (CDM, 2014).

The relevance to forestry of the two Gold Standard protocols (GSa, GSb, n.d.) and one large-scale CDM methodologies (CDM, 2013) is therefore limited to cases where forest residues are used. By contrast, the two other CDM protocols (CDM, 2012, 2014) and the VCS one are more widely applicable to sources of renewable biomass from forests.

As Table VII below shows, the breadth of the project boundary considered varies. These differences are, in part, related to differences in the focus of the protocols.

Table VII: Project coverage under protocols for energy generation & thermal applications

		Gold Standard		Verified Carbon Standard	Clean Development mechanism		
	Activities covered:	Ecologically sound fuel switching to biomass	Switching from fossil fuels to biomass residues in boilers	Switching to renewable biomass for thermal applications	Electricity and heat generation from biomass	Electricity generation from biomass residues in power-only plants	Thermal energy production with or without electricity
	Version	v1.0	v1.0	v2.1	v12.1.1	v3.0	v20.0
	Date	n.d.		2011	2012	2013	2014
Project types	Plants generating electricity only					Y	Y
	Plants generating heat only		Y				Y
	Plants generating heat and power				Y		Y
	Thermal applications			Y			
	Biomass substitution and energy efficiency	Y					
Project site	Location fuel switching occurs	λ		Y			
	Boiler and related equipment – including on-site transportation and preparation		Y				
	Plants generating electricity only				Y	Y	Y
	Plants generating heat only		Y		Y		Y
	Plants generating heat and power				Y		Y
External to project site	Facilities consuming enegy produced by project						Y
	Power plants connected physically to grid the project power plant is connected to				Y	Y	Y
	Sources that supply heat to the project site	Y			~		
	Sites where the biomass produced						
	Dedicated biomass plantations				β		
	Transport of biomass		Y		Y	β	α
	Site where biomass residues would have been left to decay or dumped		Y		Y		
	Plant processing biomass residues				β		

Notes: Y covered; α covered if transported over 200km; β covered where used; ~ covered in some cases; λ protocol refers to CDM methodology AMS III.b, Version 12, 13 which state that 'The emission baseline is the current emissions of the facility expressed as emissions per unit of output'.

Baseline and underlying counterfactual

The GHGs accounted for also vary between the different protocols. Although carbon dioxide (CO_2) is the main focus, accounting extends to nitrous oxide (N_2O) and methane (CH_4) in some cases, as Table VIII below shows.

Table VIII: GHGs covered under protocols for energy generation & thermal applications

		Gold Standard		Verified Carbon Standard	Clean Development mechanism		
		Ecologically sound fuel switching to biomass	Switching from fossil fuels to biomass residues in boilers	Switching to renewable biomass for thermal applications	Electricity and heat generation from biomass	Electricity generation from biomass residues in power-only plants	Thermal energy production with or without electricity
	Version	v1.0	v1.0	v2.1	v12.1.1	v3.0	v20.0
	Date	n.d.		2011	2012	2013	2014
Baseline	Electricity generation					CO_2	
	Heat generation		CO_2				
	Heat and power generation				CO_2		
	Heat and/or power generation	CO_2					
	Uncontrolled burning or decay of biomass residues		(CH_4)		(CH_4)	(CH_4)	
	Non-renewable fuel consumption-related emissions which would otherwise have been produced in production facility/facilities			CO_2			CO_2 ψ
Project	Onsite fossil fuel consumption		CO_2		CO_2	CO_2	
	Onsite electricity consumption		CO_2				
	Co-firing fossil fuel use	CO_2					
	Onsite transportation of biomass					CO_2	
	Offsite transportation of biomass		CO_2		CO_2		
	Onsite & offsite processing of biomass residues	CO_2 ψ				CO_2	
	Combustion of biomass for electricity only					$[CH_4]$	
	Combustion of biomass for heat only		$[CH_4]$				
	Combustion of biomass for electricity & heat				$[CH_4]$		
	Wastewater from treatment of biomass				$\{CH_4\}$	$\{CH_4\}$	
	Cultivation of land to produce biomass feedstock where a dedicated plantation used				CO_2 N_2O CH_4		
	Competing uses of biomass residues (if source under control of project participants)	CO_2 ψ					
	Any emissions related to shifts in pre-project activities / land use	CO_2 ψ					

Notes: ψ any GHGs apart from CO_2 covered unspecified; () decided by project participants; [] included if CH_4 emissions from uncontrolled burning or decay of biomass residues included in the baseline; {} included where wastewater treated (partly) under anaerobic conditions.

The approach to estimating the carbon savings associated with biomass use is broadly similar under the two Gold Standard protocols and the CDM methodologies. In each case the savings are estimated as the project emissions minus baseline emissions minus leakage (GSa, n.d., p.6; GSb, n.d., equation 15, p.19; CDM, 2012, equation 1, p.21; CDM, 2013, equation 1, p.23; CDM, 2014, equation 21, p.24).

The VCS protocol adopts a slightly different approach in most cases. Carbon savings are calculated as the product of an annual production-specific emission factor and the annual number of units produced at the facility (VCS, 2011, equation 1, p.4), with leakage assessed separately (VCS, 2011, Annex III). However, the emission factor used to estimate the carbon savings (VCS, 2011, equation 2, p.5) is adjusted to account for leakage if the assessment identifies increased non-renewable biomass consumption due to the project (VCS, 2011, para 7.3, p.5). Furthermore, the project developer has to assess the level of surplus biomass in the region where the project is to be located and if this is found to be less than a quarter larger than the amount of biomass to be used by the project, leakage associated with competing uses of biomass is deducted from the estimated carbon savings (VCS, 2011, p.11).

Baseline and project emissions under the Gold Standard and CDM protocols are similarly based upon emission factors representing GHG emissions per unit of input. Emission factors are used for carbon dioxide emissions per unit of energy generated using electricity (GSb, n.d., p.14) and using different types of fossil fuel (GSa, n.d., pp.5-6; GSb, n.d., p.9). Where transportation emissions of bringing biomass to the site are accounted for, emissions factors are used to represent average carbon dioxide emissions per kilometre travelled, or for the type of fossil fuel used (GSb, n.d., p.15). In cases where baseline emissions due to uncontrolled burning of biomass residues, or methane emissions from the combustion of biomass residues, are accounted for, emission factors are used for methane emissions per unit of energy generated (GSb, n.d., p.12, p.15).

Under the Gold Standard, for example, baseline emissions from fossil fuel use are calculated as the product of an emissions factor multiplied by the level of net output (GSa, equation 1, p.5) or primary energy input from firing with biomass residues (GSb, n.d., equation 2, p.9). The emissions factor is calculated as the product of the total fossil fuel consumed, the emissions factor for the fossil fuel and the net calorific value of the fossil fuel, all divided by the corresponding net energy generated (GSa, equation 2, p.5). A conservative approach is adopted based upon calculating the emissions factor for the least carbon-intensive fuel type used in the previous 3 years (GSb, n.d., p.9). Project emissions are similarly given (in part, at least) as the product of fossil fuel consumed by the project for energy generation, the emissions factor for the fossil fuel and the net calorific value of the fossil fuel (GSa, equation 3, p.6; GSb, n.d., equation 7, p.13). Emission factors may be based upon reliable national or local data (GSa, n.d., p.5), in-situ measurements, or IPCC default values in some cases (GSb, n.d., p.15).

The two large-scale CDM methodologies similarly specify baseline emissions (in part) in terms of the product of fossil fuel use and emissions factors (CDM, 2012, equation 2, p.22; CDM, 2013, equation 3, p.24). In addition to the emissions factor for fossil fuel use in the absence of the project going ahead, the small-scale CDM methodology also includes a term reflecting the efficiencies of the plant that would otherwise have been used (CDM, 2014, equations 1, 3, 4 and 5, pp.10-12, 15).

Uncertainty of the methane emissions factor for combustion of biomass residues is considered relatively high in many cases. The same approach to handling this is used under the Gold Standard protocol for switching from fossil fuels to biomass residues in boilers and the large-scale CDM methodologies. A 'conservativeness factor' (used to multiply the default emissions factor by) ranging from 0.73 (where >100% uncertainty) to 0.98 (where ≤10% uncertainty) is applied in estimating baseline emissions (GSb, n.d., Tables 3, p.12; CDM, 2012, Table 3, p.46; CDM, 2013, Table 4, p.45). A default of 300% uncertainty is assumed and an associated 'conservativeness factor' of 1.37 applied in estimating project emissions (GSb, n.d., Tables 4 and 5, p.16; CDM, 2012, Tables 4 and 5, p.50; CDM, 2013, Tables 5 and 6, p.49).

Leakage

The different types of leakage accounted for under the different protocols are summarized in Table IX below. These differences reflect, in part, differences in project types covered by the different protocols.

In some cases leakage is only considered relevant under certain baseline scenarios. Under the two large-scale CDM methodologies, for example, these are where biomass residues i) would have been used at other sites; ii) are used for other energy purposes (e.g. biofuels); or iii) have been purchased and their fate in the absence of the project cannot be determined (CDM, 2012, p.53; CDM, 2013, p.50).

Table IX: Forms of leakage accounted for (energy generation and thermal protocols)

	Gold Standard		Verified Carbon Standard	Clean Development mechanism		
	Ecologically sound fuel switching to biomass	Switching from fossil fuels to biomass residues in boilers	Switching to renewable biomass for thermal applications	Electricity and heat generation from biomass	Electricity generation from biomass residues in power-only plants	Thermal energy production with or without electricity
Version	v1.0	v1.0	v2.1	v12.1.1	v3.0	v20.0
Date	n.d.		2011	2012	2013	2014
Use of fossil fuels or GHG emissions elsewhere due to diversion of biomass residues from other uses		Y		~	~	
Shifts of pre-project activities:	Y					
Use of otherwise set-aside or marginal land	~					
Other (e.g. deforestation)	~					
Production of biomass:	Y					
Biomass residues previously uncollected or dumped		~				
Fertiliser use & nitrous oxide emissions	~					
Competing use of biomass:	λ					Y a
Abundant surplus of biomass residue in the region (at least 25% more than used by the project)		~				
Suppliers in region unable to sell all their biomass residues		~				
Quantity & use of biomass resource in region (e.g. 50 km radius)	~					
Former consumer of the biomass residue has substituted other biomass residues previously uncollected or dumped, or for which there is an abundant surplus		~				
Replacement of equipment			~			
Use of replaced equipment			~			
Transfer of energy generation equipment from elsewhere (where outside project boundary)						Y
Use/Diversion of non-renewable biomass			~			
Any increased use by non-project households/users attributable to the project			~			
Transport of biomass residues over 200km (where collection, processing and transport outside project boundary)						Y b
Storage and usage of displaced refrigerant (where a GHG and not destroyed)						Y

Notes: Y covered; ~ covered in some cases; λ covered if source of biomass not under control of project; based on CDM(2009); b based on CDM (2011).

Ownership rights

In each case the carbon units associated with any carbon substitution benefits due to use of woody biomass are credited to the project developer who runs the renewable energy facility.

5. Discussion and Recommendations

Omitting to account for carbon in wood products can result in significant over-estimates of atmospheric carbon emissions in the year wood is harvested (USDoE, 2006a). This can also be an issue in subsequent years.

At first sight, inclusion of carbon storage benefits associated with harvested wood products may appear far from straight-forward given the range of potential uses. The further wood products move through the value chain, the more uncertain carbon storage estimates become (Mensink, 2007). Monitoring based upon periodic sampling of carbon storage in wood products is thought to be far more difficult and costly than for forest carbon pools, with variability in processes and end uses, as well as final consumer disposal, suggesting a need to apply uncertainty discounts (Ingerson, 2011) or buffers.

However, the review of the four carbon standards illustrates that relatively simple approaches to the inclusion of the carbon storage benefits associated with HWP exist based upon applying fixed decay rates to different categories of wood products that aim to provide conservative estimates. Avoiding the need for long-term monitoring, the cost of implementing such approaches could be expected to be modest. Although the proportions of different HWP categories produced differ from the US – with full utilisation of sawmill residues for co-products and almost no wood sent to landfill (Cameron Maxwell, pers. com.), a similar approach would also be simple to apply if the Woodland Carbon Code were extended. Country averages within the UK adjusted for different yield classes might be used, along with fixed decay rates – such as those used for national level GHG accounting. The approach would be simple to apply. Potentially, an extension to accounting for carbon storage in HWP could just be limited to the main forestry types producing HWP – such as just 'productive conifer' and 'productive broadleaves' (Cameron Maxwell, pers. com.). However, whether this would be best would also depend whether there are any significant problems (e.g. potential perverse incentives) anticipated in adopting different approaches for different woodland carbon projects.

The extent to which such simple approaches offer robust metrics is unclear. Uncertainties exist not just regarding the proportion of wood harvested from any given woodland that will be used for different types of HWP and the level of associated wood processing emissions, but also concerning wood product decay rates (which remain an area of ongoing research), as well as in establishing the counterfactual underpinning the baseline. (Uncertainty about the baseline is a pervasive issue, that does not just affect carbon storage benefits of HWP). In addition, GHG emissions associated with transport of HWP can also be a significant issue where material is processed and used outside the region in which the wood has been grown. According to Ingerson (2011), in the US, for example, carbon emissions from processing and transportation may approach the level of long-term carbon storage in HWP in some cases - but this does not imply there are no carbon substitution savings relative to using alternatives such as concrete and steel.

Although important in determining the level of carbon savings associated with a project or activity (see also case studies in Bird et al., 2010), making detailed recommendations on the best approach to carbon accounting for carbon storage in HWP is beyond the scope of this paper. However, Pearson, Swails and Brown (2012) provide a useful review and comparison of the three approaches (Winjum, Brown and Schlamadinger, 1998; IPCC, 2006; Smith et al., 2006), noting that the constant rate of retirement assumed of the long-term HWP pool by Winjum, Brown and Schlamadinger (1998) is unlikely to hold, and an exponential decay process is more likely - as suggested by a number of other studies, including IPCC (2006). Furthermore, they argue that assuming all the carbon in wood products with a lifetime of less than 100 years is emitted immediately is overly conservative, while assuming this in the baseline can inflate the credits issued as it implies projects could claim credits for emissions reductions that may only occur in 99 years' time. They instead recommend either adopting an average based on modelling retirement and emissions from wood products over many cycles and the associated quantity stored in the HWP pool long-term (in cases of stable harvest cycles), or a radiative forcing approach calculating the atmospheric impact of keeping carbon out of the atmosphere over a product's life.

The extent to which extending the Woodland Carbon Code to cover carbon storage in HWP would fit with wider GHG accounting, and downstream standards, or pose potential issues of double-counting carbon savings of HWP with risks to the integrity of the Code is a further important consideration. The Publicly Available Specification (PAS) 2050 - a specification for life cycle assessment of the GHG emissions of goods and services developed in 2008 by the British Standards Institution, for example, takes into account the carbon storage benefits of HWP. Thus, if the Woodland Carbon Code were extended, carbon benefits of HWP coming from a woodland certified under the Code risk being double-counted if the same carbon saving were accounted for by a construction company under a standard such as PAS2050 (Mark Broadeadow, pers. com.).

Definitions of double-counting vary and can cover diverse forms (Schneider et al, 2014; Hood et al, 2014; Foucherot et al, 2015). These include i) double issuance (more than one carbon unit issued for a single benefit); ii) double certification (a single emissions reduction is certified under more than one standard); iii) double claiming (a benefit claimed twice towards attaining mitigation pledges); iv) double use (a carbon unit used twice to attain mitigation pledges); v) double selling (the same carbon benefit is sold to multiple buyers to attain each's mitigation pledges); vi) double payment (payments are made for the same carbon benefit to more than one supplier); vii) double accounting (a carbon saving sold as voluntary carbon unit is also accounted for by the state as a Kyoto unit); and viii) double purpose (a carbon unit counted both towards attaining mitigation and another pledge such as development finance). In this study, double-counting will be considered to encompass the first six forms above, but only to be of concern where harmful in the sense of risking the credibility and integrity of other mitigation activities. (We will not be concerned where it does not pose a risk the credibility and integrity of other mitigation activities). The last two forms of double-counting are not considered further on the grounds that issues of carbon accounting by the state lie beyond our focus here on relationships between voluntary standards, and that double purpose similarly need not concern us here to the extent that it is primarily an issue in relations between countries.

Let us now return to the example given above of carbon storage in HWP being covered both by the Code and a downstream standard such as PAS2050. Neither double issuance nor double use would occur if (as currently) no carbon units are issued or sold to others under such standards (which apply to specific products or supply chains), but double certification and double claiming would occur. Whether this would be harmful in our sense (of risking the credibility and integrity of other mitigation activities) is unclear. If the carbon saving associated with HWP use in the specific construction project would not have occurred without both the woodland owner and the construction company being paid, payments to each for the carbon saving would seem unproblematic – providing it is understood that both are necessary and give rise to a single carbon saving. Providing neither the forest owner, nor the construction company claim exclusive ownership to the carbon saving, but recognise complementary roles involved in growing the wood and using the HWP, with any subsequent purchasers of associated carbon units also recognising the role played by each, double claiming would seem unlikely to be problematic either. Similarly, double certification seems unlikely to be problematic if complementary roles involved in growing the wood and using the HWP is recognised under each standard. On the other hand, if carbon units are issued under the Woodland Carbon Code to a woodland owner without any recognition of the claim under the downstream standard, both double claiming and double certification are likely to be problematic because claims by the construction company and the woodland owner to have each delivered the same carbon saving would be incompatible.

Double selling could be problematic in some cases. However, it would not be expected to be an issue where a single entity makes payments both to the landowner and the construction company. Providing the entity recognises its two payments are for the same carbon benefit, it could be expected to seek to limit each level of payment consistent with just providing sufficient incentive for the timber to be grown and harvested and for the HWP to be produced and used in the specific project. If the forest owner is paid for carbon storage benefits up-front on initial planting (as generally the case for sequestration benefits under the Woodland Carbon Code) and the construction company is paid once the HWP is used, relatively few instances involving a single entity making both payments may be expected due to the number of years elapsing between planting and harvesting. Instances of a single entity making both payments may be more likely if the forest owner were instead paid at the time of harvesting. (In the latter case, the payment would give less of an incentive for initial woodland creation, and more of an incentive for adopting forest management practices consistent with ensuring sufficient quality wood to process into HWP with high carbon storage benefits). A single entity could conceivably make payments to both in other circumstances too, although upfront payments to construction companies for carbon storage benefits associated with wood yet to be grown seems implausible.

Instances where different entities make payments for the carbon saving may similarly seem unlikely to be problematic in terms of double payment providing three conditions are fulfilled: i) the entity paying the construction company recognises that the landowner growing and harvesting the wood for HWP has already been paid for the associated carbon benefit; ii) the entity paying the forest owner recognises that the construction company may have to be paid to use the HWP in order for the carbon benefit to be realised after the wood is harvested; and iii) none of the actors (forest owner, construction company, purchasers or any subsequent buyers or sellers of the carbon) claim exclusive ownership of the carbon saving. In each case the entity paying the construction company would similarly be expected to try to limit its payment to the level needed to provide sufficient incentive for the HWP to be used in the specific construction project, which may be viewed as a necessary 'top-up' in order to realise the carbon benefit. By themselves, neither double payment nor double claiming would appear to be harmful in our sense (of risking the credibility and integrity of other mitigation activities) in such cases so long as each actor recognises that there are more than one payment for the same carbon benefit and does not claim or sell exclusive rights to the carbon saving. However, ensuring the latter condition holds in subsequent transactions may prove difficult unless underpinned by formal rules.

Instead of seeking to avoid potentially harmful effects, in principle double-counting could be avoided altogether by adopting an approach that explicitly tackles the distribution of ownership rights associated with the carbon saving (and implicit in any issue of carbon units). This could be achieved firstly through allocating a share of the carbon units associated with the carbon saving to both the woodland owner and the construction company. The share for the woodland owner might be issued at least in part at the time of woodland planting, while that given to the construction company is kept back until after the wood has been harvested, processed and used. For example, instead of a reduction in carbon units issued due to a fall in long-run carbon sequestration associated with harvesting, where at least equivalent carbon benefits are expected to be realised subsequently through carbon storage in HWP, the woodland owner might instead be issued with the same level of carbon units as would arise if no harvesting were planned. The proportion of the carbon units allocated could potentially be contentious as, for example, rather than most going to the woodland owner, downstream users may argue that the construction company should have the major share for realising the carbon saving if they could instead have chosen to use HWP made with imported timber. (It may also be worth noting also that the larger the share of carbon units allocated to the construction company, the greater incentive to use UK-grown timber rather than imported timber). The distribution could conceivably be agreed at the outset based upon principles negotiated by representatives of the two sectors. Secondly, to avoid double claiming, the share due to the construction company would then need also to be reflected in any claim under the downstream standard. (Without the carbon saving claimed by the construction company under a downstream standard being reduced to a level corresponding to its share of the carbon units, the units issued to the woodland owner would still represent double-claiming as the saving would still also be being claimed by the construction company). The approach could entail significant costs to establish, involving changes both to the Woodland Carbon Code and to downstream standards, but appears to offer a more robust approach in avoiding double-counting.

Initial exploration has helped illuminate some aspects of double-counting and how these could be tackled, but a comprehensive treatment of all potential issues that might arise in extending the Code to carbon storage in HWP and how they could best be addressed is beyond the scope of this paper, with further investigation required in some areas. However, the cursory examination above suggests that the primary issue relates more to selecting a robust approach to prevent double counting (in our sense of being harmful), than to any problems inherent in extending the Code per se. To avoid potential double issuance and double use problems in future, for example, linking registries covering carbon units issued under different standards could help to ensure only one tradeable carbon unit is issued for a specific benefit. Alternatively, consideration might be given to potential for issuing non-additive 'partial' carbon units covering complementary aspects (e.g. growing/harvesting the wood for HWP vs subsequent use of HWP), or just to ways of ensuring that the non-additive nature of claims relating to complementary aspects of a specific carbon saving are clear.

Concerns about carbon sequestration benefits of woodlands also being accounted for under national GHG reporting (i.e. potential double accounting) led to the adoption of the existing approach under the Woodland Carbon Code that similarly recognises the non-additive character of claims to carbon sequestration savings. In particular, to clarify the position prior to any further consideration of potential for development of a domestic carbon offsetting scheme, it led to a decision not to name the carbon sequestration benefits 'credits' or permit their use as offsets, but instead to name them 'units'. (While avoiding double accounting, the decision to name the carbon benefits 'units' rather tradeable 'credits' remains controversial due to implicit ownership rights issues, though, as while the UK includes the benefits in national carbon accounting, no compensation is paid to landowners for any associated reduction in income – see for example: http://www.forestcarbon.co.uk/the-uk-forest-carbon-market---a-win-win-win-win..../).

In considering the potential to extend the Woodland Carbon Code to carbon storage in HWP, taking existing approaches under the four voluntary carbon standards (ACRFPS, ARB, CAR, and VCS) into account, the following recommendations are made:

- consider adopting a system of fixed duration (i.e. temporary) carbon units based on the expected lifespan of different product types (e.g. longer for hardwoods than softwoods).
- consider adopting a simple approach that accounts for carbon storage benefits over a fixed time horizon (e.g. the longest lifespan of the different product types), assuming the complete re-volatilisation of the carbon savings thereafter.
- for each product category, consider applying a simple decay function to the carbon stored.
- consider how transport emissions can best be included in estimating the net carbon savings and the extent to which incentives for local processing and use of wood products arising from inclusion of transport emissions could help increase overall carbon benefits to society.

- explore the costs of empirical monitoring of carbon storage benefits of HWP and, if the anticipated increased value of carbon credits issued due to greater precision and reduced uncertainty outweigh the expected costs, consider adoption of monitoring.

- consider further the extent to which extending the Woodland Carbon Code fits with wider GHG accounting, and downstream standards, or poses potential issues of double-counting carbon savings with risks to the integrity of the Code, and how these can be minimised.

As we have seen, credits for increased carbon storage in HWP are allocated to forest owners under existing protocols. By contrast, allocating carbon credits to users of the wood that is harvested would provide an incentive to increase carbon benefits by using it for more durable purposes – such as in construction, rather than relatively short-lived products. This would also tend to increase the demand for wood for more durable uses. The net impact of allocating carbon credits for any increase in HWP to users rather than project developers could be expected to be an increase in carbon benefits due to the benefits of increased use for more durable purposes outweighing any reduction associated with a smaller volume of timber harvested. However, whether this occurs will depend upon factors including the price elasticities of supply and demand, and the extent to which greater demand for more durable uses translates into increased prices for wood harvested. For example, were users of wood able to obtain carbon credits for increased carbon storage in their products irrespective of the source of the timber and were supply including imports perfectly elastic (as often assumed in the UK), increased demand for the wood harvested would not translate into a price increase for wood. In this case, the net impact of allocating credits to the users would depend upon whether the increase in carbon benefits per unit of wood is greater than any decrease in the supply of wood harvested compared to a situation in which credits were allocated instead to the forest owners.

- consider commissioning a study to explore potential mechanisms to allocate carbon units for storage in wood products between woodland owners and wood users that provide incentives to increase the supply and quality of wood and the carbon storage benefits per unit of wood used, in order to maximise the overall net benefits to society.

Compared to carbon sequestration and wood product decay rates which can be measured, substitution benefits are inherently more uncertain because they require far more assumptions about what would otherwise have occurred. The benefits generally depend upon a large number of factors – including production efficiencies (Stewart and Nakamura, 2012), sources of power used, transportation distances, recycling and waste management practices. Although in a wider context specific types of substitution have been studied, estimating overall effects is extremely difficult at a global level given the huge number of product substitutions and scenarios to consider (Miner and Perez-Garcia, 2007).

Furthermore, temporal differences in emissions and sequestration associated with using wood are sometimes viewed as problematic. The use of wood instead of more fossil fuel intensive materials or directly in place of fossil fuels in energy production may be characterised as involving a 'GHG payback time' (Matthews et al., 2014b), or as creating a 'carbon debt' as harvesting reduces carbon storage in forests which takes years to be restored. By contrast, woodland creation for future wood production or bioenergy use is considered following the same logic to create a 'carbon credit' due to the carbon sequestration that occurs prior to the wood being harvested (Ros et al, 2013). However, this suggests potential time-inconsistency / framing problems for decision-makers if landowners are encouraged initially to plant woodlands for timber or bioenergy, but then subsequently discouraged from harvesting in order to retain resultant carbon sinks intact.

Although lack of widescale coverage of carbon substitution in carbon standards may be in part due to the greater uncertainties and complexities involved, in some cases it also reflects expected regulatory changes. In the case of CAR, for example, reductions in GHG emissions resulting from use of HWP in place alternative materials are not accounted for because it is assumed that emissions from production of the latter will be capped in the relatively near future under a regulatory cap-and-trade system (CAR, 2010). The imposition of a cap would be likely to imply that reductions in GHG emissions due to carbon substitution benefits of using HWP instead of more fossil fuel intensive materials is offset by increased energy use and GHG emissions elsewhere in the sector. Analogous arguments have been made in the UK to support not valuing carbon emissions reductions in sectors covered by the EU Emissions Trading Scheme (EU ETS) in the same way as those not covered by the scheme. Where a cap-and-trade scheme accounts for some or all of the carbon substitution benefits of using wood products, establishing a separate mechanism of incentives for their provision raises concerns of additionality and potential double counting, and can also lead to a different approach to carbon valuation. Thus, for example, as carbon savings associated with woodfuel use in electricity generation are currently accounted for under the EU ETS, in UK policy appraisals they are valued differently from carbon substitution savings not covered by the EU ETS (see Valatin, 2014).

As previously noted, potential double accounting under the Woodland Carbon Code due to carbon sequestration benefits also being counted under national GHG reporting was a concern in establishing the Code. This concern would equally apply to other benefits accounted under national GHG reporting if the Code were extended. However, potential for problems would be greater in extending the Code to cover carbon substitution benefits than is the case currently for carbon storage in HWP because (as we have seen), carbon credits are currently issued for use of woody biomass under some existing carbon standards for renewable energy projects. Thus, in addition to double certification, double claiming and double selling, double issuance, and double use could potentially also be problematic. Double-counting problems could also arise due to the EU Emissions Trading Scheme covering woodfuel use in some sectors.

However, as in the case of carbon storage in HWP, the primary issue is selecting a robust approach to prevent forms of double counting that are harmful (in the sense of posing risks to the credibility and integrity of mitigation activities), rather than to any problems inherent in extending the Code per se. Linking registries covering carbon units issued under different standards to ensure only one tradeable carbon unit is issued for a specific benefit, or simply clarifying that different carbon units are not additive could help to avoid double-counting. Tackling the distribution of ownership rights between woodland owner and HWP user explicitly may be especially useful in avoiding potential double-counting associated with the downstream issue of carbon units for woodfuel use.

Full exploration of double counting issues is beyond the scope of this study. However, it is recommended to:

- explore further potential issues of double-counting carbon savings and any associated risks to the integrity of the Code if it were to be extended, including how any significant risks could be minimised.

A further factor in limited coverage under voluntary carbon standards to date may relate to controversies surrounding some carbon substitution benefits – especially those associated with large-scale bioenergy projects using imported biomass. In the European context, desirability, benefits of and equity of projects using mainly imported biomass have been questioned (e.g. Ernsting, Bastable and Munnion, 2013). Britain's largest existing coal-fired power station, for instance, in 2015 was expected to have received over £500m a year in public support (Renewable Obligation Certificates and Levy Exemption Certificates) after switching two of its facilities to biomass (Thompson, 2016; see also Economist, 2013). Short-lived climate pollutants such as black carbon ('soot') – not yet covered by international carbon accounting or carbon market protocols, as well as associated health impacts of particulates from incomplete combustion are further sources of potential concern (e.g. Bond and Sun, 2005; Schmale and Seddon 2013; Williams, 2014).

Substantive issues raised by such wider controversies will also be important in considering potential for extending the Woodland Carbon Code to cover carbon substitution benefits, but detailed consideration of issues involved is beyond the scope of the current study. For a recent literature review on forest bioenergy life cycle assessment, see Matthews et al. (2014b).

Although a more complex task than for carbon storage, it is also recommended to:

- explore the feasibility, as well as associated costs and benefits, of empirical monitoring of carbon substitution benefits.

Prior to deciding in principle whether to try to extend the Woodland Carbon Code to carbon substitution benefits, it is recommended to:

- consider commissioning a study drawing upon existing international trade and inter-sectoral models aimed at quantifying the magnitude of rebound and leakage effects associated with use of UK-grown wood.

Where rebound and leakage effects are considered minor, it is recommended to:

- explore potential mechanisms for sharing carbon units from HWP substitution between the landowners and the users of HWP in order to increase the overall level of carbon substitution and net benefits to society.

As the review of existing protocols has shown, methodologies are currently better developed for carbon benefits of woodfuel than for use of HWP in place of more fossil-fuel intensive materials such as concrete and steel. In the first instance, at least, the Code might just be extended to cover the former (Cameron Maxwell, pers. com.), although in that case it would be important to consider potential risks of perverse incentives arising from only partial coverage of carbon substitution benefits.

Changes in baselines associated with increasing efficiency expected in production of energy and materials that wood substitutes for, and any introduction of end-of-pipe carbon sequestration and storage technologies expected, as well as any energy recovery at the end of the life of HWP, are also important considerations.

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Annex: Rebound Effects

Khazzoom (1980) first brought the rebound effect to the notice of energy economists, but William Stanley Jevons initially hypothesized (subsequently termed the "Jevon's Paradox") that energy efficiency improvements increase rather than decrease energy use in 1865 (Sorrell and Herring, 2009b). Noting that the reduction in coal used per ton of iron produced to under a third of the previous level had been followed by a tenfold increase in coal consumption in the Scottish iron industry, Jevons (2001, p.99) argued "it is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth… Every improvement of the engine when effected will only accelerate anew the consumption of coal." (Cited in Sorrell, 2009, p.138).

Rebound effects are sometimes considered to fall into two main categories: 'Direct rebound' effects result from the lower cost of use of a more energy-efficient product leading to its increased use by the individual or firm; 'Indirect rebound' effects are associated with increased demand for other goods and services (Chitnis et al., 2014). The Overall (aggregate) rebound effect is then the sum of all the direct and indirect rebound effects associated with a specific measure. It is often calculated as a percentage of the expected energy savings from an energy efficiency improvement (Sorrell and Herring, 2009b).

However, empirical evidence on direct rebound effects is reported to be 'very patchy', focused overwhelmingly on consumer energy services in OECD countries, with indirect and overall rebound effects very difficult to quantify empirically and thus 'rare' (Sorrell and Herring, 2009a,b).

Rebound effects are generally defined in terms of impacts of measures to increase the efficiency of energy or resource use. However, it is argued that similar effects can also result from dynamic feedbacks associated with wider climate policies. For example, higher carbon prices may encourage innovation that stimulates economic growth and increased emissions. (For a discussion of innovation feedbacks, see: Fölster and Nyström, 2010). Time-saving may also increase energy use – such as where faster transport speeds leads to increased energy consumption per mile. (For discussion of how such increases can be reinforced by a 'rebound effect with respect to time', see: Binswanger, 2001).

A broader categorization of rebound effects is proposed here encompassing a range of contexts to which rebound effects can apply. In the Table X below twenty forms are distinguished, categorized by whether they are associated with energy efficiency or substitution measures (E), time-saving (T), taxes (R), consumption (C), or input choices (I):

Table X: Types of rebound effect

Category	Type	Description
E	**Production**	a reduction in unit costs leads to producers increasing output and associated energy use
E	**Substitution**	money saved due to a measure is spent on other goods and services, increasing energy use
E	**Income**	reduced energy use by an appliance makes it cheaper to use, leading to increased use
E	**Usage**	reduced energy leads to less attention to switching off appliances not in use, increasing use
E	**Price**	reduced demand for energy leading to a reduction in energy prices, stimulate greater use in the wider economy and other countries
E	**Structural**	energy price reductions reduce the relative price of energy-intensive goods and services, increasing demand for these and associated energy use
E	**Installation**	equipment for installing energy efficiency measures uses energy to manufacture and use, increasing energy use
E	**Infrastructure**	consumption patterns shift increasing demand for associated infrastructure and energy use
E	**Transport**	reduced transportation costs stimulating trade and associated energy use
E	**Growth**	increased energy efficiency raising productivity and stimulating economic growth, increasing demand for goods and services and associated energy use in the wider economy
E	**Norm**	energy efficiency giving companies and households a pretext to neglect wider social and moral norms on limiting greenhouse gas emissions, leading to higher emissions than otherwise.
E	**Multiplier**	relatively expensive low carbon products and services increasing profits and payments to staff and shareholders, increases associated demand and energy use
E	**Upstream**	increased energy efficiency in manufacturing producer goods for manufacturing final goods and services reduces costs, increasing output of producer goods and associated energy use
E	**Downstream**	increased energy efficiency in producing final goods and services reduces their cost and sales price, increasing demand for inputs to produce them, and associated output and energy use
T	**Time**	reduced time needed for a specific activity, stimulates demand and increased energy use
T	**Activity**	reduced time needed for a specific activity, increases time and energy used in other activities
R	**Tax**	environmental (e.g. carbon) tax increases government receipts and expenditure, increasing demand for goods and services in the wider economy and associated energy use
C	**Consumption**	reduced consumption of goods and services by some individuals, companies and countries leads to price reductions, increasing demand of others and associated energy use
I	**Labour**	substitution of human or animal power for fossil fuel use increasing related expenditure and energy use
I	**Capital**	substitution of manufactured inputs for fossil fuel increasing energy use in their production

Rebound effects are defined in relation to a specific time-frame and category of energy consumption (‘system boundary’) – whether household, firm, sector, national or international. Estimates of the level of rebound effects vary markedly, in part due to studies adopting different definitions, empirical evidence being sufficiently sparse, ambiguous and inconclusive to be open to widely varying interpretations, and fundamental assumptions regarding how the economy operates being disputed (Sorrell and Herring, 2009b).

Indeed, Berners-Lee and Clark (2013, p.61) state ‘With so many ripples and rebounds at work, trying to quantify the overall global impact of any efficiency gain or local carbon saving is impossible. The effects are too numerous, too complex and too subtle.’ A review of existing evidence suggests that overall rebound effects in some cases could exceed unity (Sorrell and Herring, 2009a), implying that energy efficiency measures can lead to increased total energy use. Thus, Berners-Lee and Clark (2013, p.61) argue ‘efficiency improvements and piece-meal savings can’t be relied upon to ever solve the problem [of climate change mitigation] in themselves.’

Forest Research

Alice Holt Lodge
Farnham
Surrey GU10 4LH, UK

Tel: 0300 067 5600

Fax: 01420 23653

Email:research.info@forestry.gsi.gov.uk

www.forestry.gov.uk/forestresearch

Northern Research Station
Roslin
Midlothian EH25 9SY, UK

Tel: 0300 067 5900

Fax: 0 131 445 5124

Forest Research in Wales
Edward Llwyd Building
Penglais Campus
Aberystwyth
Ceredigion
SY23 3DA

Tel: 01970 621559

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