Forest Research

Carbon storage and substitution benefits of harvested wood products

Gregory Valatin

July 2021

Wood products provide significant climate change mitigation benefits. These include carbon storage in wood products and carbon substitution benefits associated with the use of wood instead of more fossil energy-intensive materials such as concrete and steel, or of fossil fuels in energy production. This Research Note considers the potential of extending coverage of the UK Woodland Carbon Code to the carbon benefits of wood products associated with woodland creation projects. It builds on previous approaches to including the carbon benefits of harvested wood products under existing carbon market standards. The key recommendations include: (1) exploring ways of allocating carbon units between woodland owners and wood users that provide incentives to increase the quality and supply of timber, the carbon storage and substitution benefits per unit of wood, as well as the overall benefit to society; (2) consideration of potential double-counting issues and how these can be minimised; and (3) investigating rebound and leakage effects, which affect by how much fossil fuel use in the economy changes as a result of increased woodfuel use. Depending on the management system and species used, woodland creation projects involving wood harvesting may increase overall carbon benefits once carbon storage and substitution benefits have been accounted for particularly over multiple rotations. Further work would be required to assess whether average and generic values of carbon storage and substitution benefits could be incorporated into the Woodland Carbon Code's project-level accounting and impacts on the levels of carbon credits that could then be claimed.

Introduction

Woodland creation can offer significant carbon benefits beyond those within the forest. These include carbon storage in harvested wood products (HWP), and substituting wood in construction instead of more fossil energy-intensive materials, such as concrete and steel, as well as using wood instead of fossil fuels in energy and heat production. Taking carbon substitution and storage benefits into account can affect comparisons of the benefits for climate change mitigation of different woodland creation options. For example, recent analysis indicates that typical carbon benefits to 2100 from planting native broadleaves as conservation woodlands are 6.2 tonnes of carbon dioxide (tCO_2)/ha/year, while those for 'productive forests' managed for wood production are 7 tCO_2/ha/year once carbon storage and substitution benefits are included (Scottish Forestry, 2020).

Carbon standards such as the UK Woodland Carbon Code (Forestry Commission, 2014) help to underpin market confidence and the claims of project developers about the climate change mitigation benefits associated with undertaking their projects. Accounting for carbon storage and substitution benefits under carbon standards covering woodland creation projects could be desirable for a variety of reasons. First, incentives for carbon sequestration—a process by which carbon dioxide (CO_2) is removed from the atmosphere and held in solid or liquid form—on their own may fail to maximise the overall carbon benefits of woodland creation, and they may potentially provide perverse incentives. (A perverse incentive is an incentive that has an unintended and undesirable result that is contrary to the intended outcome.) This could occur, for example, if incentives reduce wood harvesting and the consequent reduction in carbon storage and substitution is larger than the carbon savings from increased sequestration (Valatin, 2012). Second, the wider the coverage of climate benefits of woodland creation, the more comprehensive the estimates and the more attractive forestry becomes as an investment compared with alternative options. Third, if carbon storage and substitution benefits are not covered, there is no incentive for landowners or investors to consider them in their land use and investment decisions, which may lead to woodland creation opportunities being missed. Fourth, product and energy substitution may be more effective long-term climate change mitigation strategies than sequestration (e.g. Niles and Schwarze, 2001), although this also depends on the rate at which energy and construction sectors become more efficient in their use of fossil fuels, and how quickly any end-of-pipe carbon sequestration and storage technologies are introduced. Fifth, focusing upon carbon sequestration alone may prove counterproductive if it leads to less harvesting and the use of more fossil energy-intensive products (Miner and Lucier, 2004).

In principle, accounting for a broader range of carbon benefits is desirable. However, there are also potential costs associated with taking a more comprehensive approach, and significant technical obstacles to this being feasible. The Woodland Carbon Code follows a project-level approach to carbon accounting, and the potential incorporation of average and generic values for carbon storage into this framework would require careful scrutiny.

Quantifying the carbon benefits of HWP is less straightforward than for carbon sequestration as, once harvested, wood is subject to a range of processes and has a wide variety of end uses. The carbon savings of HWP depend not only upon the specific end use, material displaced, efficiency of use and what recycling or disposal process is used at the end of the product's life, but also upon wider 'leakage' and 'rebound' effects. Furthermore, there is also potential double-counting to consider.

A review (Valatin, 2017) identified four carbon standards that account for the carbon storage benefits of HWP: the American Carbon Registry (ACR), the California Air Resources Board (ARB), the Climate Action Reserve (CAR) and the Verified Carbon Standard (VCS). None of the existing carbon standard protocols for forest projects cover the carbon substitution benefits of HWP, either the use of wood instead of more fossil fuel-intensive materials such as concrete and steel, or of using wood as a source of energy instead of fossil fuels.

Commissioned to help inform consideration of the potential to extend the coverage of the UK Woodland Carbon Code, this Research Note summarises and develops the findings of the review of approaches to incorporating the carbon benefits of harvested wood products under existing carbon market standards (Valatin, 2017). It is structured in sections covering carbon storage in wood products, carbon substitution benefits and wider issues (i.e. potential double-counting and rebound effects), monitoring and accounting, followed by recommendations.

Carbon storage in wood products

Total carbon storage in HWP in Great Britain is significant compared with that in British woodlands. For example, one estimate suggests that in 2000 it was around 300 million metric tonnes of carbon dioxide equivalent ($MtCO_2e$), approximately half the level of the current above-ground forest carbon stock in Great Britain (Forestry Commission, 2020).

The findings of the initial review (Valatin, 2017) regarding the protocols that cover the carbon storage benefits of HWP under the four carbon standards (i.e. ACR, ARB, CAR and VCS) were supplemented by also considering newer protocols (American

Carbon Registry, 2017, 2018; Climate Action Reserve, 2017; Verra, 2015, 2016), which also cover these benefits. It was found that:

- A 100-year time frame is used in each case when accounting for carbon storage benefits. Carbon stored for 100 years or longer in HWP is assumed to be stored permanently. This includes wood products in use, but also in some cases the proportion of carbon stored for 100 years or more in wood products sent to landfill. Carbon stored for less than 100 years is assumed to release the carbon stored immediately or over a fixed period (e.g. 20 years), or according to a fixed decay rate. Table 1 presents the half-lives (i.e. the time taken for one half of the carbon stored to decay and be emitted to the atmosphere) assumed for different categories of HWP under two carbon standards (ARB and CAR). Further information on the half-life recommended for different categories of wood products in various countries can be found in Penman *et al.* (2003, Table 3a.1.3, p. 3.270); for instance, one study in the Netherlands gives estimates for sawn timber of 18 years for spruce and poplar and 45 years for oak and beech.

Table 1 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
Manufacturing	Furniture	30
	Other products	12
Shipping	Wooden containers	6
	Pallets	6
	Dunnage	6
Other uses for lumber and panels		12
Solid wood exports		12
Paper		2.6

Source: US Department of Energy (2006, Table D3, p. 218).

- The estimated carbon storage benefits of HWP vary, partly because there are differences in the approaches used to determine the expected net carbon emissions if a project does not go ahead (i.e. 'baseline' emissions). Baseline emissions are often assumed to reflect compliance with wider legal requirements such as existing timber harvest plans or specific forest management rules on the diameter of trees harvested. In some cases historical records, or 'common practice' emissions, are used instead. Under one standard, baseline emissions are estimated using economic optimisation to determine the legally permissible harvesting scenario that maximises the net present value of the wood harvested from a perpetual series of rotations. For afforestation and reforestation projects, the wood products component of baseline emissions is often simply assumed to be zero.
- Carbon credits for carbon storage benefits of HWP accrue to the project developer. This is generally the forest owner, even though the carbon storage benefits of HWP depend upon processes that occur outside the forest.

Carbon substitution benefits of wood

None of the existing carbon standard protocols for forestry projects cover the carbon substitution benefits of HWP, either the 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 (Valatin, 2017). However, several renewable energy project protocols cover the carbon substitution benefits associated with woodfuel use. The findings of the initial review of protocols under two voluntary carbon standards—the Gold Standard and the VCS—along with the United Nations Clean Development Mechanism (Valatin, 2017), were supplemented by considering two more recent protocols (UNFCCC, 2017, 2018). The conclusions were:

- The impacts of climate change mitigation activities within forests where the biomass originates are seldom taken into consideration when quantifying the carbon benefits of woodfuel use. Only one protocol covers activities within the forest.
- A variety of 'emissions factors' that represent emissions per unit of input are used to estimate the carbon benefits of woodfuel use. These include emissions per unit of energy generated, and transport emissions per kilometre travelled and fuel type. Differences in the emissions factors used partly reflect different project types.
- The forms of leakage (increased greenhouse gas [GHG] emissions outside the project boundary attributed to the project) accounted for differ, in part reflecting different project types. These include diversion of biomass from other uses, shifts in deforestation and shifts in other activities.
- CO_2 is the primary focus, but nitrous oxide (N_2O) and methane (CH_4) emissions are also covered in some cases. High uncertainty is associated with some of these. For example, a default of 300% uncertainty is assumed for CH_4 emissions from the combustion of biomass residues under some protocols.
- The project developer running the renewable energy plant, rather than the forest owner, receives the carbon credits.

Wider issues

There are several other important considerations. These include whether extending the Woodland Carbon Code to cover carbon storage and the substitution benefits of HWP could give rise to double-counting if the same benefits are accounted for under a different standard in a downstream sector such as construction, potentially undermining the credibility and integrity of climate change mitigation activities. Accounting for potential rebound effects is also included.

Double-counting

Would extending the Woodland Carbon Code to cover the carbon storage and substitution benefits of HWP fit with wider GHG accounting and carbon standards in downstream sectors, or could it pose intractable issues of double-counting that would risk the integrity of the Code? For example, 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 – takes account of the carbon storage benefits of HWP. Thus, were the Woodland Carbon Code extended to the carbon storage benefits of HWP, there would be a risk that they would be double-counted if the same benefits were also claimed by a construction company under a standard such as PAS2050.

In considering potential double-counting, it is useful to note that definitions vary and a variety of forms can be distinguished (Hood, Briner and Rocha, 2014; Schneider, Kollmuss and Lazarus, 2014; Foucherot, Grimault and Morel, 2015). Of the types shown in Table 2 below, the first six are the most relevant when considering the potential for extending the Woodland Carbon Code.

Table 2 Forms of double-counting.

Type		Description
1	double issuance	more than one carbon unit issued for a single benefit
2	double certification	a carbon benefit certified under more than one standard
3	double claiming	a benefit claimed twice towards attaining mitigation pledges
4	double use	a carbon unit used twice to attain mitigation pledges
5	double selling	a carbon benefit sold twice to attain different mitigation pledges
6	double payment	payments for the same carbon benefit to more than one supplier
7	double purpose	a carbon unit counted both towards climate change mitigation and to attain another pledge (e.g. international development finance)

Double-counting can be considered a concern only to the extent that it risks the credibility and integrity of climate change mitigation activities. It is unlikely to be invariably harmful in this respect. Consider, for example, if the same carbon benefit were accounted for under the Woodland Carbon Code and PAS 2050. If each stakeholder and purchaser of any associated carbon units recognises and accepts the role of others involved in generating the benefit without claiming exclusive ownership, inclusion of the carbon benefit under both standards would be unlikely to undermine the credibility or integrity of either party.

A direct approach that explicitly addresses the distribution of ownership rights associated with the carbon benefits of HWP between users of wood products and the owners of the woodlands from which they are sourced could avoid double-counting altogether. This could be achieved in cases where a benefit associated with the use of wood in construction is claimed by both a woodland owner and a construction company, for example, by allocating each a share of the associated carbon units. The share of the woodland owner might be issued at the same time as carbon units are issued for carbon sequestration, with the construction company's share kept back until the wood has been harvested, processed and used, and potentially varied according to the level of carbon saving associated with the specific use selected. Where the carbon substitution and storage benefits from HWP use are expected to be at least as great (after accounting for permanence issues) as the reduction in net carbon sequestration associated with future wood harvesting, then, compared with a case without harvesting, no reduction in the number of carbon units issued to a woodland owner would appear to be warranted. Focusing on differences in overall carbon benefits would be feasible providing that carbon substitution and storage benefits from HWP can be reliably tracked, quantified and verified.

Further exploration of potential double-counting issues can be found in Valatin (2017).

Rebound effects

Rebound effects are closely related to the concept of 'leakage' (emissions that increase elsewhere as a consequence of the project, measure or policy being introduced). They similarly result inadvertently in increased GHG emissions. Rebound effects occur, for example, where a reduction in unit costs leads to greater use of a product or service, or to increased demand for other products or services. In contrast to leakage, increased emissions do not necessarily occur outside the specific (project or geographical) boundary, nor do they always refer to impacts of a project, measure or policy.

---

*Noting that the reduction in coal used (per tonne of iron produced) to less than a third of the previous level had been followed by a 10-fold increase in coal consumption in the Scottish iron industry, Jevons argued that '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 often considered in relation to energy efficiency. In this context, they not only reduce the energy-efficiency savings anticipated, but sometimes result in a negative overall impact. This result is characterized as a case of 'back-fire' or the 'Jevons paradox', which refers to William Stanley Jevon's 1865 hypothesis that energy-efficiency improvements increase rather than decrease energy use*.

Rebound effects can also result from dynamic feedbacks associated with wider policies and changes in relative prices, aspects that are more relevant to carbon savings associated with HWP. For example, policies encouraging greater use of woodfuel (and other forms of renewable energy) may reduce the demand for fossil fuels in energy generation, consequently leading to a reduction in fossil fuel prices, thus stimulating their greater use in other activities. Similarly, policies to encourage the use of HWP and other low carbon materials in construction may reduce the prices of fossil fuel-intensive materials such as concrete and steel, stimulating their greater use elsewhere in the economy (e.g. transport infrastructure). Ultimately, policies encouraging greater HWP use and the development of a low carbon economy may stimulate innovations leading to economic growth, which in turn may lead to increased emissions. (For wider discussion of innovation feedbacks, see: Fölster and Nyström, 2010).

Table 3 lists various rebound effects for a range of contexts, where each one is classified according to its association with energy-efficiency or substitution measures, time-saving, taxes, consumption or input choices.

The two key types of rebound effect (price and structural) to consider in quantifying the carbon savings of HWP are given in the first two rows. Others that are particularly relevant for quantifying the carbon benefits of HWP—infrastructure, installation, norm, transport and usage—are listed in the next five rows. The next most directly relevant rebound effects, namely, income, production and substitution, follow in the next three rows.

Some of these rebound effects (e.g. the installation rebound) are accounted for in traditional life-cycle assessments (LCAs)—for an example of approaches to LCA, refer to Matthews, Hogan and Mackie (2018)—while others (e.g. the production rebound) may be limited by wider regulations (e.g. GHG emission limits for different sectors). There has been little work to date on rebound effects in relation to HWP and none of the current protocols attempt to account for them. However, Grafton, Kompas and van Long (2012) identify a potential 'green paradox' in regard to subsidies for renewable energy use, whereby the direct effect of a reduction in demand for fossil fuels on the extraction of fossil fuels is outweighed by the indirect effect of a reduction in fossil fuel prices. This helps to illustrate the potential importance of a price rebound (see the first row of Table 3).

Monitoring and accounting

The inclusion of carbon storage benefits associated with HWP may appear far from straightforward, given their range of potential uses. Also, the further wood products move through the value chain, the more uncertain carbon storage estimates become (Mensink, 2007). These benefits depend on manufacturing, transportation and end use, as well as end-of-life recycling and disposal processes. Monitoring based upon periodic sampling of carbon storage in wood products is, in general, far more difficult and expensive than for forest carbon pools. To allow for variations in the carbon storage benefits of HWP, uncertainty discounts (Ingerson, 2011) can be used, or buffers that involve withholding a proportion of carbon units to cover the risk that some potential benefits will not arise.

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. The costs of implementing such approaches are expected to be modest as they avoid the necessity for long-term monitoring. Although the proportions of different HWP categories produced in the UK differ from those in the USA, a similar approach would be simple to apply were the UK Woodland Carbon Code extended. Country averages, possibly adjusted for different species, could be used, along with fixed decay rates, such as those used for national level GHG accounting.

However, the extent to which such simple approaches offer robust metrics is unclear. Uncertainties exist, not only concerning the proportion of wood harvested from any given woodland that will be used in the future for different types of HWP and the level of associated wood processing emissions, but also regarding wood product decay rates, as well as in quantifying baseline emissions. (Uncertainty about baseline emissions is pervasive because the baseline is a hypothetical construct, although this is true more widely in relation to quantifying carbon benefits, and does not only affect carbon storage and the substitution benefits of HWP). Where material is processed and used outside the region in which the wood has been grown, emissions associated with the transport of HWP can be significant. In the USA, for example, carbon emissions from processing and transportation may approach the levels of long-term carbon storage in HWP in some cases (Ingerson, 2011), although there still may be carbon substitution savings compared with using alternatives such as concrete and steel, which are associated with relatively high emissions.

Providing a single recommendation detailing the best method to account for the carbon benefits of HWP is beyond the scope of this Note. However, it is overly conservative to assume that all the carbon in wood products with a lifetime of less than

Table 3 Types of rebound effect by relevance to quantifying harvested wood products (HWP) carbon savings.

Category	Type	Description
E	Price	Increased use of low fossil energy-intensive products (e.g. HWP) reduces the (demand for and) prices of fossil fuels, stimulating demand for and greater use of fossil fuels in the wider economy and/or other countries
E	Structural	Increased use of low fossil energy-intensive products (e.g. HWP) reduces the (demand for and) prices of fossil energy-intensive goods and services, increasing demand for the latter and associated energy use
E	Infrastructure	Increased demand for low fossil energy-intensive products (e.g. woodfuel) necessitates new infrastructure (e.g. local wood transport and storage facilities), thus increasing energy use
E	Installation	Adoption of renewable energy (e.g. woodfuel use) or energy-efficiency measures requires energy for the manufacture, transport and installation of new equipment (e.g. new boilers to use woodfuel), thus increasing energy use
E	Norm	Adoption of renewable energy (e.g. biomass boilers) or energy-efficiency measures provides a pretext to neglect wider social norms on limiting emissions, leading to higher emissions in other areas (e.g. flights)
E	Transport	Increased demand for low fossil energy-intensive products leads to economies of scale and reduced transportation costs (e.g. for shipping woodfuel), stimulating longer distance trade in these products and increasing associated energy use
E	Usage	Increased energy efficiency or use of low fossil energy-intensive products leads to less attention to switching off appliances when not in use, increasing energy usage
E	Income	Increased energy efficiency of using a good (e.g. of woodfuel due to more efficient boilers) makes it cheaper to use, thus stimulating increased use
E	Production	Reduction in unit production costs leads producers to lower prices and raises output, increasing energy use (i.e. lower prices stimulate consumer demand)
E	Substitution	Cost savings (e.g. switching to woodfuel where less expensive) lead to increased spending on other goods and services, increasing energy use
T	Activity	Reduced time required for a specific economic activity (e.g. installing a new boiler) increases the time available for and energy use in other activities
I	Capital	Substitution of manufactured inputs (e.g. insulation) for use of fossil fuel (e.g. central heating) increases energy use in manufacturing
C	Consumption	Reduced consumption of goods and services by some leads to price reductions, increasing demand by others and associated energy use
E	Downstream	Increased energy efficiency in producing final goods reduces unit costs, leading to a reduction in sale prices and increased demand, creates additional demand for inputs, increasing the energy use associated with their production and transport
E	Growth	Increased energy efficiency raises productivity and stimulates economic growth, increasing demand for goods and services and their associated energy use in the wider economy
I	Labour	Measures involving greater use of human power instead of fossil fuels (e.g. cycling rather than travelling by car) may lead to an increase in associated expenditure (e.g. on bicycles) and energy used in their production
E	Multiplier	Shifts to higher priced low fossil energy-intensive products and services (e.g. rail travel) from lower priced high fossil energy-intensive products and services (e.g. air travel) may increase total profits and payments to staff and shareholders of supply companies, increasing their consequent demand and energy use
R	Tax	An environmental (e.g. carbon) tax increasing government receipts and expenditure increases the demand for goods and services in the wider economy and associated energy use
T	Time	Reduced time required to use a specific service (e.g. train travel between cities) stimulates demand from users and increases energy use
E	Upstream	Increased energy efficiency in manufacturing reduces unit costs, leading to a reduction in the sales price and increased demand, as well as increased output and demand for producer goods, with each leading to higher energy use

C, consumption; E, energy-efficiency or substitution measures; I, input choices; R, taxes; T, time-saving.

100 years is emitted immediately. Assuming this in the baseline can inflate the credits issued, because it implies that projects could receive credits for emission reductions that may only occur in 99 years' time (Pearson, Swails and Brown, 2012). Instead, it is preferable to use an average based on modelling retirement and emissions from wood products over many cycles and the associated carbon stored in the HWP pool over the long term. Alternatively, a radiative forcing approach can be adopted, based upon estimating the atmospheric impact of keeping carbon out of the atmosphere over a product's lifetime (Pearson, Swails and Brown, 2012).

Permanence and equivalence issues between carbon sequestration and the carbon substitution and storage benefits of HWP need to be considered when developing an approach to accounting for both. The carbon sequestration benefits of woodland creation projects are currently computed under the Woodland Carbon Code over up to 200 years, with those involving cycles of clearfelling and restocking based upon a long-term average that is typically between 30 and 50% of the cumulative total carbon sequestered over one rotation (West, 2018). In contrast to carbon sequestration, the average carbon substitution and storage benefits of HWP associated with a woodland creation project tends to increase over time (due to more wood being harvested). Nonetheless, a long-term average could potentially also be used to take account of the carbon substitution and storage benefits of HWP, although detailed consideration of the best approach to this is beyond the scope of this Note.

The failure of existing carbon standards to account for rebound effects may be because they are complex and expensive to estimate. However, this represents a significant potential weakness in quantifying the carbon substitution benefits of HWP, and particularly in regard to reductions in fossil fuel use. Increased HWP use could potentially influence fossil fuel supply and demand in the wider economy in ways that stimulate greater use of fossil fuels in other activities.

Whether extending carbon standards for woodland creation projects to cover benefits of HWP is worthwhile depends partly on the cost of quantifying and certifying these benefits. While forestry options deliver a range of ecosystem services in addition to climate change mitigation – such as the absorption of other pollutants like ammonia and nitrates – there can also be potential disadvantages. The emission of particulates – matter in the form of minute separate particles – is associated with the use of (especially) damp woodfuel in domestic fires. This is a cause of concern: for instance, the UK Committee on Climate Change advised the UK Government not to support the use of biomass for heat in urban areas (Committee on Climate Change, 2018). Potentially adverse impacts on forest carbon stocks (e.g. Matthews, Hogan and Mackie, 2018) should also be considered, if the extension of carbon standards to cover projects involving wood production through forest management of existing 'under-utilised' woodlands is to be contemplated.

Recommendations

This report provides a technical contribution to discussions about whether it is feasible to extend the UK Woodland Carbon Code to the carbon storage and substitution benefits of HWP. Further work will be needed to assess the practical feasibility and whether it can be done in a robust way that underpins market confidence and maintains the integrity of the Woodland Carbon Code. In terms of exploring the technical potential, it is recommended to:

- consider adopting a system of units for carbon storage that takes account of the expected lifespan of different product types (e.g. sawn softwood, sawn hardwood);
- 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);
- consider applying a simple decay function to the carbon stored for each product category;
- consider how transport emissions can best be included in estimating net carbon savings and the extent to which their inclusion would provide incentives for local processing and HWP use to help increase overall carbon benefits to society;
- explore potential mechanisms to allocate units for carbon storage and substitution between woodland owners and wood users that would provide incentives to increase domestic timber supply and quality, the carbon storage and substitution benefits per unit of wood and overall net benefits to society;
- explore the costs and benefits of empirical monitoring of carbon storage and carbon substitution;
- consider potential double-counting issues further and how these can be minimised;
- investigate how carbon storage and substitution benefits, taking rebound and leakage effects into account, can be quantified by drawing on international trade and inter-sectoral models.
- Consider further whether covering carbon storage and substitution benefits of harvested wood products on the basis of national average wood use, product assortment and generic half-lives would fit with project level projections of carbon sequestration on which the Woodland Carbon Code is based.

References

AMERICAN CARBON REGISTRY (2017). *Methodology for the quantification, monitoring, reporting and verification of greenhouse gas emission reductions and removals from afforestation and reforestation of degraded land.* Version 1.2. American Carbon Registry, Arlington, VA, USA.

AMERICAN CARBON REGISTRY (2018). *Improved forest management methodology for quantifying GHG removals and emission reductions through increased forest carbon sequestration on non-federal U.S. forestlands.* Version 1.3. American Carbon Registry, Arlington, VA, USA.

CLIMATE ACTION RESERVE (2017). *Forest project protocol.* Version 4.0. Climate Action Reserve, Los Angeles, CA, USA.

UNFCCC (2017). ACM0018. *Large-scale consolidated methodology: electricity generation from biomass residues in power-only plants.* Version 4.0. Clean Development Mechanism. United Nations Framework Convention on Climate Change, Bonn, Germany.

UNFCCC (2018). ACM0006. *Approved consolidated baseline and monitoring methodology: consolidated methodology for electricity and heat generation from biomass.* Version 14. Clean Development Mechanism. United Nations Framework Convention on Climate Change, Bonn, Germany.

COMMITTEE ON CLIMATE CHANGE (2018). *Biomass in a low-carbon economy.* London, UK.

FÖLSTER, S. and NYSTRÖM, J. (2010). Climate policy to defeat the green paradox. *Ambio* 39, 223–35.

FORESTRY COMMISSION (2014). *The Woodland Carbon Code.* Version 1.3. Forestry Commission, Edinburgh.

FORESTRY COMMISSION (2020). *Forestry Statistics 2020.* Forest Research, Edinburgh.

FOUCHEROT, C., GRIMAULT, J. and MOREL, R. (2015). *Contribution from I4CE on how to address double counting within voluntary projects in Annex B countries.* Note. Institute for Climate Economics, Paris, France.

GRAFTON, R.Q., KOMPAS, T. and VAN LONG, N. (2012). Substitution between bio-fuels and fossil fuels: Is there a green paradox? *Journal of Environmental Economics and Management* 64(3), 328–41.

HOOD, C., BRINER, G. and ROCHA, M. (2014). *GHG or not GHG: Accounting for Diverse Mitigation Contributions in the Post-2020 Climate Framework*. Paper 2014(2). Climate Change Expert Group, OECD, Paris, France.

INGERSON, A. (2011). Carbon storage potential of harvested wood: summary and policy implications. *Mitigation and Adaptation Strategies for Global Change* 16, 307–23.

MATTHEWS, R., HOGAN, G. and MACKIE, E. (2018). *Carbon impacts of biomass consumed in the EU: supplementary analysis and interpretation for the European Climate Foundation.* Project report for ECF. Forest Research, Farnham.

MENSINK, M. (2007). *Framework for the development of carbon footprints for paper and board products.* Confederation of European paper industries, Brussels, Belgium.

MINER, R. and LUCIER, A. (2004). *A value chain assessment of climate change and energy issues affecting the global forest-based industry.* A report to the WBCSD Sustainable Forest Products Industry Working Group. NCASI. www.greenbiz.com/sites/default/files/document/CustomO16C45F60545.pdf. Accessed 21/4/21.

NILES, J. and SCHWARZE, R. (2001). Editorial. *Climatic Change* 49, 371–6.

PEARSON, T., SWAILS, E. and BROWN, S. (2012). *Wood product accounting and climate change mitigation on projects involving tropical timber.* Report TMT-PA 007/11 Rev.1 (1). International Tropical Timber Organization/Winrock International, Washington D.C., USA.

PENMAN, J., GYTARSKY, M., HIRAISHI, T., KRUG, T., KRUGER, D., PIPATTI, R., BUENDIA, L., MIWA, K., NGARA, T., TANABE, K. and WAGNER, F. (eds) (2003). *Good practice guidance for land use, land-use change and forestry.* Intergovernmental Panel on Climate Change (IPCC) National Inventories Programme Technical Support Unit, Institute for Global Environmental Strategies. Hayama, Japan.

SCHNEIDER, L., KOLLMUSS, A. and LAZURUS, M. (2014). *Addressing the risk of double counting emission reductions under the UNFCCC.* Working Paper 2014-02. Stockholm Environmental Institute, Sweden.

SCOTTISH FORESTRY (2020). Climate mitigation: woodland creation and management. Information Note. Edinburgh, UK.

SORRELL, S. (2009). Economy-wide rebound effects. In: S. Sorrell and H. Herring eds. *Energy efficiency and sustainable consumption: the rebound effect*. Palgrave Macmillan, Basingstoke, UK. pp. 136–64.

US DEPARTMENT OF ENERGY (2006). *Technical guidelines for voluntary reporting of greenhouse gas program.* Part I: Appendix. Office of Policy and International Affairs, US Department of Energy, Washington, D.C., USA.

VALATIN, G. (2012). Additionality and climate change mitigation by the UK forest sector. *Forestry* 85(4), 445–62.

VALATIN, G. (2017). *Harvested wood products and carbon substitution: approaches to incorporating them in market standards.* Research report. Forest Research, Farnham.

VERRA (2015). VM0034. *British Columbia Forest Carbon Offset Methodology.* Version 1.0. Verified Carbon Standard. Verra, Washington, D.C., USA.

VERRA (2016). VM00010. *Methodology for improved forest management: conversion from logged to protected forest: approved VCS methodology.* Version 1.3. Verra, Washington, D.C., USA.

WEST, V. (2018). *Using the WCC Carbon Calculation Spreadsheet Version 2.0.* UK Woodland Carbon Code. https://woodlandcarboncode.org.uk/images/PDFs/WCC_CarbonCalculation_Guidance_V2.0_March2018.pdf. Accessed 21/4/21.

Enquiries relating to this research should be addressed to:

Gregory Valatin
Forest Research
Alice Holt Lodge
Farnham, Surrey, GU10 4LH

+44 (0)300 067 5699

gregory.valatin@forestresearch.gov.uk
www.forestresearch.gov.uk

For more information and to view and download Forest Research publications, visit:

www.forestresearch.gov.uk/publications

We will consider all requests to make the content of our publications available in alternative formats. Please send any such requests to publications@forestresearch.gov.uk

FRRN041/PURE/WWW/JUL21

ISBN: 978-1-83915-011-1