Wood in construction, a policy and data summary

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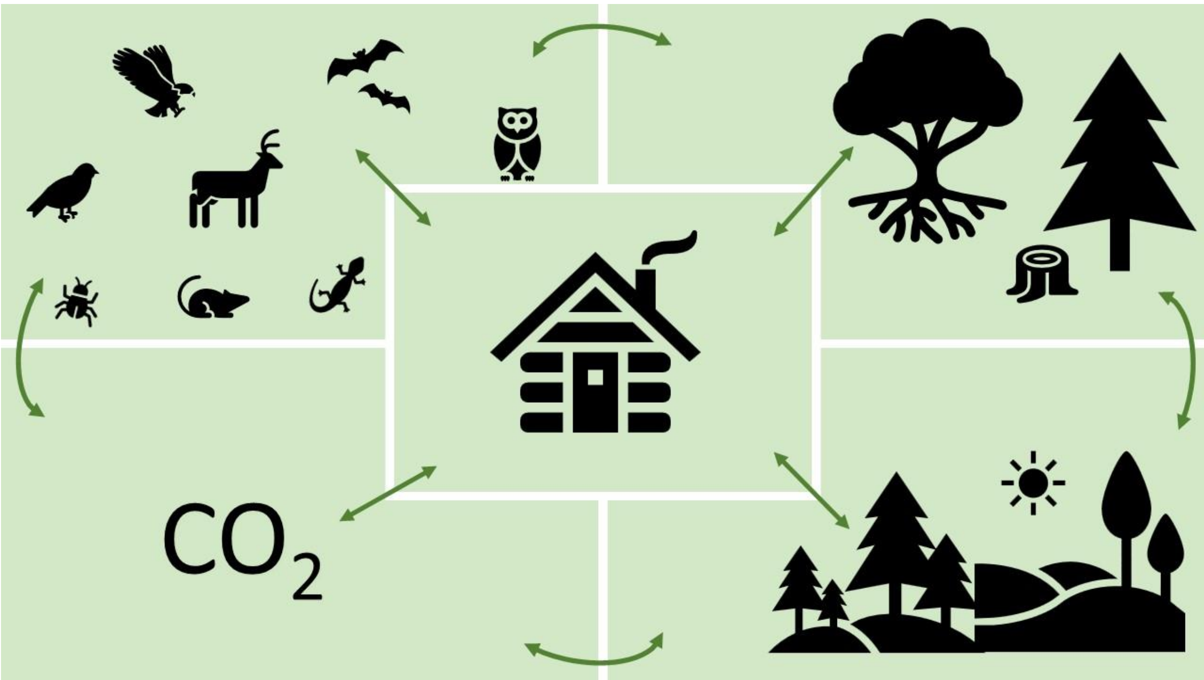

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Executive Summary

This report provides a policy background and information on carbon emissions and sequestration in the construction industry, along with recommendations for policy. The UK has set a legally binding target of net-zero emissions of greenhouse gases by 2050, and Scotland has set the earlier target of net-zero emissions by 2045. One of the proposed measures to meet these targets is via increased woodland creation and increased use of wood to substitute higher carbon intensive materials. The Committee on Climate Change advised to encourage the construction industry to increase the use of wood fibre where appropriate.

The use of wood in construction has two climate benefits:

1. Reducing the embodied emissions of greenhouse gases (those caused by the extraction, manufacture, transportation, assembly, maintenance, demolition and disposal of the products and elements in an asset).
2. Increasing the amount of stored carbon.

This report further highlights the need to look at forestry in a holistic way, where the carbon sink within the forest system, the carbon storage in harvested wood products, and the avoidance of fossil emissions by product substitution are all taken into account.

Introduction

The Landscapes as Carbon Sinks project aims to investigate the interventions that can be made to accelerate the land sector's contribution to Scotland’s 2045 net-zero emissions of greenhouse gases target. As part of this initiative, we consider how the carbon benefits of wood fibre in construction can be scaled-up, using Scotland as an example. Using information derived from three sequential expert workshops, we developed a system map on the factors that currently enable or inhibit the use of wood from Scottish forests in the UK construction sector (https://centre-for-sustainable-forests-and-landscapes.kumu.io/wood-in-construction-system-map). This report is linked to the system map and provides policy background and information on carbon emissions and sequestration in the construction industry, along with recommendations for policy.

Planting trees is considered to be an important pathway for mitigating climate change. This mitigation potential of woodlands and forestry can be realised through the carbon sequestration within the forest habitat itself, as well as in the long-term storage of carbon in forest-derived products, and through the substitution of carbon intensive materials, such as steel, by wood-based materials. Therefore, it is important to consider all three carbon functions of forested lands: sink, storage, and substitution.

Summary of main policies on wood in construction

General climate change policies

To keep the UK in line with the commitments it made as part of the 2016 Paris Agreement to keep global warming under 2 degrees, the UK has set a legally binding target of net-zero emissions of greenhouse gases by 2050. Scotland has set a more ambitious target of net-zero by 2045. The Climate Change Act 2008 set a UK target to reduce net emissions of greenhouse gases by at least 80% of the 1990 baseline, and this forms the basis for the UK’s approach to tackling and responding to climate change. The Climate Change Act 2008 (2050 Target Amendment) Order 2019 amends to 2008 act to the more ambitious target of net zero emissions of greenhouse gases by 2050. The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, which amends the Climate Change (Scotland) Act 2009, sets Scotland’s target to reduce greenhouse gas emissions to net zero by 2045, with interim targets for reductions of at least 56% by 2020, 75% by 2030, and 90% by 2040. A strategic delivery plan for meeting these targets must be published every 5 years, as required by Scotland’s legislation. The climate change plans cover a 10-15 year period from publication. The third Climate Change Plan was published in February 2018, and an update, expected by end of 2020, to this plan is currently underway to reflect the more ambitious targets set in the 2019 Act.

The Intergovernmental Panel on Climate Change (IPCC) provides the world with objective, scientific information on how human-induced climate change impacts nature, politics and economics and its risks. For the UK, the Committee for Climate Change (CCC), a non-departmental public body, was established through the Climate Change Act 2008, and ensures that emissions targets are evidence-based and independently assessed. The CCC has a statutory role in mitigation and adaptation of climate change.

In Scotland, the Land Use Strategy (LUS) was produced as a requirement of section 57 of the Climate Change (Scotland) Act 2009. It sets out a strategy by which climate targets might be achieved through land use, land use change, and forestry (LULUCF), and includes the objective of sustainable 'integrated' land use. It brings together a range of sectors and industries (e.g. agriculture, forestry, academia, food and drinks sector, etc). In policy there is an increasing emphasis for integrating land use, such as agriculture and forestry, with other land uses to deliver multiple benefits for Scotland. Key Scottish Government policies, such as the National Planning Framework 3, and Scottish Planning Policy (SPP) both identify Scotland's LUS as crucial to achieving this.

Additional to the LUS, the Scottish Government is committed to establishing Regional Land Use Partnerships (RLUPs) by 2021, which stems from the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019. These RLUPs aim to drive the delivery of the land use change needed to meet the 2030 and 2045 targets by promoting governance systems that enable more integrated approaches that empower local decision making. Their implementation is hindered by uncertainties regarding their functions and structure (Ponta et al., 2020), namely:

1. There are profound historic and socio-economic differences across Scotland and there is no one-size-fits-all model, even when two initiatives have the same official designation.
2. Most partnerships play an advisory role and lack enforcement powers.
3. Land ownership is the decisive authority when it comes to land management.
4. Ensuring continuity is a challenge faced by most partnerships.
5. Partnerships recognize the value of investing in social capital, but this does not always translate into an engagement strategy, and there are trade-offs to consider.
6. Landscape scale approaches are becoming the norm, but agencies and NGOs often do not have the resources to manage these large and complex projects.
7. The commitment and dedication of individuals – board members as well as volunteers – have been crucial for the performance of collaborative initiatives.

The first pilot RLUPs are expected to be established in early 2021, with the aim to have 12-16 established by 2023.

Wood in construction policies

In the Climate Change Plan (2018) there is one core policy outcome for wood in construction:

"*Increase the use of sustainably sourced wood fibre to reduce emissions by encouraging the construction industry to increase its use of wood products where appropriate*."

For this outcome there is one sub-policy identified set out as:

"*In collaboration with the private forest sector and other public sector bodies the Scottish Government will implement the Timber Development Programme through an annual programme of projects that support the promotion and development of wood products for use in construction*."

The CCC advised that to meet the net zero targets, at least 15,000 ha/yr of forest should be planted in Scotland by the mid-2020s. The Scottish Government set out to do this in Scotland's Forestry Strategy (SFS) 2019-2029. The Programme for Scotland 2020-2021 announced that annual woodland creation targets would be increased "*from the current level of 12,000 hectares in 2020/21 up to 18,000 hectares in 2024/25*". Given this forest creation target, the Climate Change Plan outlines the aim to increase the use of Scottish wood products in UK construction from 2.2 to around 3 million cubic metres by 2031-2032.

Renewable biological resources can replace fossil resources in products, processes, and services. The bioeconomy represents the economic potential of this. The UK & Industry joint bioeconomy strategy 2018-2030 has 4 main goals:

- maximise productivity and potential from existing UK bioeconomy assets
- create the right societal and market conditions to allow novel bio-based products and services to thrive
- capitalise on our world class research, development, and innovation base to grow the bioeconomy
- deliver real, measurable benefits for the UK economy

The strategy claims there is potential for more forests in the UK, which will help ensure wood processing and bioenergy businesses have access to sufficient wood. Understanding resource flows and creating national and international supply chains for new businesses is critical for growth of the bioeconomy.

The Forest and Timber Technologies Industry Leadership Group wrote an ambitious strategy for Scotland's forest and timber technologies sector to 2030. While not a government policy document, the strategy was endorsed by the Cabinet Secretary for the Rural Economy. The Scottish Government Forestry Strategy states that it will support the ambitions of the Forest and Timber Technologies sector as set out in their strategy. Their vision is that "*in 2030 the Scottish forest and timber technologies sector's present contributions to the sustainable low carbon growth of the Scottish economy from using virgin, reused and recycled wood fibre will have doubled*". To realise this ambition there is a need for more production oriented commercial forests to be planted in Scotland, since they state that the potential coniferous roundwood availability is forecast to decrease significantly after 2030. Even with a rapid increase in planting now, there is still likely to be a domestic supply gap after 2030. Increasing the productivity of current forests is therefore another objective of the Leadership Group. Companies need to have confidence about the reliability of future wood supplies in Scotland when making decisions about allocating capital to investments and funding innovation. The strategy has five immediate strategic priorities for the forest and timber technologies sector (Scottish Forest & Timber Technologies, 2018):

1. Maximise the economic outputs of Scotland's forest and fibre resource.
2. Improve the safety and productivity of the wood fibre supply chain.
3. Expand markets and add value
4. Develop a work force with skills for the future which support inclusive growth.

5. Understand and communicate the forest and wood-based industries' contributions to Scotland's economy.

One of the four prioritising areas in the Circular Economy Strategy for Scotland is the construction and the built environment: construction accounts for about 50% of all waste in Scotland and has a major influence on efficient use of resources (Scottish Government, 2016). The strategy aims to stimulate debate on a more comprehensive approach to producer responsibility, and argues that this should be done through a single framework, for all product types, that drives choices for reuse, repair, and remanufacture, whilst also fully exposing and addressing the costs of recycling and disposal. Reducing waste is the priority, but maximising the value of biological resources that would otherwise end up in lower value uses or as waste is also emphasised.

A research project into offsite construction to support policy decisions and industry innovation found that 80% of new houses in Scotland are already built using offsite construction methods (Deakin et al., 2020). A clear national strategy is needed to support the industry, and to set a road map for the future. The study found that the current manufacturing sector wants to expand and progressively adopt more advanced manufacturing systems which should be captured in this national strategy for offsite construction. The strategy should also be seen as a vehicle which contributes to the targets that Scottish Government has set for net zero carbon, zero waste, and the circular economy (Deakin et al., 2020).

Timber import policy

When increasing the use of wood in construction it is also important to look at the policies on imported wood. The trade in timber products has been linked with deforestation and forest degradation for a long time (Jennings et al., 2017). The total annual footprint of imported timber into the UK between 2011-2015 is 4.2 million ha. This is timber used for fuelwood, furniture, particleboard, plywood, and sawnwood. Most of it comes from low-risk countries, however, an estimated 750,000 ha of the footprint comes from Brazil, China, and Russia, where there are high risks of deforestation and social challenges. Well-established certification schemes help to mitigate the risks and are widely used by UK companies. However, they do not cover all imported products, and there is no reliable information on the levels of certified products on the market. The EU Timber Regulation is intended to close the market to illegal timber, and the UK government's Timber Procurement Policy is creating market incentives for sustainably produced timber (Jennings et al., 2017).

Between the 25th of August and the 5th of October 2020, the UK government issued a consultation on proposed legislation to make it illegal to use or trade commodities, or goods incorporating them, linked to illegal deforestation. It also requires UK companies to conduct due diligence of procurement processes. This was one of the key recommendations of the independent taskforce Global Resource Initiative, which looked at how the UK could make its international supply chain greener (Global Resource Initiative Taskforce, 2020). The proposed law would only require a relatively small number of large businesses to ensure legality of the commodities they use. Earthsight (2020) have written an article in response to the proposed legislation, highlighting that it is the first concrete statement of intent from any government worldwide to try to de-link deforestation from supply chains through binding legislation, and that this should be applauded. Nonetheless, they also argue that focussing only on illegal deforestation will incentivise producer countries to weaken their forest conservation laws to maintain access to the UK market. For companies and authorities, it is easier to determine whether goods originate from deforestation then it is to also determine of that was done legally. Further, the only proposed penalty for non-compliance are fines, and there is no suggestion that goods could be seized when violating the law. Earthsight highlights that it is essential that any law allows for non-compliant goods to be seized and removed from the market. Otherwise the illegal products could be "legalised" through fines (Earthsight, 2020).

Summary of main reports on GHG and wood in construction

Embodied emissions and sequestered carbon in buildings

In 2018 total embodied emissions (those caused by the extraction, manufacture, transportation, assembly, maintenance, demolition and disposal of the products and elements in an asset) for residential new build across the UK are estimated at 3.04 $MtCO_2e$, and sequestered carbon at 1.25 $MtCO_2e$ (Spear et al., 2019). A high-level analysis for non-residential buildings showed a 43.8 to 78.9 $KtCO_2e\ yr^{-1}$ and sequestered carbon of -22.2 to 40 $KtCO_2e$ (Table 1, Spear et al., 2019).

According to the UK Green Building Council, embodied emissions can account for over half of the overall carbon footprint of a building across its lifetime (UK Green Building Council, 2017). Another major contributor to emissions is the operational phase, mainly from energy and water use. Emissions directly related to the construction and demolition phases are only a few percent at most of the overall lifecycle emissions.

Table 1 Estimation of timber usage (air dry tonnes) within current timber non-residential structures, used to derive embodied emissions (tCO2e) and stored sequestered carbon (tCO2e) for timber structures, and for counterfactual steel hybrid and concrete systems (from Spear et al., 2019).

	Timber and engineered wood material used (t p.a.)	Stored sequestered carbon, timber system (t CO_2e p.a.)	Embodied emissions, timber system (t CO_2e p.a.)	Embodied emissions, steel hybrid system (t CO_2e p.a.)	Embodied emissions, concrete system (t CO_2e p.a.)
Timber framed non-residential	3,700 to 6,600	-5,800 to 10,200			
CLT non-residential	4,700 to 5,500	-7,300 to 8,500			
Glulam non-residential	5,900 to 13,700	-9,100 to 21,200			
Total	**14,300 to 25,700**	**-22,200 to -40,000**	**6,900 to 12,400**	**19,000 to 34,200**	**17,900 to 32,300**
i.e. abatement relative to alternative				12,200 to 21,900	11,100 to 19,900

Carbon emissions in construction must be lowered to achieve net zero emissions. The target in the Construction Sector Deal, a sector deal between government and construction industries, which builds on the Construction 2025 strategy, is a 50% reduction in greenhouse gas emissions by 2025 (based on the industry performance in 2013). This will require reductions in both the operational and embodied emissions (HM Government, 2018b).

Concrete and steel are fundamental construction materials with high CO_2 emissions; each responsible for about 4% of global CO_2 emissions. One of the main components of concrete is Portland cement, which is the most carbon-intensive element of concrete manufacturing. Over 50% of the carbon footprint of Portland cement is derived from the chemical reaction involved in making it, rather than the energy required for its manufacture. It has proven difficult to find alternatives that are available in the volume required to meet the global demand for cement (KLH Sustainability, 2019).

Steel production also has a high CO_2 footprint. About 20% of the total embodied carbon emissions of primary steel production is attributable to the chemical reaction taking place in its manufacture. Recycled steel has a much lower carbon intensity than primary steel (0.47 tCO_2/t steel compared to 2.89 tCO_2/t steel). The supply scrap steel is roughly equivalent to demand for new steel in the UK and some European countries, but much of the rest of the world has yet to reach this equilibrium (KLH Sustainability, 2019). Even with substantial innovation and investment, it is unlikely that emissions associated with steel and concrete can be greatly reduced to the extent that they become carbon neutral (KLH Sustainability, 2019). An alternative, therefore, is their replacement with wood in construction.

Spear et al. (2019) compared embodied emissions and sequestered carbon of typical UK residential buildings for different construction systems. In 2016, 28% of new builds where timber framed in the UK, although the proportion in Scotland, at 83%, is much higher than the rest of the UK (Structural Timber Association, 2017). The embodied emissions of a timber framed house are about 20% (1.7-3.2 tCO_2e) lower than a functionally equivalent masonry house. The timber framed house also stores about 50% (2.0-4.2 tCO_2e) more sequestered carbon in structural elements than a masonry house. When substituting cross laminated timber (CLT) for concrete, a reduction of approximately 60% in carbon emissions is achieved and CLT stores 400% more carbon than a concrete structure (Spear et al., 2019). Timber frame buildings still have significant levels of embodied emissions, mainly due to the use of concrete for foundations and brick used for exterior wall cladding (Spear et al., 2019). This shows how important it is to also reduce the emissions of concrete.

Wood cladding can also reduce embodied emissions and store carbon in buildings. Using timber cladding instead of brick facing for only 10% of the exterior wall area of all residential new builds would result in a reduction in embodied carbon of 35 $KtCO_2e$ (Spear et al., 2019). Increasing this to a 25% exterior wall area with wood cladding translates to a reduction of 88 $KtCO_2e$, or an overall 2.9% reduction in total embodied carbon of the building materials. Timber cladding usually needs replacing every 25-30 years, but the lower emissions per unit of timber cladding would still result in a reduction of total embodied carbon (Spear et al., 2019).

Total greenhouse gas emissions of sawn timber used in construction is between -570 and -8,376 kg CO_2e per tonne of sawn timber depending on displacement and disposal assumptions. The

-570 number is when sawn timber replaces steel in construction and, after the end of the life of the building, wood waste is disposed into landfill with energy recovery (with associated CH_4 emissions from the landfill site and avoided GHG emissions from displaced grid electricity). It also assumes that forest roads are subjected to a high maintenance strategy. The -8,376 number is when sawn timber displaces brick cladding and, at the end of the life of the building, waste wood is disposed of by incineration with energy recovery (Whittaker et al., 2010).

Offsite construction

Offsite construction is an umbrella term that can refer to a variety of different construction systems. Here the following definition is used: "*the design, planning, manufacture and pre-assembly of construction elements or components in a factory environment prior to installation on-site at their intended, final location*" (UK Parliament, 2018). Eighty percent of Scotland's new homes are built using offsite systems. The majority of these are open frame timber panel systems, rather than more advanced closed panel, modular, or volumetric systems. Using offsite construction methods has been shown to reduce embodied greenhouse gas emissions, life cycle energy use, production of construction waste, material requirements, and water consumption. In 2018 there were 33 companies, and 19 sub-assembly suppliers, within the offsite manufacturing sector across Scotland. Seventy-five percent of these use timber, 15% steel, and 10% concrete components (Deakin et al., 2020). When comparing a traditional residential building with a low energy, affordable house built using an offsite panellised modular timber frame system, a 34% reduction in embodied carbon was found for the latter (Monahan and Powell, 2011).

Insulation materials

Thermal insulation materials have small carbon footprints when compared to other building materials. However, they significantly reduce a building's environmental impact, due to the energy saved on heating and, potentially, on cooling. Extruded polystyrene, polyurethane foam, foam glass and mineral wool of high density have the greatest carbon footprint of thermal insulation materials in building envelopes, while low density wood fibre wool had the lowest (Figure 1) (Kunič, 2017).

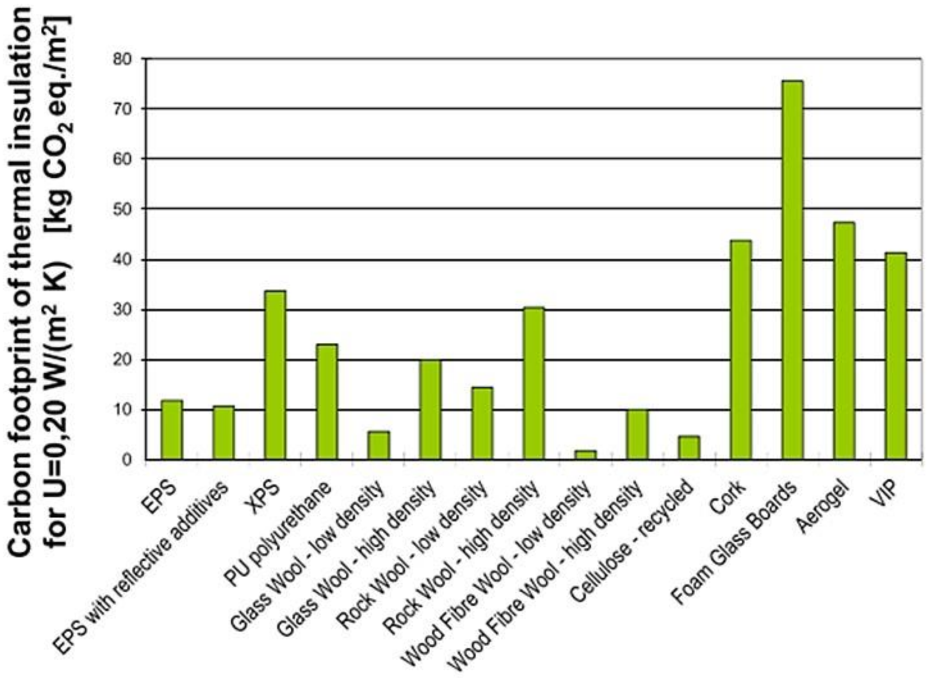

Figure 1 Carbon footprint of thermal insulation materials needed to achieve the value of thermal insulation of the building envelope with the same amount of thermal transmittance transfer, U = 0.20 W/(m^2 K); presented per unit area of building thermal envelope (m^2). With EPS= Expanded polystyrene, XPS= Extruded polystyrene, PU= Polyurethane, and VIP= Vacuum insulation panel (from Kunič, 2017).

Carbon footprint of local versus imported timber

In 2019, 34% of sawn timber and 50% of wood-based panels consumed in the UK were supplied from UK forests (Forest Research, 2020b). Table 2 shows the estimated split between UK manufactured and imported construction materials for 2018 (Spear et al., 2019). Supply chains for offsite construction companies are mostly located within the UK, with 85% of the products sourced from suppliers based in Scotland (Deakin et al., 2020).

Table 2 Split between UK manufacture and import used in UK carbon accounts, estimations for 2018 (from Spear et al., 2019).

	Est. UK manufacture	Est. import
Sawn wood	33%	67%
CLT	0%	100%
Wood-based panels	67%	33%
Plasterboard	89%	11%
Inorganic insulation	90%	10%
PUR insulation	90%	10%
Brick	90%	10%
AAC block	80%	20%
Cement mortar	84%	16%
Reinforced concrete	80%	20%
Fibre-cement cladding	50%	50%

The target in the Construction Sector Deal is a 50% reduction in the trade gap between total exports and total imports of construction products and materials by 2025 (based on the industry performance in 2013) (HM Government, 2018b). Currently demand for Scottish timber is limited to a small range of tree species which produce construction grade material, with the remaining market share provided by imports. At less than 5% a year the rate of change to the timber resource in the UK is slow (Beauchamp, 2018). This is due to regulations limiting the area that can be felled annually and the limited harvesting capacity. This slow rate of change limits the adaptation ability of the industry, but also gives the processing sector time to adapt to gradual changes in timber composition. With the construction sector committed to reduce the trade gap between exports and imports of construction products and materials, combined with policies to increase the use of sustainably sourced wood fibre, the demand for Scottish timber is likely to increase. Timber availability will, however, likely be impacted by climate change, both domestically and internationally. An international supply chain might therefore increase the resilience of companies to domestic timber supply risks (Beauchamp, 2018). Researchers have also highlighted that increasing the demand for wood could increase foreign imports, which could have a negative impact on forest biodiversity elsewhere (Mayer et al., 2005).

To understand the effects of importing less construction material on the UK net carbon account it is important to understand how the emissions are counted. The construction sector falls within Scope 3 of the Greenhouse Gas Protocol, and accounting is covered by the Corporate Value Chain standard. Emissions from manufacturing most construction products are consequently already accounted for within the EU ETS component of national accounts. This means that the carbon is accounted in the nation where the manufacture occurs, and in some cases within the non-traded emissions component (for example the biomass-based elements such as timber). Spear et al. (2019) conducted an analysis of which part of the embodied emissions of the residential sector were attributable to UK manufacturing, and which part to imports, for 2018 based on estimated market shares of products and their origin (Table 2). They found that 81% (2.48 $MtCO_2e$) was attributed to the UK and 19% (0.56 $MtCO_2e$) to imports. The split within the different materials categories is shown in Figure 2.

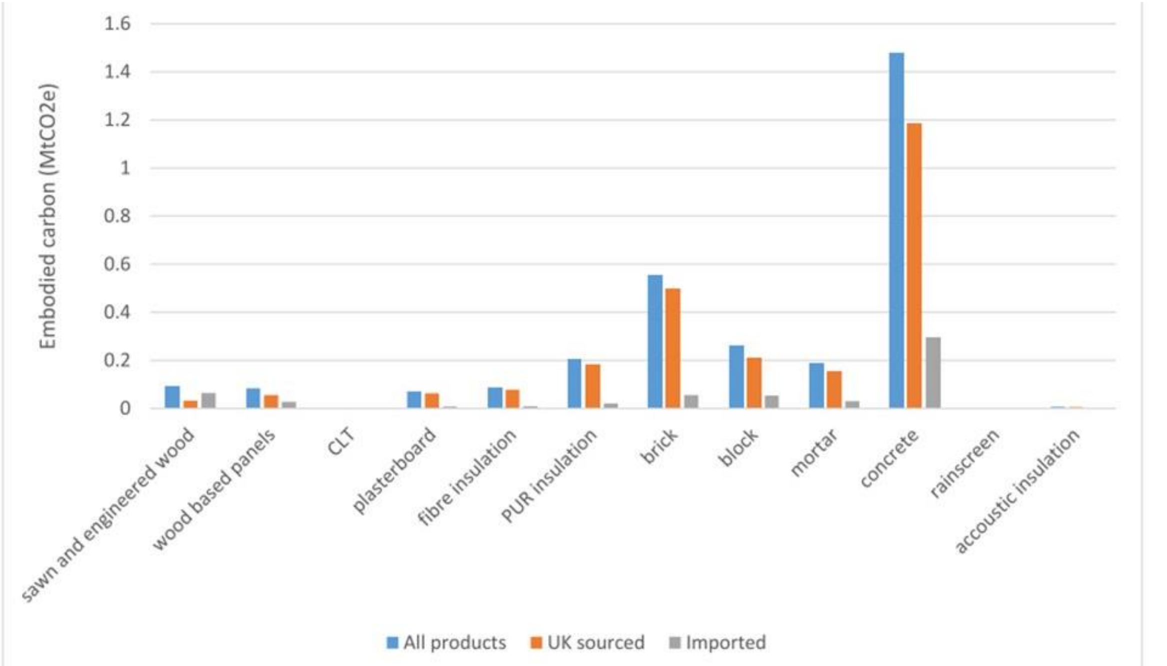

Figure 2 Total embodied carbon in 2018 by material type, and the embodied carbon attributable to UK carbon accounts vs. imported products where embodied carbon is accounted elsewhere (structural elements only) (from Spear et al., 2019).

Transport

Emissions from transporting timber are made up of direct and indirect emissions. With direct emissions being, for example, fuel used by lorries, and indirect emissions derived from the upkeep of vehicles and road maintenance. Fuel consumption of lorries makes up 49% of the timber's greenhouse gas emissions during transport, and 29% of emissions is from manufacturing and maintaining timber lorries. GHG emissions from timber transport are 35 kg CO_2e per tonne of sawn timber used in construction, which is only 6% of the total GHG emissions of 568.7 kg CO_2e per tonne of sawn timber, when excluding avoided emissions from the use of sawmill waste as a fuel, substitution of other construction materials and end-of-life disposal, and carbon sequestration (Whittaker et al., 2010). Table 3 shows a comparison of timber transport emissions to Perth, Scotland, from various origins, using different transport methods. The least carbon intensive route for a company operating in Scotland is from a supplier in Scotland transporting materials using a 44 tonne (28 tonne payload) lorry (Burnett, 2006).

Table 3 Comparison of timber transport emissions, from different countries to Perth, Scotland and using different transportation means (from Burnett, 2006).

Example journey - Sweden to Scotland	Methods of transport	Total tCO_2 per tonne transported
Vaxjo - Gothenburg - Newcastle - Perth	60 tonne lorry, large ship, 44 tonne lorry.	0.038

Example journey - Latvia to Scotland	Methods of transport	Total tCO_2 per tonne transported
Gulbene - Riga - Newcastle - Perth	Train, small ship, 44 tonne lorry.	0.128

Example journey - Canada to Scotland	Methods of transport	Total tCO_2 per tonne transported
Shawinigan - Montreal - Liverpool - Perth	44 tonne lorry, Large ship, 44 tonne lorry	0.134

Example journey - Scotland (locally sourced)	Methods of transport	Total tCO2 per tonne transported from origin to Perth
Fort William - Perth	44 tonne lorry	0.007

Timber gap after 2030

As mentioned previously, due to a lack of planting trees in the 1990s and early 2000s the potential coniferous roundwood availability is forecast to decrease significantly after 2030. A possible solution for the forecasted timber gap, is short rotation forestry (SRF), where faster growing trees are planted and harvested in 8-20 years, instead of 30-plus years. A range of species can be grown as SRF, from conifers including Sitka spruce, Grand fir, Noble fir, Douglas fir, Western Red Cedar and Western Hemlock, to broadleaf species like Birch, Aspen, Poplar, Alder, Lime and Sycamore. It is important to also consider the potentials of SRF to adapt to, and mitigate, climate change. Soil carbon content changes with the establishment of SRF, with most studies showing declining soil organic carbon by up to 20% in the initial years following planting, followed by 57% improvement in soil carbon (Singh et al., 2019). In the UK soil carbon sequestration is likely to increase from ash (and broadleaves) to spruce (and conifers) (McKay, 2011). Soil carbon sequestration of SRF is highest on carbon poor soils, such as many arable soils, where leaf litter inputs and tree rooting will enrich the soil carbon levels (McKay, 2011). There is, however, a trade-off with food production if mineral arable soils are to be planted with trees, especially considering projections of a significant shortage of farmland by 2030 (Montague-Fuller, 2014).

Holistic view on forestry

Woodlands support a number of ecosystem services including carbon storage, water supply and regulation, resource production, energy, biodiversity, clean air, recreational, cultural and many others (Apsalyamova et al., 2015). They can also have a support function, for example shading for cattle, or cooling in urban settings.

A silvicultural system is the process of managing, harvesting, and regenerating a forest. Utilising different ecosystem services (for example conservation of an ancient semi-natural woodland, or production of timber from a conifer plantation) is likely to lead to different silviculture systems used. There are many different silvicultural systems, though broadly they can be split in two groups: even-aged (one or two distinct tree-age classes) and uneven-aged (at least three distinct tree-age classes). Even-aged stands are generally managed using clear felling and shelterwood systems. Uneven-aged stands are managed using selection systems (Forest Research, 2020a). Different forest management will have different effects on forest productivity, though results are not consistent, as some studies report greater productivity in even-aged stands, while others report the opposite. It is unlikely that one management regime is consistently more productive than another, and much depends on local contexts and other aspects of management (O'Hara, 2014). This is also likely to be the case for carbon sequestration.

Continuous cover forestry (CCF) is a management approach "*in which the forest canopy is maintained at one or more levels without clearfelling*" (Forestry Commission, 2008). CCF is likely to be beneficial for maintenance of soil carbon, since it makes less use of intensive site cultivation for establishing young trees (Forestry Commission, 2017). Swedish researchers have concluded that it is desirable to use more CCF to increase the resilience of production forests to climate change and to enhance the range of ecosystem services they provide (Felton et al., 2020).

Morison et al. (2012) used the carbon accounting model CSORT to estimate the impacts of the use of harvested wood from forests in Britain. They found that the contribution of harvested wood products to the overall carbon stocks of the UK forest sector (which includes carbon stock both in the forests, vegetation, litter and soil, and outside the forests, harvested wood products of woodfuel and timber), is significant, but that the model needs to be run for many more tree species, yield classes and management regimes to be able to present a full picture. They also looked at the greenhouse gas emissions reduction when using woodfuel to substitute fossil fuel derived energy sources and conclude that when comparing the carbon stock of the full system, substitution benefits can continue to accrue for as long as substitutions occur, but growing forests tend to reach a maximum carbon stock. However, they highlight that there needs to be a better link between research on substitution benefits and the carbon dynamics of the resulting forest vegetation, so that the emission reduction from substitution can be assessed in relation to carbon stock changes within the forest due to management changes.

A modelling study of climatic cooling or warming effects of Finland's production forests concluded that it is necessary to take account of multiple factors, including forest harvest levels, forest type, the surface albedo of forests, the direct and indirect forcing of secondary organic aerosols (SOA), carbon storage in harvested wood products, and the avoidance of fossil emissions by product substitution (Kalliokoski et al., 2020) (Figure 3). The direct climate cooling of SOA and climate warming due to decreased surface albedo of the forest counterbalanced each other. Differences between harvest levels (50, 65, 80, 100, and 130% of current annual increment) were almost entirely due to the different carbon impacts derived from the increase in main stem volume. Over a projected 50-year timeframe, the largest mitigation effects emerged in scenarios where carbon stocks increased because of longer rotations. When harvesting was increased over the baseline (65% of current annual increment) there was a climate warming effect, even after accounting for carbon storage in harvested wood products and avoidance of fossil emissions by product substitution. This was explained as a post-harvest climate debt, whereby the recovery of net carbon stocks through regeneration and forest growth is subject to a significant delay. Kalliokoski et al. (2020) conclude that innovative long-living wood products should form the main share of wood extraction if effective climate mitigation with increased wood use is pursued. While their results are not necessarily directly comparable to production forestry in Scotland, such results should caution policies that promote the utilisation of forest biomass for short-lived products and bioenergy as a measure to mitigate climate change.

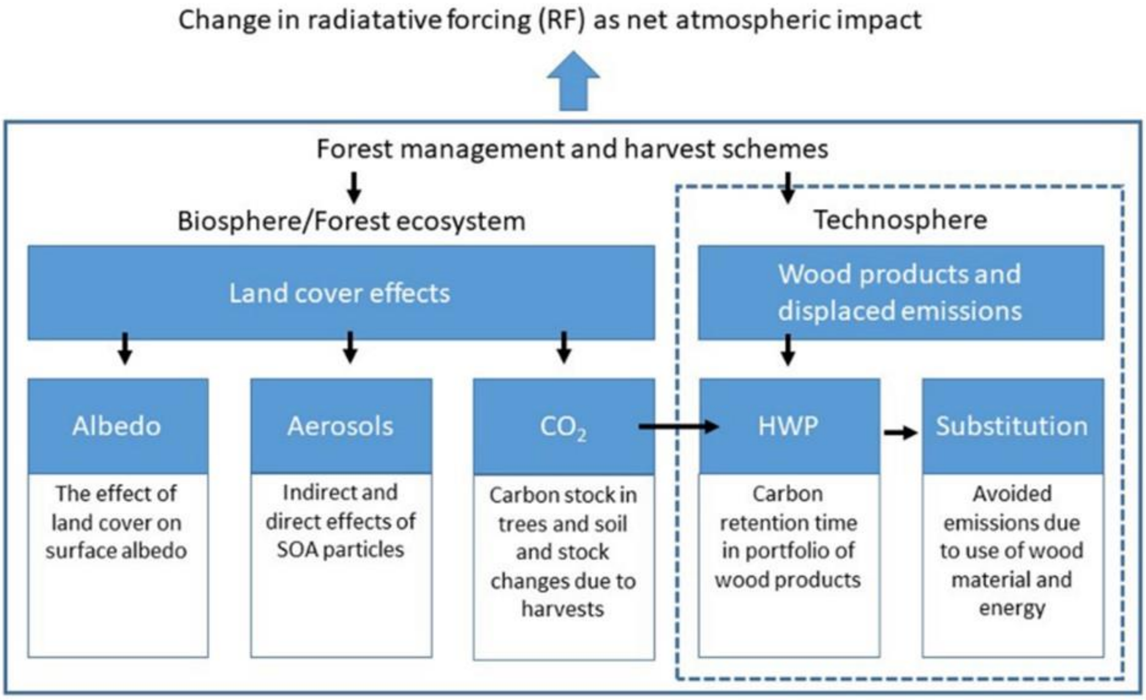

Figure 3 Schematic presentation of all components of the model used by Kalliokoski et al. (2020) (HWP=harvested wood products) (from Kalliokoski et al., 2020).

Recommendations

It is clear that all UK governments are serious about addressing climate change and achieving their net-zero emission targets. Using more wood in construction has the potential to substantially contribute to these targets. From this report a few data gaps have become clear:

- Woodland research is very rarely tied to research on harvested products, and this link needs to be made for a systems understanding of carbon mitigation potential. Research into all three carbon functions of forested lands; sink, storage, and substitution, should be linked.
- There are still high uncertainties associated with the possibility of climate change mitigation of different forest management approaches.
- Caution should be used when promoting increased utilisation of forest biomass for short-living products and bioenergy as a measure to mitigate climate change, given that benefits might be very limited when considering all factors affecting climate warming.

To effectively mitigate climate change with increased wood use, it could be better if innovative long-living wood products form the main share of wood extraction.

Based on interviews with representatives of Scottish Government, CONFOR, and sustainable construction sector, we derive a number of policy-relevant issues that should be considered further:

- Policy-makers are often somewhat removed from the practicalities of land management, and there is a need for better integration of land management realities into policy design and development.
- Scottish building standards could be improved to include embodied emissions of buildings. Currently, standards only consider operational carbon and there is no recognition of timber products, short supply chains, and locally sourced materials.
- The main focus for improving carbon efficiency is on what can be added onto a building to reduce environmental impact, such as solar panels. Changing the standards and building requirements to encompass the environmental impact of the materials that buildings are made from incentivise the industry to reduce embodied emissions.
- Favouring carbon rich sustainable natural materials in public procurement policies for construction could stimulate the increased use of long-life wood products in buildings. Consequently, this would increase the amount of carbon stored in buildings in Scotland. A proposal to do this has been submitted to Scottish Government as part of the Scottish Forestry and Timber Technologies Industry Leadership Group Green Recovery Plan (Andy Leitch, Personal communication). Such policies are likely to be resisted by vested interests, notably the steel and concrete industries, so this will be an issue of political negotiation. Political leadership will be required to secure a future bioeconomy that, while disruptive of current systems, has the potential to deliver climate change targets, new and diverse employment opportunities across the supply chain, as well as better quality buildings.
- The largest potential domestic market for sustainable natural materials is England, where timber use in buildings remains limited. Scalability might be readily achieved by improving regulations in England, though this would require improved supply and the expansion of the wood product supply chain.
- CLT and wood fibre insulation need additional research and innovation centres to accelerate the development of CLT, wood fibre insulation, and other wood based products for construction. Expertise is currently concentrated at Napier University and University of Cambridge, although the New Model Institute for Technology and Engineering being built in Herefordshire is expected to have a centre for advanced timber technology.

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