



Carbon Sequestration By Buildings

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Executive Summary

Bio-renewable building materials (BBMs) are materials which comprise mainly recent (non-fossil) carbon compounds derived from either plants or animals. The carbon in these materials has been removed from the atmosphere by photosynthesis and consumption of plants by animals. The carbon stored in BBMs is held there until such a time as it decomposes or is burnt. This storage of carbon which has recently been removed from the atmosphere is known as carbon sequestration.

The potential to sequester carbon in buildings through the use of BBMs on a national or global scale is considerable. This study aims to establish the magnitude of carbon sequestration by buildings in the UK, project this forward and establish the significance of the resulting carbon removal from the atmosphere by comparing the results with UK greenhouse gas (GHG) emission reduction commitments.

Whilst this work considers carbon sequestration by products other than wood, the current circumstances are that BBMs are dominated by wood and wood products and therefore in this study wood and wood products are considered a proxy for BBM. For future projections the potential increased usage of BBMs other than wood is taken into account.

The approach taken has been to review existing estimates of wood usage, develop a new estimate for wood usage in new non-domestic buildings and develop a simple dynamic model for BBM movement in and out of buildings to 2050.

Based on extrapolations of current trends in timber frame construction, the total annual added increment of harvested wood products (HWP) in construction is expected to increase from about 8MtCO₂ in 2005 to 10MtCO₂ in 2020 and 14MtCO₂ in 2050. If losses from the product pool (disposal and decay) were taken into account these figures would be reduced by about 20-30%.

The potential effects of policies designed to encourage increased use of BBMs in all UK buildings suggest that the net (taking into account losses from the product pool) carbon sequestration could be as high as 10MtCO₂ in 2020 and 22MtCO₂ by 2050.

The UK Government is committed through the Climate Change Act to reduce GHG emissions by 34% by 2020 and 80% by 2050. The targets for reductions in emissions by 2022 are 12MtCO₂/yr from homes and communities and 41MtCO₂/yr from work places and jobs. At present UK policy does not consider carbon sequestration as one of the means of achieving the targets and there is no policy or guidance explicitly encouraging the use of BBMs over other construction materials.

Comparison of the projected carbon sequestration in buildings with the UK targets for homes and communities and work places and jobs shows the very significant potential of carbon sequestration to make a relevant contribution to the national targets.

Internationally, the relevance of harvested wood products on GHG emissions has long been recognized and in December 2011 at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (known as COP17) it was agreed for the first time that these effects must be included in the national GHG inventories required by the Kyoto Protocol. The accounting procedure used is a version of the production approach, where the benefits of carbon sequestration remain in the country where the wood is grown.

This study considers carbon sequestration by all wood products used in construction in the UK including those imported and is therefore at odds with the COP17 decision, but is still considered because it forms the basis of discussions on how future policy might change.

Whilst there is considerable uncertainty in the projections, they provide a strong basis for arguing the relevance of a UK wood industry using UK grown timber.

Furthermore the potential significance of non-wood BBMs could support future UNFCCC discussions on including non-wood construction materials along with HWP.

1 Introduction

Rationale

Bio-renewable building materials (BBMs) are materials which comprise mainly recent (non-fossil) carbon which is derived from either plants or animals. These materials remove carbon from the atmosphere through the process of photosynthesis during the life of plants, and in the case of animal based BBMs such as sheepswool, through consumption of plants by the animals. The take up of carbon from the atmosphere reduces the atmospheric carbon dioxide (CO₂) concentration. The carbon stored in BBMs is held there until such a time as it decomposes or is burnt. This storage of carbon which has recently been removed from the atmosphere is known as carbon sequestration.

Considering sequestration of carbon by BBMs on a national or global scale it is possible to envisage circumstances where the amount of carbon sequestered is very significant. The Alliance for Sustainable Building Products (ASBP) has commissioned Piers Sadler Consulting to undertake a study to quantify the amount of carbon that can be sequestered in this way. This builds on work by Davis Langdon (2010) which considered the life cycle analysis (LCA) implications of carbon sequestration; Sadler (2010) which quantified the potential for carbon sequestration by UK housing and Robson and Sadler (2012) which quantified the annual carbon sink associated with use of wood in construction and projected this forward to 2050.

Terminology and Units

In this paper the following terms, consistent with United Nations Framework Convention on Climate Change (UNFCCC) usage (Ford-Robertson, 2003) have been used to describe the sequestration:

- A sink is any process, activity or mechanism that removes a greenhouse gas (GHG) from the atmosphere.
- A source is any process, activity or mechanism that releases a GHG into the atmosphere.
- A reservoir is a component of the climate system in which a GHG is stored.

When plants grow they act as a carbon sink because they actively remove carbon from the atmosphere; when they decompose or are burnt, they act as carbon sources releasing the carbon contained in their structure back to the atmosphere; the carbon contained in standing plants or in products, such as BBMs, is a carbon reservoir. The size of a carbon reservoir varies depending on the relative sizes of the sources and the sinks (rates of growth and decay). For carbon sequestration in buildings, the carbon reservoir is the carbon present in building products at a particular time, but from a GHG emissions perspective, the size of the net carbon sink or change in the size of the carbon reservoir is the most important statistic, as this measures the rate at which carbon is removed from (or added to) the atmosphere. The term pool is often used in place of reservoir when describing carbon in products eg wood products pool.

Bio-renewable materials typically have a carbon content between 40 and 50%. In this paper the Inter-Governmental Panel on Climate Change (IPCC, 2006) default value of 0.5 is used in all cases. To convert the sequestered carbon to the sequestered carbon dioxide involves multiplication of the carbon content by 44 divided by 12 (the relative masses of CO₂ and carbon respectively). This means that a mass of 1 unit of BBM removes 1.83 (0.5 x 44/12) units of CO₂ from the atmosphere.

In this paper GHG emissions are expressed in CO₂ equivalents (CO_{2e}) which combine the effects of different greenhouse gases into a single unit. The only other gas relevant in this instance is methane, which has a GHG potency of 22 times that of carbon dioxide. Methane can be emitted when BBMs decay in landfills.

Objectives

The main objective of this study is to establish the magnitude of potential carbon sequestration by buildings in the UK, project this forward and assess its significance by comparing the results with UK GHG reduction commitments.

A key aspect is to model the size of the reservoir of carbon in buildings over time taking into account both sinks and sources of GHG including the effects of disposal of BBMs after demolition of materials.

Whilst this work considers carbon sequestration by products other than wood, the current circumstances are that BBMs are dominated by wood and therefore existing data on wood are considered a proxy for BBMs.

The beneficial effects of energy recovery from burning waste wood and from methane generation from landfills have not been considered.

Methodology

This paper includes a summary of previous reviews of LCA and carbon accounting methodologies and how these account for the carbon sequestered in bio-renewable products. A number of approaches have then been taken to quantify the magnitude of the existing and potential future carbon sink in UK buildings. The approaches taken have, by necessity, been simplified due to the lack of good data on wood usage in building, demolition rates and fate of building materials on demolition.

The approach has been to compile a range of estimates using top down (national statistics on wood usage) and bottom up (national statistics on building rates combined with wood usage in buildings) approaches. These estimates include total UK consumption, total UK construction usage and wood usage in houses. An additional calculation has been undertaken within this work to provide an estimate of wood usage in new non-domestic buildings, providing a cross check against other data.

These estimates have been reviewed to develop a best estimate of wood usage in UK buildings in 2005 and this has been used as the basis of a forward projection of the development of the wood products pool in buildings to 2050.

Robson and Sadler (2012) undertook a study with similar objectives, approaching the question of projected future scenarios assuming an annual increase of 2% in timber frame construction, but not considering movement of product out of the building pool and not considering the implications of policy to increase the use of BBMs.

Sadler (2010) developed a detailed model of the pool of BBMs in housing including demolition, disposal and methane generation from landfills.

Combining the results of Robson and Sadler (2012) with the findings of Sadler (2010) has provided the opportunity to explore the effects of future policies to encourage use of BBMs.

2. Literature Review

This review comprises:

- review of policy related to carbon sequestration by products;
- review of literature related to the methodology (LCA and carbon sequestration);
- review of studies with similar objectives or which provide information relevant to the objectives of this study.

Policy

The UK government is committed through the Climate Change Act (The Stationery Office, 2008) to reducing GHG emissions by 34% by 2020 and 80% by 2050 compared to 1990 levels. The Department of Energy and Climate Change (DECC) has set out a plan - The UK Low Carbon Transition Plan (DECC, 2009) – of how these legally binding targets will be met. The interim targets published in the plan are shown in Table 1.

Table 1: UK GHG emission targets

	2008-2012	2013-2017	2018-2022	2050
Annual average GHG Emissions (MtCO _{2e})	604	556	509	154

The Low Carbon Transition Plan also sets out the reductions within various sectors for the third budget period between 2018 and 2022. The annual reduction rates for the third budget period for the two sectors which relate to this study are as follows:

- Homes and Communities – 12MtCO_{2e}/yr
- Work places and jobs – 41MtCO_{2e}/yr

The UK Code for Sustainable Homes has a role in contributing to the targeted 12MtCO₂ emissions reduction for homes and communities. The Code includes a section on building materials, which is based on the Green Guide to Specification (Anderson and Shiers, 2009) which in turn uses the Building Research Establishment (BRE) Environmental Profiles Methodology (BRE, 2007) to assess the life cycle impacts of building materials. The intention of the materials section of the Code is to encourage use of more sustainable materials. This is the only area of UK construction where there is an explicit section on sustainable materials. Davis Langdon (2010) provides a detailed review of the implications of the methodology to BBM. From the point of view of UK policy it is sufficient here to observe that the Green Guide does not attribute any environmental advantage to use of BBMs over traditional construction materials such as brick and concrete.

The international policy surrounding carbon sequestration by bio-renewable materials has developed very slowly since the first Guidance on Greenhouse Gas Inventories (IPCC, 1996) was published. Internationally the discussions have always been about how to treat harvested wood products (HWP), with other bio-renewable materials ignored (presumably due to assumed short life). The IPCC (1996) approach assumed immediate oxidation of wood when trees are harvested and release of the resulting CO₂ to the atmosphere. The updated IPCC Guidance (IPCC, 2006) contains a section (Vol. 4, Chapter 12) on HWP and the details of how to account for emissions from

these. Supporting documentation (Ford-Robertson, 2003) outlines the following approaches for accounting for HWP:

- stock change approach where the benefits of carbon sequestration follow the product;
- production approach, where the benefits of carbon sequestration remain in the country where the wood is grown;
- atmospheric flow approach where the benefits of growth are attributed to the country that grew the trees and the effects of emissions are attributed to the country where the product goes out of use.

Following the COP 17 (17th Conference of the Parties to the UNFCCC) meeting in Durban, the Ad Hoc Working Group on Further Commitments for Annex 1 Parties to the Kyoto Protocol published its conclusions (UNFCCC, 2011) which included for the first time a mandatory section on HWP. HWP will now be addressed within the Kyoto Protocol by a version of the production approach.

The life of HWP in use is described by first order decay. First order decay rates are defined by a half-life, which is the amount of time taken for half the product to go out of the in-use pool. The default half-lives are: 2 years (paper), 25 years (wood panels) and 35 years (sawn wood). If more detailed country specific data on wood stocks are available and verifiable, these data can be used instead of half-lives to model the movement of materials in and out of the HWP use pool.

Immediate loss of the sequestered carbon is assumed for HWP resulting from deforestation, HWP disposal to waste disposal sites (landfills) and combustion for energy purposes. The benefits of substituting wood for fossil fuels are still implicit in the method as the carbon emitted on combustion is balanced by the carbon sequestered through growth. It appears that the assumption of instantaneous oxidation in landfills will result in both carbon sequestration and methane generation by HWP in waste disposal sites being ignored.

One implication for countries which import more wood than they grow such as the UK (Food and Agriculture Organization, 2009) is that the amount of carbon sequestered by HWP is relatively small.

This has a significant bearing on this study because the premise of the estimates in this study is that the stock change method is used. Further discussion of this issue is presented in Section 6.

The UK undertakes National GHG Inventory reports each year (AEA, 2011). The inventory is used to meet the UK's international obligations eg under the Kyoto Protocol and it's national obligations set under the Climate Change Act (2008) and Low Carbon Transition Plan (DECC, 2009). The calculations for meeting these requirements can differ (AEA, 2011) as the UK adopted elements of IPCC (2006), whilst Kyoto was still based on IPPC (1993).

The most recent UK Greenhouse Gas Inventory report for the Department for Environment, Food and Rural Affairs (DEFRA) on land use, land use change and forestry (DEFRA, 2009) uses the production approach to assess the effects of HWP ie carbon sequestration by HWP made from UK grown timber only is considered. The

following half-lives were used for products in use: HWP from thinnings – 5 years; softwood HWP – 14 years and hardwood HWP 21 years.

The effects of methane emissions from landfill are treated separately from the HWP, in the UK GHG inventory, and are based on estimates of different types of waste, the content of the waste, the proportion of degradable carbon in the waste and a decay rate. Different decay rates are set for different types of material. The UK GHG inventory methodology is developing in this respect and uses different values for the key parameters from the IPCC methodology (AEA, 2011). The implication of using this approach is that only sequestration of carbon by UK grown timber is considered, whilst emissions from landfills include those from imported HWP.

The UK methodology may yet change again following the decision from COP 17 (UNFCCC, 2012) since it would appear that HWP in landfills should now be assumed to oxidise instantly.

LCA and Carbon Sequestration

Sadler (2010) reviewed the following methods of LCA and carbon accounting:

- IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006);
- ISO14047 (International Organization for Standardization, 2003);
- PAS2050 (British Standards Institute, 2008);
- Environmental Profiles Methodology (BRE, 2007).

It was concluded that all these methodologies allow for carbon sequestration by wood (and in cases other bio-renewable materials), but that the in-use life and post use decay are dealt with differently.

The IPCC methodology is addressed above under Policy.

ISO14047 includes the use of first order decay of products in service and acknowledges the effects of methane release on disposal, but gives no specific methodology.

PAS 2050 includes a specific service life of a product followed by linear decay over a specified time period during which the carbon is released back to atmosphere. Linear decay and release of methane is also allowed for.

BRE Environmental Profiles Methodology calculates the carbon balance at a time 100 years after a product is manufactured. It is not clear what service life assumptions are made or what end of life disposal assumptions are made. The rate of decay in landfills is based on the Environment Agency's Gassim Model (Environment Agency, 2006) which assumes various half lives for wood and 99% conversion of the carbon to methane.

Davis Langdon, 2010 reviewed LCA of BBMs in more detail. A key conclusion was that the snapshot approach used in BRE (2007) treats materials which generate carbon in manufacture and re-absorb some of it over time (eg concrete) and those which absorb lots of carbon in growth and release some of it over time, equally. From a climate change perspective, the release of CO₂ during cement manufacture at the beginning of the life of a product is much more damaging than its release at the end of

the life of the product as in the case of wood, but the Environmental Profiles Methodology does not recognise this. Furthermore it does not recognise the benefits of carbon storage in a dynamic pool such as HWP with continued input and output. Irrespective of the life cycle of individual products, if the product pool (ie BBM in buildings) is increasing in size, carbon is being sequestered each year.

Weight and Norton prefer the PAS, 2050 approach which averages the carbon storage in the product over its lifetime between manufacture and ultimate decay.

Similar Studies

Sadler, 2010: Biogenic Materials for Housing as a Climate Change Mitigation Strategy for the UK

Sadler looked at the carbon balance in and out of houses for the period 1990-2050 including the effects of recycling and disposal and including the GHG emissions associated with these activities.

The term biogenic in Sadler (2010) is interchangeable with bio-renewable in this work. Most of the data on existing buildings were based on wood, but for the future, various scenarios were developed which included other biogenic materials such as straw, hemp, cellulose and sheep's wool.

Table 2 shows the bio-renewable materials usage in units of t/m² for different house types from a range of sources. Only the Burnett (2006) examples, which include cellulose insulation, specifically include non-wood biogenic materials.

The data show a clear increase from approximately 0.03-0.04 t/m² for masonry and steel framed houses, through 0.05-0.09 t/m² for timber framed housing and approximately 0.2-0.6 t/m² for the less conventional high biomass constructions.

Table 2: Biorenewable material usage (t/m²) in different house types (from Sadler, 2010)

House type	Source					
	Burnett, 2006	CEI-bois ¹ , 2006	Bowyer et al, 2005	Kapambwe et al, 2009	TRADA, 2009	White, 2009 ⁴
Masonry/ brick and block	0.04	0.024		0.03		
Steel framed			0.034 (M) ² 0.041 (A) ³			
Timber framed	0.058 (brick clad) 0.084 (timber clad)	0.044	0.068 (M) ² 0.049 (A) ³	0.12		
Solid wood		0.24-0.6			0.17	
Modular straw panel						0.25

¹the European Confederation of Woodworking Industries

²M is the Minneapolis type house from this study

³A is the Atlanta type house from this study.

⁴Personal communication with Craig White of Modcell

The biorenewable materials intensities based on these figures which were selected for modelling purposes are presented in Table 3. The average biogenic material usage (tonnes) per house based on the average house size used by Sadler of 88m² is also shown in Table 3.

Table 3: Biogenic material content of houses of different types

	Biogenic material intensities	Biogenic material usage per house
	t/m ²	t
Brick and block	0.04	3.52
Timber frame brick clad	0.06	5.28
Timber frame timber clad	0.09	7.92
High biogenic ¹	0.2	17.6

¹unconventional buildings containing very high intensities of BBMs

Sadler produced a dynamic model of the carbon reservoir in housing between 1990 and 2050 incorporating a number of end of life scenarios including recycling, landfilling, incineration and energy recovery.

Sadler ran a number of different projection scenarios to explore the effects of policies on housing construction, demolition and disposal and concluded that continued population growth will result in continued growth in the annual carbon sink in housing, peaking at about 2.5MtCO_{2e} per year by about 2030 with no policy changes. If demolition rates increase to replace inefficient old housing and landfilling of bio-renewable materials also continues, with unfavourable assumptions about the proportion and rate of methane generation from HWP, methane generation could cancel out sequestration by 2032 making BBMs in housing a net source of emissions. However, Sadler did not take into account of the utilisation of methane generated from landfills for energy. With policies aimed at replacing old inefficient housing with new high biogenic housing (containing high intensities of BBMs) and landfilling of biogenic materials eliminated by 2036, then the net sequestration of biogenic materials in housing could reach 6MtCO_{2e}/yr by 2020 and 10MtCO_{2e}/yr by 2030. The 2020 figure represents 50% of the envisaged savings by homes and communities in the UK Low Carbon Transition Plan (Department of Energy and Climate Change, 2009).

Robson and Sadler, 2012: Carbon stored in harvested wood product construction materials in the United Kingdom

Robson and Sadler (2012) adopted several approaches to evaluate the amount of carbon going into the construction product pool in 2005 and then made a projection to 2050. The approaches taken were:

- assess all solid wood usage in the UK;
- assess the product pool using the stock change and production methods for HWP described in IPCC (2006);
- scaling up figures produced for housing to the whole construction sector;
- projecting the annual additions to the HWP pool in the construction sector to 2050 based on an extension of current trends.

The approach and results in each case are summarised below.

The total balance of UK wood and wood based panels production, import and export was evaluated using Forestry and Agriculture Organisation (FAO, 2010) statistics for the United Kingdom and converting the volume to mass of product and mass of CO₂ using IPCC conversion factors (IPCC, 2006).

The results are summarised in Table 4.

Table 4: UK solid wood production and consumption 2005

	Tonnes product	Tonnes CO ₂ sequestered
Production	3,380,220	5,946,687
Consumption	8,823,095	15,701,916

Robson and Sadler (2012) acknowledged that materials also move out of the construction products reservoir and used the FAO (2010) statistics and IPCC stock change and production methods to quantify the wood products reservoir in the UK over time.

The IPCC stock change model was run with default half-lives of wood products (30 years) and paper products (2 years). The stock change approach attributes carbon to the country where products are used. Approximately 85% of the product reservoir was attributable to wood products and in 2005 the net sink in total UK wood products was about 9.6 MtCO_{2e} with 8.1MtCO_{2e} attributable to solid wood. The results are shown in Figure 1.

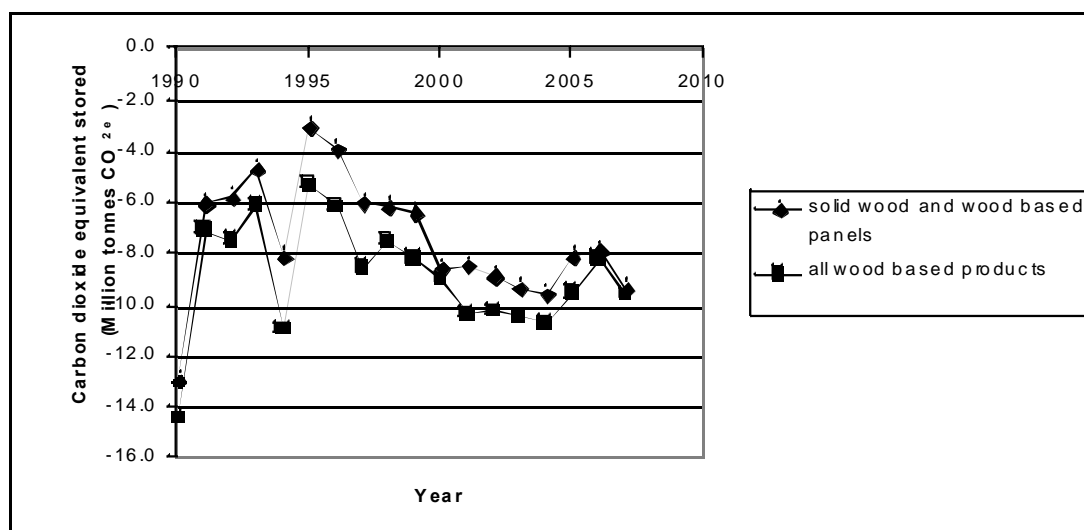


Figure 1: Net annual storage of carbon dioxide in UK wood products calculated using the IPCC model (stock change approach) for all wood and paper products and just for wood products. (Net storage of CO_{2e} is shown as a negative value) (after Robson and Sadler, 2012)

Comparison between the total consumption figure of 15MtCO_{2e} and the annual sink calculated from the stock change model of 8.1MtCO_{2e} (2005 data, see Figure 1) suggests that, based on a 30 year half-life, approximately half the quantity of carbon

sequestered in 2005 in solid wood products was being re-released to the atmosphere as products move out of the product reservoir. This figure could vary from year to year greatly if usage of HWP was being increased or decreased.

Using the production approach Robson and Sadler (2012) estimated that about 4.8MtCO_{2e} was sequestered by UK HWP in 2005 ie just over half the amount calculated by the stock change model.

Robson and Sadler (2012) considered studies of carbon stored in UK housing as a starting point for scaling up the figures to UK construction. These were Prebble (2007), Sadler (2010) and a short calculation contained within the UK Forestry Commission's report on forestry and climate change (Suttie et al, 2009).

Robson and Sadler (2012) took figures from Prebble (2007), Suttie et al (2009) and Sadler (2010) on wood usage in different house types as well as the proportions of different types of house construction (brick and block versus timber framed) and combined these data with data on housing starts (Communities and Local Government, 2011) to obtain estimates of the amount of wood and CO₂ entering the housing product reservoir. The estimated range was of 1.3-2.2Mm³ wood and 1.1-1.8Mt CO₂, respectively.

Acknowledging that the approach was unsatisfactory, but the best available with current data, Robson and Sadler (2012) used data produced by Davis Langdon (2004) on the relative value of construction materials used in different construction sub-sectors to scale up the estimated carbon sequestration by housing to the whole of construction. The relative materials value of each construction sub-sector together with the percentage wood use per unit value are presented together with estimated annual CO_{2e} sequestration in Table 5. The percentage wood usage was a judged value used by Robson and Sadler (2012) with no published evidence.

Table 5: Annual CO_{2e} sequestration by construction sub-sector (2005)

Sub-sector	% Value	% use of wood per unit value	Annual CO _{2e} sequestration based on:	
			Prebble figure for housing	Read figure for housing
Work to existing housing	32	100%	2,910,457	4,740,305
Work to existing non-residential buildings	31	50%	1,409,753	2,296,085
New non-domestic building	17	50%	773,090	1,259,143
New housing	12	100%	1,091,421	1,777,614
Civil engineering/infrastructure	8	20%	145,523	237,015
Total	100		6,330,244	10,310,163
Total construction			6,184,721	10,073,148

The data suggest that refurbishment works are responsible for approximately 2.5 times the demand for wood compared to new build and that housing is responsible for about twice the demand as non-residential building.

Robson and Sadler (2012) then projected these data forward assuming housing construction at 200,000 units per year and increasing timber frame percentage at 2% per year, with other sectors increasing at a similar rate. This projection was based on the average of the Prebble (2007) and Read (2010) estimates for 2005. However the effects of demolition and materials moving out of the product reservoir were not considered. Robson and Sadler's results are summarised in Table 6.

Table 6: Projected additional sequestered carbon in UK construction

Year	tonnes CO _{2e}	% of total UK GHG emissions 2005
2010	8,952,735	1.37%
2020	10,233,201	1.56%
2030	11,513,667	1.76%
2040	12,794,133	1.96%
2050	14,074,599	2.15%

TRADA, 2005: Wood used in construction: the UK mass balance and efficiency of use
This study provides a detailed breakdown of wood usage in the UK in 2002 including imports, exports, production, consumption, disposal and recycling. Wood usage is divided into the following categories:

- construction
- joinery
- pulp and paper
- furniture
- packaging

Figure 2 illustrates the proportions of wood usage by mass in each of these sectors.

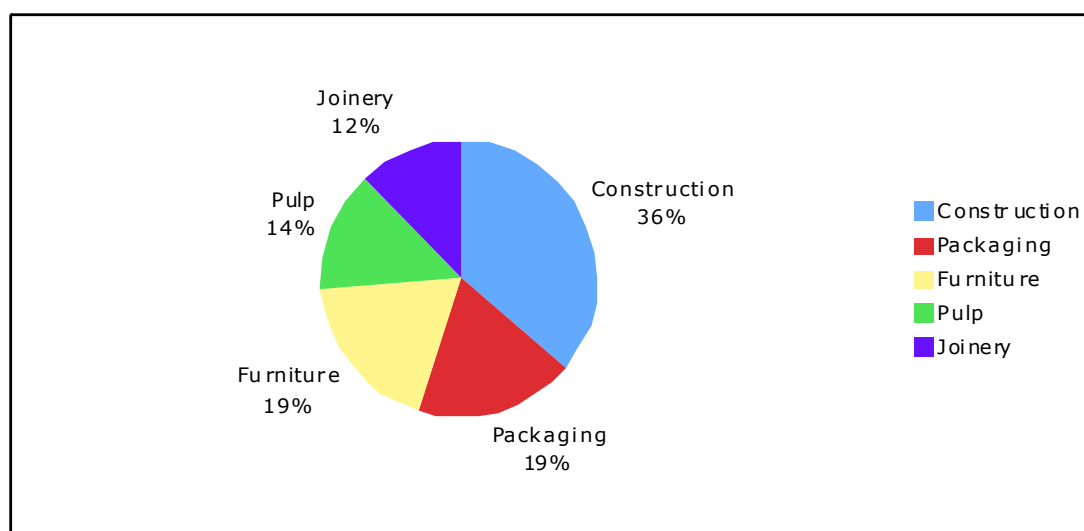


Figure 2: Total UK Consumption in 2002 by Sector Share (after TRADA, 2005)

These proportions have been combined with the total UK consumption figure for 2002, to obtain an indication of UK wood usage by sector. These figures are presented in Table 7 together with the carbon sequestration in each sector.

Construction and joinery have been combined on the basis that joinery is generally part of construction and that other estimates used in this paper do not distinguish between them.

Table 7: Wood Usage by sector based on sector share (TRADA, 2005) and total consumption (FAO, 2010)

	Total	Construction including joinery	Packaging	Furniture	Pulp
Wood consumption (tonnes)	8,823,095	4,235,085	1,676,388	1,676,388	1,235,233
Carbon sequestration (tCO _{2e})	16,175,674	7,764,324	3,073,378	3,073,378	2,264,594

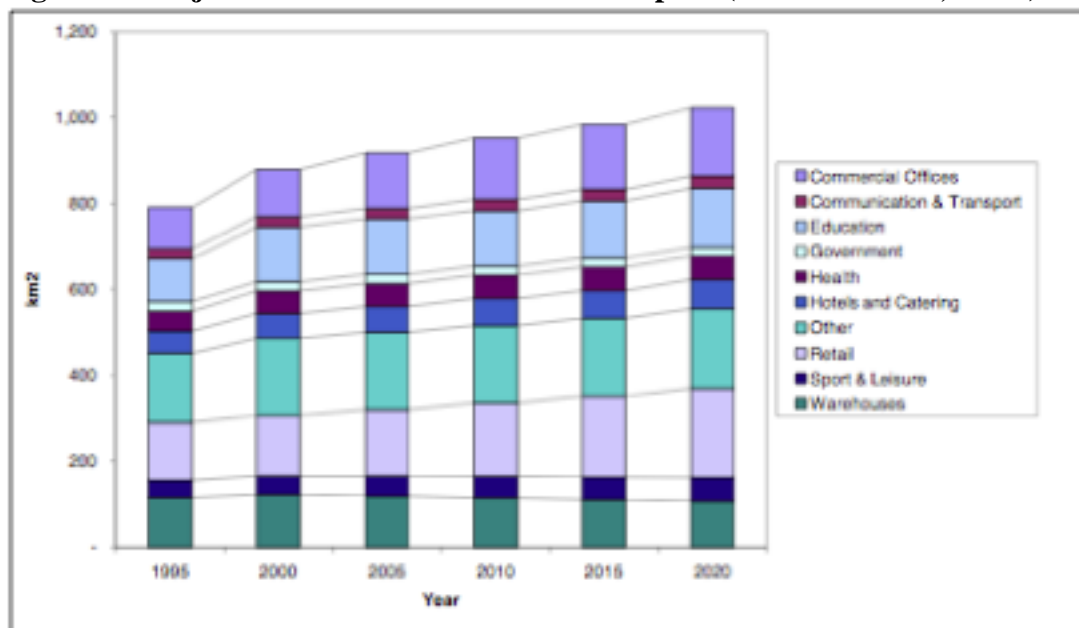
There are no data in the TRADA (2005) report which enable further breakdown of construction data into buildings, although the data in Table 5 suggest that buildings account for over 90% of materials used in construction by value and therefore 7.7MtCO_{2e} would be a reasonable estimate of the amount of wood used in buildings in 2005.

3. Carbon sequestration by New UK Non-Domestic Buildings

This new calculation has been undertaken based on the annual increase in floorspace of non-domestic buildings in the UK and the average wood content of new non-domestic buildings.

Pout et al, 2002, projected the floorspace of the UK non-domestic building stock forward to 2020. The results are presented in Figure 3.

Figure 3: Projection of UK non-domestic floorspace (from Pout et al, 2002)



The figure shows a growth rate of 16.7Mm²/yr from 1995-2000 slowing to approximately 6.5Mm²/yr from 2010-2020. The average of the data from 2000-2010 (ie representative of 2005) was approximately 7.7Mm²/yr. It is notable that the main areas of anticipated growth are retail, education and commercial offices. These building types are all amenable to timber frame construction.

The author found no published data on timber or BBM usage in non-domestic buildings, but was able to obtain some information through architects with an interest in these matters. These data are summarised in Table 8.

Table 8: BBM and carbon content of some non-domestic buildings

	John Fernelley College ¹	Dalby Forest visitors centre ¹	BRE innovation centre ¹	Retail buildings ²
Area (m ²)	6841	1380	230	
BBM usage (t)	107	187	53	
BBM intensity (t/m ²)	0.016	0.135	0.23	0.03-0.06
Carbon sequestration intensity (t/m ²)	0.029	0.24	0.42	0.05-0.10

¹ Personal communication, Rachel Bramley, White Design

² Personal communication Rosi Fieldson, Simons Group

John Ferneley College is a steel framed school building and was assessed to evaluate wood content of a building with low wood usage. The other buildings are timber frame. The results suggest a similar range of BBM usage as for domestic buildings presented in Table 2. Given that most growth in non-domestic buildings is in building types amenable to timber frame construction, it is reasonable to assume a BBM intensity of somewhere between the steel framed building and the retail building. A figure of 0.04 t BBM/m² for new build non-domestic buildings for the year 2005 has been selected. This is the same as is typical for a brick and block house and allows room for future increases.

Using these figures, the annual incremental increase in carbon sequestration in non-domestic buildings in 2005 is estimated at 568,000 tCO_{2e}.

4. Comparison of Figures

Housing

Figures for carbon sequestration by housing have been calculated in different ways based on Robson and Sadler's (2012) analysis of the data in Prebble (2007), Suttie (2009) and Sadler (2010). The results are as follows:

Prebble method – 1.1MtCO₂

Read method – 1.8MtCO₂

Sadler method – 1.4MtCO₂

The differences between the three approaches are related to assumptions about the amount of wood used in construction of new houses. Comparing the wood intensity assumptions of Sadler and Prebble, Sadler uses a consistently higher figure for both traditional build and timber frame, but the methods also differ in that Sadler used an average house size and wood intensity, whilst Prebble used a quantity of wood in three different house types (detached, mid-sized and flat). The figures based on Read's data on wood usage in houses are lower than Sadler or Prebble for traditional build, but much higher for timber frame. The Read figures also include fixtures, fittings and garden material.

Non-Domestic Buildings

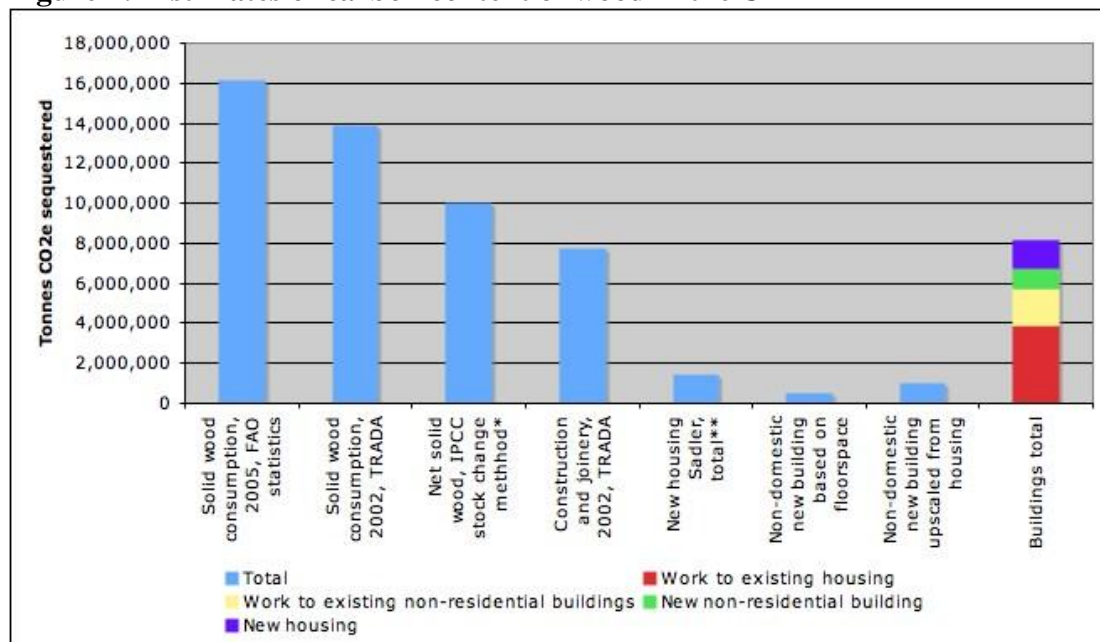
If Robson and Sadler's (2012) estimates of carbon sequestration by non-domestic buildings (Section 2) were scaled from the mean figure for housing of 1.4MtCO_{2e} for housing, the mean (of the two estimates for non-domestic buildings - Table 5) of approximately 1MtCO_{2e} would apply. The figure calculated in this paper is 0.568 MtCO_{2e}. The confidence in both these figures is low due to uncertainty about the assumptions made and accuracy of data, but the level of agreement serves the purpose of this study which is to get an indication of the magnitude of the figure.

All

Figure 4 combines the main estimates for wood usage in 2005 or the nearest year with available data. The following observations can be taken from the figure:

- total CO₂ content of solid wood consumed in the UK was about 16Mt in 2005 based on FAO statistics;
- the equivalent figure for 2002 based on TRADA wood consumption figures is 14Mt;
- if the whole solid wood product pool is taken into account (using the IPCC stock change method), the net sequestration in 2005 was about 10MtCO₂, with 6Mt leaving the product pool;
- the TRADA figure for all construction and joinery for 2002 is very similar to the figure from this paper for buildings for 2005, since the only difference between the two is civil engineering where demand for wood products is expected to be relatively low, this agreement is considered encouraging;
- new housing and non-domestic buildings consume less than half the wood estimated for buildings.

Figure 4: Estimates of carbon content of wood in the UK



The IPCC stock change calculation, is not directly comparable with the other quantities in Figure 4 because it is the only dynamic calculation with material both entering and leaving the product pool, but its inclusion in the figure illustrates the importance of considering the dynamics of the system.

There is still considerable uncertainty surrounding the 8Mt/annum figure for carbon sequestration by buildings, although this figure would appear to be consistent with the top down data (based on national statistics) and the bottom up data (based on construction data).

It would be reasonable to apply 2Mt uncertainty to the figure so that the estimate is that in 2005 carbon sequestration by buildings was $8 \pm 2 \text{MtCO}_2$.

5. Future Projection

The projection of carbon sequestration in this paper is based on total building floorspace and intensity of BBM usage. This projection relies on having a grasp of trends in the following:

- changes in building floorspace;
- use of BBMs in construction;
- rates of demolition;
- end of life treatment.

Each of these is affected by the economic climate, population (mainly housing) and policy. Some preliminary attempts at modelling different scenarios indicate that the range of possibilities is huge, from methane in landfill cancelling beneficial effects to very significant quantities of sequestered carbon of 10s MtCO_{2e}/yr.

Sadler (2010) showed that in a worst case scenario of high levels of disposal of BBM to landfill and rapid degradation producing methane, methane generation could cancel out the beneficial effects of carbon sequestration altogether. In this case the beneficial effects of landfill gas utilisation were not considered. In most of the modelled scenarios, however, the effects of methane generation resulted in about a 10-20% reduction in the net benefit of carbon sequestration even though the assumptions used were conservative (indicative of higher rates of methane generation than research supports). The conclusion was that policy designed to encourage the use of BBMs should be accompanied by policy designed to reduce and ultimately eliminate landfilling of these materials.

To illustrate the potential for carbon sequestration by BBMs a simple model has been developed for all new build and refurbishment of UK buildings. The starting point of the model is the floorspace of all buildings, an average BBM intensity in those buildings and the additional 8MtCO₂ sequestered by BBM in buildings in 2005 (Section 4). Zero growth in carbon sequestration in buildings between 2005 and 2010 is assumed. Since the objective of the model is to quantify the annual increment in stored BBMs, the starting point has only a small effect on the outcomes. The key assumptions and model inputs are as follows:

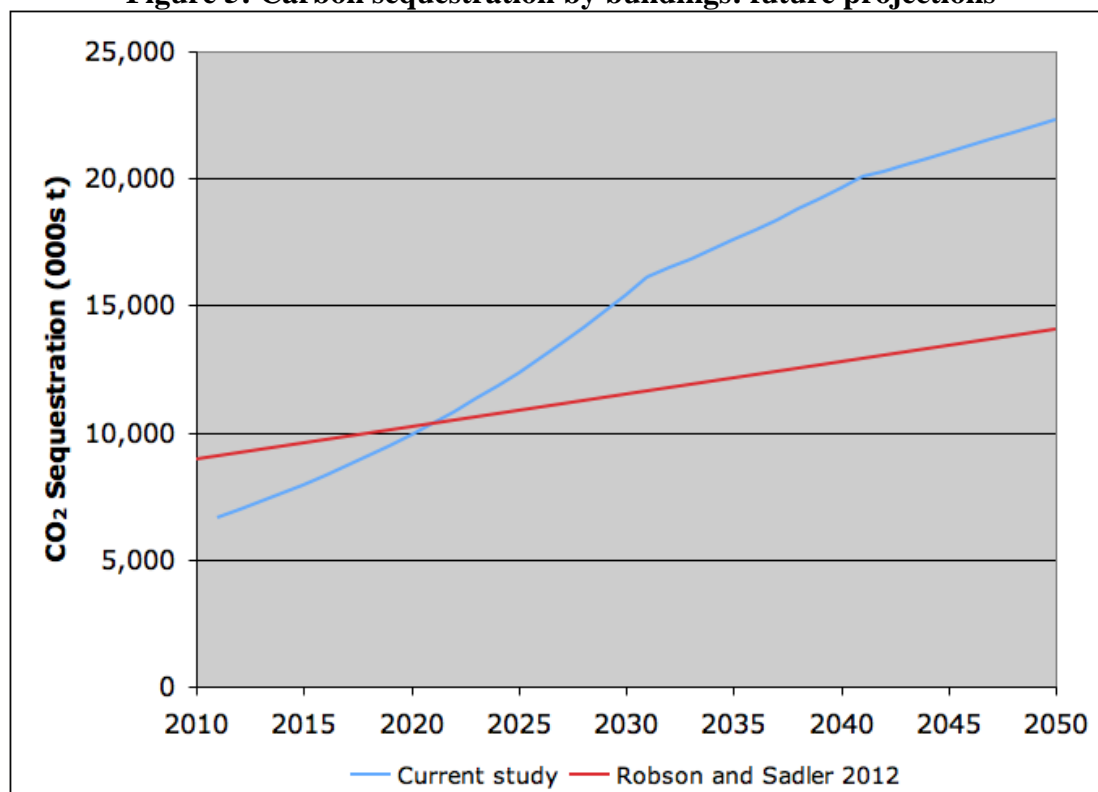
- the starting year for the model is 2010;
- modest growth of the building sector by 0.5% annually to 2030 and 0.25% to 2050;
- initially a 4% annual increase in BBM usage per total building floorspace is assumed, slowing to 2% by 2030 and 1% by 2040;
- initial BBM quantity in buildings based on existing floorspace and BBM intensity of 0.03t/m²;
- demolition removes 0.1% of the total BBM quantity annually;
- methane emissions reduce overall benefits of carbon sequestration by 15%.

The most difficult to justify assumption is the annual growth in BBM usage. The assumption is that the benefits of using BBMs are recognised and policy is developed to encourage growth in their use. The increases used are very modest compared to the growth in the photovoltaic market in the UK (iSuppli Corp, 2010). However, there is a ceiling BBM intensity of around 0.2-0.4t/m² which is unlikely to be exceeded

(Table 2) and a much lower figure for the average of all UK construction is to be expected. The approach taken envisages a growth in BBM intensity in all building construction of a factor of approximately three. This is considered an ambitious but plausible target.

The results of the model are illustrated in Figure 5 which shows growth in net (after removals) annual BBM sequestration from 7.8MtCO_{2e} in 2010 to about 10MtCO_{2e} in 2020 and 22MtCO_{2e} in 2050. The figure also shows the Robson and Sadler (2012) projection.

Figure 5: Carbon sequestration by buildings: future projections



The Robson and Sadler (2012) projection is more modest, indicating that 14MtCO₂ could be sequestered annually by 2050. However, this figure is based on extrapolation of current trends with increased timber frame construction being the cause of increased annual carbon sequestration. It is also a total figure which does not allow for the effects of demolition removing material from the product pool in buildings. Direct comparison can only be made with the observation that the net carbon sequestration would be less than the quantity shown on the graph for Robson and Sadler (2012).

Comparing the approach of Robson and Sadler (2012) with that used in this paper suggests that buildings could sequester an additional >12 MTCO_{2e} by 2050 if policy was geared towards this aim.

6. Discussion

This paper considers the amount of wood stored in UK buildings, the annual added increment to the wood product pool in UK buildings and the potential future carbon sequestration by BBMs in buildings. The general approach is a stock change approach which does not take account of the origins of the wood. This approach attributes the benefits of carbon sequestration by BBMs to the importing country.

The methods described in this paper for assessing BBM sequestration by housing and non-domestic buildings are by necessity product specific (rather than based on production statistics for wood and other materials) and based on country specific statistics about the movement of product in and out of the usage pool. This aspect is in broad agreement with the UNFCCC (2011) methodology. Whilst the results of Sadler (2010) could perhaps be justified for use in the UK GHG inventory (due to the relatively comprehensive data available on housing), the methodology used in this work for estimating carbon sequestration by non-domestic buildings (Section 3) and all buildings (Section 5) could not, as they are based uncertain estimates of non-domestic building demolition and BBM content.

The approaches used in this paper differ from the methodologies for the UK National GHG inventories in the following respects:

- stock change approach rather than production approach used;
- product specific calculations ie for wood use in buildings, are based on insufficiently robust statistics;
- all BBMs are taken account of rather than just wood.

It is considered instructive to evaluate carbon sequestration by buildings using a stock change approach because, irrespective of whether the UK can account for this carbon in its GHG inventory, this carbon is being removed from the atmosphere and is contributing to climate change mitigation. The total figure for net annual carbon sequestration represents a ceiling figure which is achievable by all BBMs. This ceiling figure could be as high as 10MtCO_{2e} by 2020 and 22MtCO_{2e} by 2050. The 2020 figure is equal to over 80% of the UK target for emission reductions from homes and communities. This illustrates the very substantial implications of use of BBMs.

The implication of this study is that for increased use of BBMs to have an impact on UK GHG inventories and achieving emissions targets, the aim should be to use BBMs grown in the UK. Furthermore, the only allowable BBM at present is wood. The UK should lobby for all harvested products to be considered in GHG inventories when those products have a long life-time, because the benefits of using non-wood products are exactly the same as those for using wood.

Considering the potential for increasing UK grown wood for use in building, the total area of forestry in the UK is 2.84 million ha (though this is not all 'productive forest') and the production of wood is about 10Mm³ (Forestry Commission, 2009). By 2025 this production will have risen to 11.5Mm³ through existing plantations maturing (Forest Industry Council of Great Britain, 1998). About 80% of this current forest production is used to produce sawn timber and wood-based panels (if we assume that all residues from sawmilling go into wood-based panels).

There are three ways to increase the amount of UK wood going into construction:

- It is estimated that there are 500,000 ha of under-managed woodland that could be brought into production, however this is mainly mixed hardwoods and will probably go for wood fuel;
- About 1Mt of wood products currently go into landfill (Waste and Resources Action Programme, 2011) and this could be recycled into wood-based panels but may also go for fuel;
- New plantings: there is almost 7 million ha of marginal and sloping Grade 3 and 4 agricultural land potentially available for new forestry in the UK and a further 450,000 ha of brownfield land (often unsuitable for food production) (Mark Broadmeadow, Forestry Commission, pers. comm.).

While the third option of new plantings seems attractive, there has been little current tree planting in recent years and trees planted now (even with the 23,000 ha/year planting levels suggested by Matthews and Broadmeadow (2009) will not be felled for sawlogs until around 2050 (though there will be thinnings and short rotation products for wood-based panels). Tree plantings may increase in the future, encouraged by the new Woodland Carbon Code (Forestry Commission, 2011) and the recent decision that UK GHG emissions can be offset by carbon in forests and woodlands (DEFRA, 2011) and products from these forests and woodlands could be used in construction.

Non-wood biogenic materials can generally be brought into production much more quickly than wood and so their future UK production potential is potentially important. Sheepswool, straw and cellulose (recycled paper) are all bi-products of much larger industries. In each case no additional demand for land would occur as a result of increased demand for these products. Taking the example of straw, UK straw production is about 10Mt/year (Woolley and Kimmins, 2002). The main demands for straw are for animal bedding and biomass energy, so an increased demand for straw by the building industry would have a knock on effect on these uses, but it is possible to envisage a 5% shift in straw usage from these areas to construction, especially if there were incentives to use BBMs. This would result in an additional 9Mt/yr CO₂ sequestration into buildings.

There are also several crops which could be specifically grown for BBM production, the most prominent being hemp. Growth of 100,000 ha of hemp would produce around 0.5Mt hemp shiv, which could sequestered about 0.9Mt CO₂.

Accounting for UK grown wood or BBMs in all new build and refurbishment, accurately would not be possible based on available statistics and collection of the data required to achieve this would be difficult. It is easier to envisage collection of national statistics on the types of wood product and other BBM produced at sawmill or factory gate and combining these with export data. This approach would not specifically measure the effects of increased BBM usage in buildings, but since buildings account for a large proportion of the wood product pool, particularly the long life time products, increased use of UK grown BBMs in buildings would still benefit the inventory (especially if all BBMs and not just wood are considered).

In terms of product LCA the source country of the BBM is also important because of transport emissions. The dynamics of the BBM product pool with materials continuously moving in and out of use, supports the use of LCA methodologies which account for sequestered carbon over the life time of the product such as PAS 2050 (British Standards Institute, 2011) or ISO 14047 (International Organization for Standardization, 2003) with first order decay, over methods eg Environmental Profiles Methodology (BRE,2007), which use a final snapshot approach where the embodied carbon at a particular time in the future is considered (eg 100 years).

According to UNFCCC (2011) instant oxidation must be assumed at the end of life of HWP ie the carbon sequestration ends at this point irrespective of the life of the product in the landfill. We have interpreted this as meaning that carbon sequestration and emissions from HWP in landfills are both ignored, but have been unable to confirm the implications of this very recent decision in this respect. We assume the thinking is that there is great uncertainty around both the emissions and continued sequestration of HWP in landfills and they have been assumed to cancel each other out.

However, Sadler (2010) determined that high levels of disposal of BBM from housing, combined with unfavourable assumptions about degradation rate could result in all the carbon sequestration benefits of BBM usage in housing being cancelled out. Sadler's conclusion was that the current trend of reducing landfilling of wood should be continued until landfilling of wood is eliminated. That conclusion is re-iterated here.

Conclusions and Recommendations

The available estimates for carbon sequestration vary in whether they represent an annual addition to the HWP pool or a net increase (taking into account demolition, disposal and decay). They also vary in the materials pool they represent, whether all solid wood, construction or buildings. Care should therefore be taken when comparing values in this paper.

UK Solid Wood Consumption and Net Carbon Sequestration

- total UK solid wood (sawn wood and wood based panels) consumption in 2005 was about 16MtCO_{2e};
- using the IPCC stock change model (IPCC, 2006), the net carbon sequestration by solid wood in the UK was about 8.1MtCO_{2e}, suggesting that in this particular year the losses from the HWP product pool were equal to about half the additions.

Annual additions to the HWP pool in 2005

The estimates below are all based on estimates of wood usage in 2005 and take no account of removal of HWP from the product pool. These are the best estimates based on the state of current knowledge.

- in 2005 the annual incremental increase in HWP usage in housing accounted for carbon sequestration of about 1.4MtCO_{2e};
- the equivalent figure for non-domestic buildings was 0.6-1MtCO_{2e};
- approximately 8MtCO_{2e} was sequestered by new additions of HWP to the national building stock in 2005;
- in 2005 buildings accounted for about 50% of all solid wood consumption in the UK;
- refurbishment works account for 75-80% of annual additions to the HWP pool in buildings.

Future Projections

Based on extrapolations of current trends in timber frame construction, the total annual added increment of HWP in construction is expected to increase from about 8MtCO_{2e} in 2005 to 10MtCO_{2e} in 2020 and 14MtCO_{2e} in 2050. If losses from the product pool (disposal and decay) were taken into account these figures would be reduced by about 20-30%.

The potential effects of policies designed to encourage increased use of BBMs (wood and other materials such as hemp and straw) in all UK buildings suggest that the net (taking into account losses from the product pool) carbon sequestration could be as high as 10MtCO_{2e} in 2020 and 22MtCO_{2e} by 2050. The 2020 figure is equal to more than 80% of the UK target for emission reductions from homes and communities by that date.

Even if this figure was reduced by 50% to reflect UK grown BBMs, it is still very significant.

GHG Inventory

This paper has quantified the actual and potential future carbon sequestration by BBMs in the UK, albeit with considerable uncertainty regarding some of the estimates. For future carbon inventories and to relate carbon sequestration to UK GHG emission targets, only wood products grown in the UK will be accounted for.

If the potential effects of HWP in buildings in contributing towards meeting UK emission targets can be demonstrated then the arguments for creating incentives will be well supported.

Similarly, if trends in use of non-wood BBMs can be established and their potential future significance highlighted, momentum for including these in the IPCC methodologies may develop, particularly if groups in other countries have recognised the same benefits.

The implications of this for the ASBP are to:

- publicise the findings of this paper;
- work on improving estimates of carbon sequestration by UK grown wood and non-wood BBMs;
- promote the use of home grown wood products in buildings;
- lobby for other plant and animal based products to be included in the IPCC methodologies and/or in the UK GHG inventory.

Land-use

The opportunities for increasing UK HWP production are limited due to the limited potential for increasing production from existing forests and the time it will take (~40 years) for any new policies to provide benefits. However, taking a long view on UK wood production is recommended as this will provide the immediate benefits of carbon sequestration by new trees and will provide a beneficial natural resource for future generations.

The potential exists to increase production of non-wood BBMs much more quickly, without necessarily having any land-use effects. Key products in this respect would be straw, sheepswool and recycled paper.

Landfilling

The effects of CO₂ and methane emissions from HWP in landfills will no longer be considered in the Kyoto Protocol and presumably in national GHG inventories. However, excessive landfilling of BBMs could result in elevated future methane emissions and it is recommended that the ASBP works towards eliminating landfilling of BBMs.

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