How to measure the benefits of biogenic carbon storage

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Anthropogenic greenhouse gas (GHG) emissions are making a substantial contribution to climate change (Intergovernmental Panel on Climate Change - IPCC 2007). Since pre-industrial times (before 1750) the concentration of carbon dioxide in the atmosphere has risen from a baseline level of 280 ppm (parts per million) to about 380 ppm at present. When the global warming effects of the other GHGs (primarily methane and nitrous oxide) are also taken into account, the level is around 430 ppm of carbon dioxide equivalents (CO_2e). Levels of greenhouse gases are presently higher than they have been for any time in the past 650,000 years. These contributions to the increase in atmospheric CO_2 concentration since the industrial revolution come mainly from the combustion of fossil fuels, gas flaring and emissions associated with cement production. Other sources include deforestation, land use change and biomass burning (contributing about 20%) (IPCC 2007). Although the atmospheric GHG levels continue to increase, there are various natural processes by which atmospheric carbon dioxide is removed from the atmosphere. These are:

- Photosynthetic production of biomass (terrestrial and aquatic);
- Weathering of silicate rocks;
- Dissolution in the oceans.

If all human additions of carbon dioxide to the atmosphere were to cease immediately, the atmospheric concentration would gradually return to the pre-industrial levels. About 50% of the increase above the background level of 280 ppm would be removed in 30 years. This is assuming that anthropogenic interference in the climate does not lead to irreversible effects, such as melting of methane clathrates, or oxidation of peat.

The management of carbon in the biosphere differs from fossil carbon management in that carbon can both be emitted from and sequestered to the biosphere. Whether there is a net radiative forcing, cooling or equilibrium depends on the balance and timing of the release and sequestration of the biogenic carbon. The amount of carbon stored in the living biomass of the planet amounts to 600-1,000 gigatonnes of carbon, with something of the order of 1,200 Gt being locked up in dead biomass. Most of the carbon of the terrestrial biosphere is stored in forests, which contain about 86% of the above-ground biogenic carbon and 73% of the carbon stored in the soil. Due to the activities of humanity, these carbon pools are reducing in size; carbon stocks in global forests are decreasing by 1.1 Gt per year. However, in most of the countries of Europe, the forest utilisation rate (fellings as a percentage of the annual increment) is less than 100%, meaning that the carbon pool in European forests is increasing in size. With the current rate of timber harvesting in Europe forests will move into older age classes and the net increment of wood material will consequently decline (Nabuurs et al. 2002). This provides an opportunity for increasing fellings in order to improve the carbon sequestration potential of forests. Furthermore, the utilisation of HWPs in long-life products also allows for the carbon storage benefits of timber to be extended beyond the forest. The use of biomass in the built environment represents a stable and easily accountable way of storing atmospheric carbon for long periods of time, creating a new carbon pool. Furthermore, the substitution of other building materials which often have a higher carbon footprint brings additional benefits. The question is how can this carbon storage benefit be measured and reported?

Carbon accounting refers to processes used to measure and track the flows of carbon atoms through technological systems and how these interact with the environment. Methodologies for carbon accounting are assuming greater importance due to concerns regarding the impact of the release of fossil carbon into the atmosphere, primarily as carbon dioxide and methane. It is an essential element of carbon trading schemes, such as the European Union Emissions Trading System and is also needed in order to report on national greenhouse gas inventories required under the Kyoto protocol. Carbon accounting can also be used as a means of supporting informed decisions about products and processes, using life cycle assessment methodologies; these are sometimes referred to as carbon footprints.

Carbon trading schemes have been introduced as a way to internalise the external costs of carbon emissions and are a means by which countries are able to meet their obligations under the Kyoto protocol. The EU launched a carbon trading scheme in 2005, covering power plants, aviation and energy intensive industries. There are various carbon trading schemes around the world, but there is no global trading scheme at present. In a future carbon trading market, it is envisaged that carbon credits could be given for the storage of atmospheric carbon (as biogenic products) in buildings. The value placed upon the storage of atmospheric carbon has to be represented in the market. For example credits would be given for the use of timber in construction, an idea that is not always viewed in a positive light by some highly carbon intensive industries!

The role of HWPs in mitigating greenhouse gas emissions has only recently been recognised by the Kyoto Protocol. For the first commitment period (2008-2012), it was assumed that the quantity of carbon leaving the HWP pool every year was equal to the annual inflow. For the second commitment period (2013-2020) the carbon accounting can now include carbon stock changes in the HWP pool. Although the IPCC recognises the importance of the built environment, its mitigation strategies listed in the fourth and fifth assessment reports (IPCC 2007, 2014) are almost exclusively concerned with energy consumption. The use of wood as an example of a low embodied energy material is mentioned, but there is no consideration given to the potential for timber and other plant derived products to act as carbon stores in the built environment. Furthermore, the use of mitigation strategies associated with forestry is only concerned with bioenergy and does not discuss the carbon storage potential of timber products. However, the Conference of the Parties to the Kyoto Protocol in Copenhagen in 2009 did recognise the importance of including timber products as carbon sinks and the 2011 Durban and 2012 Doha conferences stated that carbon stored in wood products should be integrated into reporting procedures.

The environmental benefits of using timber as a substitute for high embodied energy construction materials have been demonstrated (e.g., Buchanan and Levine 1999, Börjesson and Gustavsson 2000, Gustavsson and Sathre 2006, Nässén et al. 2012). The advantages of using timber and other bio-derived materials as a means of storing sequestered atmospheric carbon in the built environment has also received attention in the scientific literature (e.g. Pilli et al. 2015). Although the environmental benefits of using natural materials, such as timber in construction can be clearly demonstrated, the same cannot be said for the economics unless the external costs of climate change are internalised into the materials prices. This requires carbon accounting methods to be developed (Sathre and Gustavsson 2009). Conventional LCA methods do not assign any benefits to the temporary storage of atmospheric carbon because the timing of emissions relative to removals is not considered.

But the impacts of storing atmospheric carbon dioxide are dependent upon the length of time for which the carbon is removed from the atmosphere (Cacho et al. 2003, Levasseur et al. 2013). This has been taken into consideration in the UK Publically Available Specification 2050 (BSI 2008) and the European Commission's International Reference Life Cycle Data (ILCD) Handbook (European Commission 2010). With PAS 2050, the benefits of carbon storage are calculated on the basis of a weighted time average approach for an assessment period of 100 years. For example, if a bio-derived product containing 1 kg of atmospheric carbon is used in a building for 50 years before disposal by incineration, then the benefit of carbon storage is calculated as (50/100) x 1 = 0.5 kg. The ILCD methodology considers biogenic carbon sequestration as a negative value and emissions as a positive value. The carbon credits in biogenic materials arise from the effect of delayed emission over a 100 year assessment period. If emission of 1 kg carbon is delayed for a period of 50 years, this is calculated as (50/100) x 1 = 0.5 kg, in the same way as the PAS 2050 example. The benefits of atmospheric carbon storage in bio-derived products can only be accounted for if the material is derived from a sustainable production source. For the case of timber products, this means that there has to be regeneration of the forest after felling to produce the timber. If felling of the timber results in land use change (such as conversion to agriculture) then the benefits of atmospheric carbon storage in the HWP are no longer present and according to the ILCD guidelines this biogenic carbon should be treated as if it were fossil carbon. Brandão et al. (2013) reviewed six methods (including PAS2050 and ILCD) for accounting for the impacts of carbon sequestration and the temporary storage and release of biogenic carbon. The paper identified that the benefits of carbon storage are highly dependent upon the time horizon adopted and that this is based upon value judgements rather than having any sound scientific basis. As such, the time frame adopted is informed by policy considerations and the commonly used 100 year period for GWP calculations is based upon the desire to bring about achievable change in a crucial period in the history of humanity. The intention is to change behaviour to a sustainable development trajectory.

Although many studies of carbon storage in harvested wood products have been conducted, there are no commonly recognised methods for determining and reporting this in bio-derived products from a time perspective. PAS2050 and ILCD give two methods for dealing with the temporal factor, but other approaches have been suggested. The method of Moura-Costa and Wilson (2000) calculates a sequestration-based equivalence factor called the Absolute Global Warming Potential (AGWP). The AGWP is defined as the cumulative radiative forcing potential for CO_2 of unit mass over a specified time horizon. This is calculated from the following relationship:

$$\boldsymbol{AGWP} = \int_{\mathbf{0}}^{\boldsymbol{TH}} \boldsymbol{a_x} . [\boldsymbol{C}(\boldsymbol{t})]\, \boldsymbol{dt} \qquad (1)$$

Where TH is the time horizon under consideration, t is time, a_x is the radiative forcing due to the presence of unit mass of CO_2 in the atmosphere and C(t) is the concentration of a pulse of CO_2, decaying as a function of time, which is usually expressed in terms of the Bern model. Based upon these considerations, they found that removing 1 tonne of CO_2e from the atmosphere and storing it for 55 years counteracts the effect of releasing a pulse of CO_2 into the atmosphere with a residence time of 100 years. This method allows for benefits greater than 100% if the 55 year storage period is exceeded. Another approach, referred to as the Lashof method, assumes that the storage of atmospheric CO_2 is equivalent to a delayed emission of fossil CO_2, but the carbon tracking is performed in the atmosphere rather than the biosphere (Fearnside 2002) (Fig. 1).

Levasseur et al. (2013) examined the problem of GWP impact using a traditional LCA approach without including sequestered carbon, a traditional approach including sequestered carbon, PAS 2050, ILCD and dynamic LCA methodologies. Each approach gave different results, with there being dramatic differences in some cases.

It was concluded that the dynamic LCA approach was the preferred method for providing reliable data, although the results obtained were heavily dependent upon the assumptions made and the time horizon considered. The study also examined the problem using a functional unit of a wooden chair, which can give different results compared with studying temporal carbon storage of a pool of HWPs.

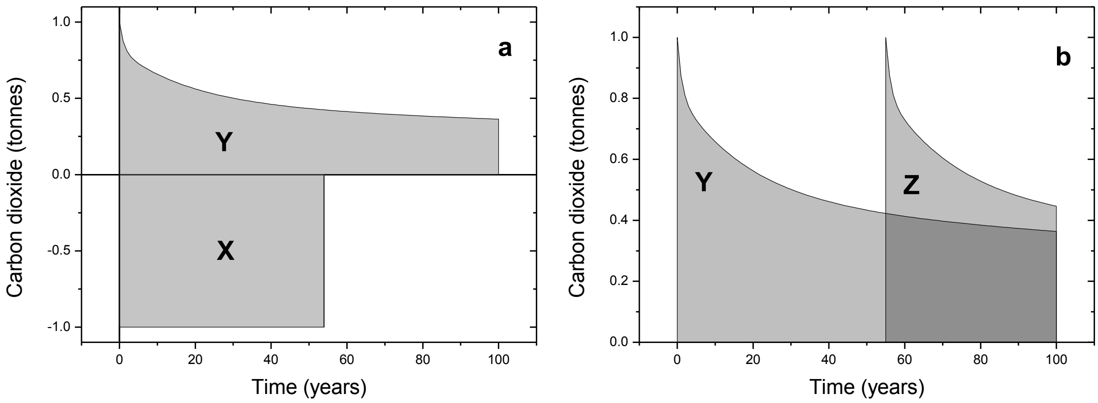

Fig. 1: Illustration of the Moura-Costa (a) and Lashof (b) methods for calculating the benefit of carbon storage. In (a) a pulse of 1 tonne of carbon dioxide is released into the atmosphere and this decays according to the Bern mechanism. The total global warming potential (GWP) over 100 years is represented by the area under the curve. The same total GWP is represented by storage of 1 tonne of CO_2 for 55 years (X=Y). In (b) the carbon is stored for 55 years and then released as a pulse of CO_2. The total GWP is the area under the curve Z, the benefit of storage is given by subtracting Y from Z.

A pool of biogenic carbon products does not release carbon to the atmosphere in a pulse, as is the case with a single product, but in a manner that is better modelled as a probability distribution (Shirley et al. 2011). Many studies investigating the release of carbon from HWP pools have modelled this behaviour as a single exponential decay (as in the IPCC guidelines), but Shirley et al. (2011) point out that this does not adequately consider that the probability of a product being taken out of service is related to the age of that product. This was dealt with by the development of a distributed decay model (Marland and Marland 2003, Marland et al., 2010), which uses a probability distribution to determine how much of production from a particular year decays in any given time interval. This type of model is analogous to the approach adopted by the life assurance industry in actuarial mathematics. This form of modelling is very useful when attempting to adopt a realistic methodology for pricing carbon and assigning a value to the cost of emissions from the HWP pool in the future.

The carbon pool of HWPs can be in one of three states, stable, increasing or decreasing. Which one of these applies obviously depends upon the rate at which harvested wood enters the pool and the rate that the carbon in the pool is oxidised. Although a huge amount of atmospheric carbon is stored in wood products, this is of no significance from the point of view of mitigation if the carbon stock is stable. Indeed, the assumption that wood is immediately oxidised after harvesting is mathematically identical to a stable stock of HWPs. If the size of the pool is decreasing then this means that more biogenic carbon is being released than is entering, which will result in an increase in atmospheric radiative forcing, as is the case with the burning of fossil fuels. From this perspective it is irrelevant whether the source of the carbon is biogenic or fossil, it is the fact that the stock in the HWP pool is decreasing that is important. Conversely, an increase in the size of the GWP pool is of benefit, since this results in a net sequestration of atmospheric carbon, provided that the amount of carbon stored in the forests from which the wood is derived is either stable or is increasing. This means that the timber has to come from sustainably managed forests. The HWP pool size can be increased by raising the amount of wood harvesting and/or by increasing the lifespan of wood products in the HWP pool (increased levels of recycling, improved durability, etc.). The best overall strategy is to increase the level of HWPs and other biogenic materials in the pool as well as increasing the retention time through extending the life of products (enhanced durability) and by adopting a cascade materials management structure. Finally, the biogenic carbon can be returned to the atmosphere by incineration with energy recovery, thereby obtaining credits for substituting a fossil fuel source.

Unfortunately, at the time of writing the situation regarding the methodology of measuring and accounting for carbon in biogenic products is not satisfactory. Although the ILCD methodology is still current, there have not been many useful developments in standardisation. Although the 2008 version of PAS2050 did include methods for calculating the temporal aspects of biogenic carbon storage in annex C, by the time that the 2011 version had been published, this was no longer present. The European Standard EN16485 giving product category rules for round and sawn timber featured a temporal calculation method for determining the storage of biogenic carbon in the draft form, but in the final published version this had been removed. This is a situation that cannot be allowed to continue and urgent action is required.

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