White Paper
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Does a life cycle carbon assessment constrain the benefits of biogenic materials?

The built environment industry directly controls 25% of total UK carbon emissions (1), and is under increasing pressure to decarbonise. In an effort to address this significant footprint, it has become common to calculate the upfront and whole life carbon emissions of a building in what's known as a life cycle assessment (LCA). This article argues that while the current LCA method enables a straightforward framework for quantifying carbon in a project, it doesn't consider all the benefits of using biogenic materials such as timber. Biogenic materials sequester carbon in their cellular structure, and their use in long-life products is an effective way to store carbon in the built environment. As an LCA is often used in comparing materials during early-stage optioneering, the industry could be missing an opportunity to meaningfully reduce carbon in construction projects.

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Part 1: the current approach

Life cycle assessments

A life cycle assessment (LCA) is a standard way to calculate the carbon footprint of a building or product, by breaking down a building's life into temporal stages and modules (see Figure 1) and calculating the carbon emissions associated with each. LCAs are done using the methodology in EN 15978 (2) and supplemented by guidance from professional bodies such as RICS (3) and IStructE (4), which have helped increase standardisation and consistency of reporting. LCAs provide important data for design teams to measure and reduce a project's carbon emissions and are a positive step towards regulating the carbon emissions of the built environment.

All parts of a building release greenhouse gases to varying degrees throughout their life cycle. The materials forming the physical elements release the bulk of their emission in Stage A, due to mining of raw materials, manufacturing, transport and construction. There is also a (smaller) emission in Stage C at the end of a building's life, representing the energy required to demolish, transport, process and recycle/landfill the now waste material. Stage B covers the service life of the building, while it is occupied, and is usually dominated by the footprints of energy and water use. Any building materials that must be repaired and replaced during this time also feature in Stage B. There is a fourth stage (Stage D), which sits outside a whole life carbon assessment. Stage D captures the carbon loads and benefits beyond an individual project boundary (the impacts of decisions made by players outside the original designers, users and owners of a building). Stage D can be used to, for example, highlight the benefits of recycling or using reused products from previous buildings, and can allow a more holistic comparison between materials.

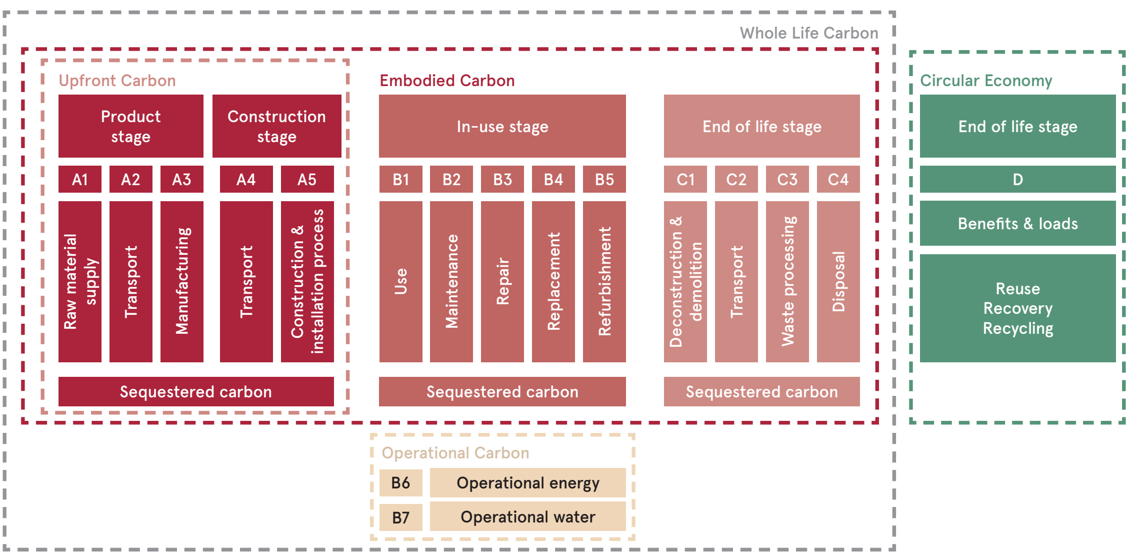

Figure 1: Life cycle stages and modules. Image from LETI Embodied Carbon one-pager (5)

The description above covers all materials, whether they originate from minerals and ores or from biogenic sources such as timber. But an important distinction must be made at this point. Biogenic materials absorb and store carbon dioxide by photosynthesis as they grow, up to the point they are harvested – this is known as sequestered carbon. A product made from a biogenic material (such as a timber joist) will keep this carbon stored within its structure until the product burns or decomposes. So that all materials can be considered under the same guidance, the sequestered carbon from biogenic materials is also reported in a life cycle assessment as a "negative" carbon emission, alongside the rest of the carbon emissions.

However, in this effort to provide fairness, we argue that life cycle assessments do not consider all the benefits of using biogenic materials. This is highlighted by two problems: LCAs do not encourage the correct end-of-life treatment at the end of life, nor do they encourage long lifetimes. The rest of this article elaborates on these issues with the current approach and presents an alternative approach to the treatment of biogenic materials in LCAs. As timber is the most-used biogenic material in buildings, the rest of this article refers mainly to timber when considering biogenic materials, but the discussion below is applicable to most biogenic construction materials.

Problem 1: Life cycle assessments do not encourage reuse and recycling over incineration and landfilling

How biogenic carbon is currently counted depends on the scope of the life cycle assessment. When reporting only Stage A, which is the carbon associated with a project up until the end of construction (also known as the "upfront" carbon) the sequestered carbon, a negative value, is not added to the net figure but is reported separately alongside the emitted carbon. This makes sense, because adding sequestered carbon to Stage A could encourage resource inefficiency: as sequestered carbon is typically larger than emitted carbon, increasing timber volumes would result in negative upfront carbon emissions.

Expanding to a whole life carbon assessment, covering the building's in-use and end-of-life stages as well as construction (Stages A, B and C) requires the end-of-life treatment to be predicted. At this point it is useful to understand what currently happens to timber construction and demolition waste: 36% is reused or downcycled (6), and the remaining 64% is incinerated for biomass energy, see Figure 2.

In a whole life carbon assessment, it is currently assumed that the sequestered carbon in timber elements is re-released into the atmosphere (which does happen if the timber is burnt or left to decompose in landfill). This means the sequestered carbon is added to Stage A, and there is a corresponding end-of-life emission in Stage C with a net of zero[1]. This is known as the -1/+1 approach (7), illustrated in Figure 3.

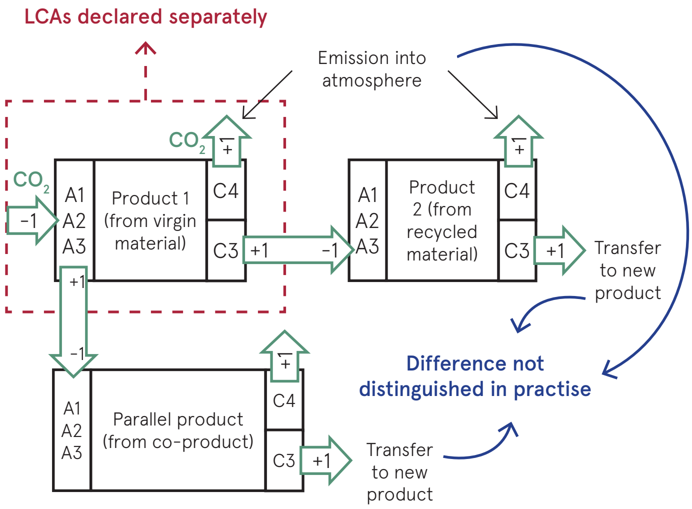

Figure 3: The -1/+1 approach. Image edited from TDUK (7)

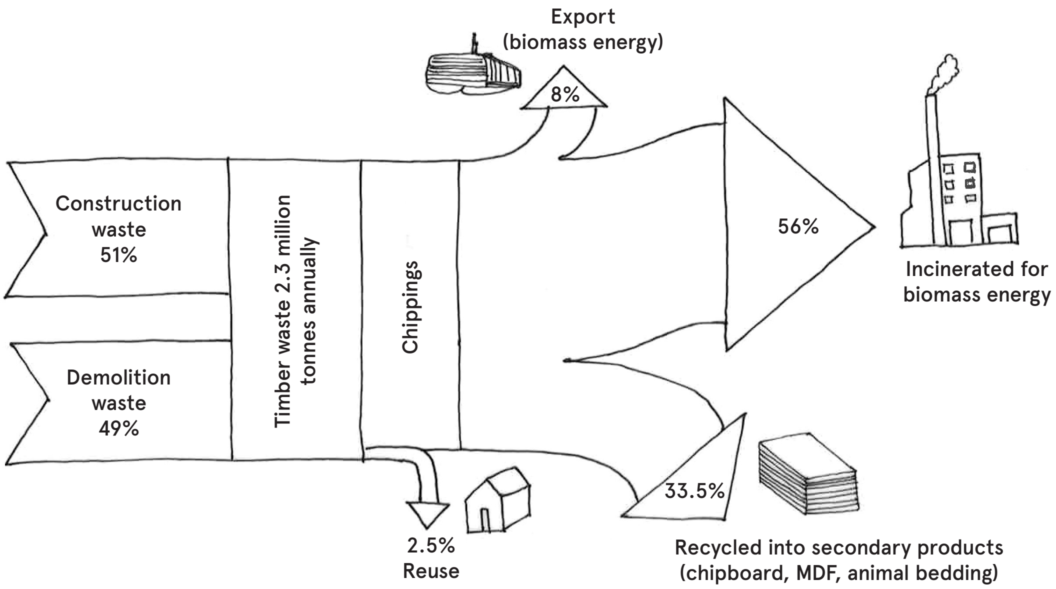

Figure 2: Flow of timber waste from construction and demolition in the UK.

1. If timber is landfilled, there is actually a net positive CO_2e emission. Only 1% of timber waste is sent to landfill so this is taken as net zero for the general case.

What happens when the timber product is not burnt nor left to rot in landfill at the end of its life, but is reused elsewhere or downcycled into a different type of timber product? The sequestered carbon remains locked in and is transferred to the next owner along with the timber product. Under the RICS methodology, the sequestered carbon must still be emitted in Stage C using the -1/+1 approach. This is to ensure that the sequestered carbon from a timber product can't be double counted. **While literature distinguishes the difference between "emitted" and "transferred", in practice this is never communicated in a whole life carbon assessment.**

Considering the end-of-life stage (Stage C) and beyond (Stage D) means designers must predict what will happen to all materials and products in their building 60 years[2] in the future. This presents both a general problem and a problem specific to timber. In general, it is impossible to predict with any accuracy what happens to buildings in general after an arbitrary 60-year lifetime. **And in particular, the rates used for timber are based on current end-of-life routes for timber products which we believe are not a credible prediction of what will happen in 60 years.**

Problem 2: Life cycle assessments do not encourage long service life

To contextualise this, first an explanation about why we must encourage reuse and recycling over incineration and landfilling. Consider a timber plantation, containing thousands of trees at different levels of maturity. Carbon is stored in the timber but also in soil, debris and litter, all at different rates. Harvesting trees from a stand (a limited zone in the forest) creates fluctuations of carbon within the system: harvested trees will stop absorbing carbon and there will be net emissions from harvesting activities and construction of supporting infrastructure, but the harvested wood will continue to store its carbon and saplings planted in the next rotation will also absorb carbon in the near future. While there is some disagreement on the overall quantity of the potential carbon store (8) it is agreed that the carbon stored in long-life harvested wood products (HWPs) is an effective climate change mitigation measure (9). This research has underpinned policy suggestions that promote the increased growth and use of timber to increase biogenic carbon stores in HWPs (10).

Timber used in construction continues to store its carbon while in use. Two variables affect the theoretical peak of carbon store in the built environment: the amount of harvested timber entering the system and the service life of these products (12). The flow of carbon within a forest system is shown in Figure 4. A sustainably managed forest needs to ensure that the regeneration rate matches or exceeds the extraction rate[3]. As a result, supply can't be increased at rates found in other industries. Production of timber is forecast to increase but this will only increase the carbon store by a small percentage. As supply is ultimately constrained by land and therefore has a theoretical maximum, the most effective method of increasing the carbon store is by increasing the average service life of HWPs, as shown in Figure 5.

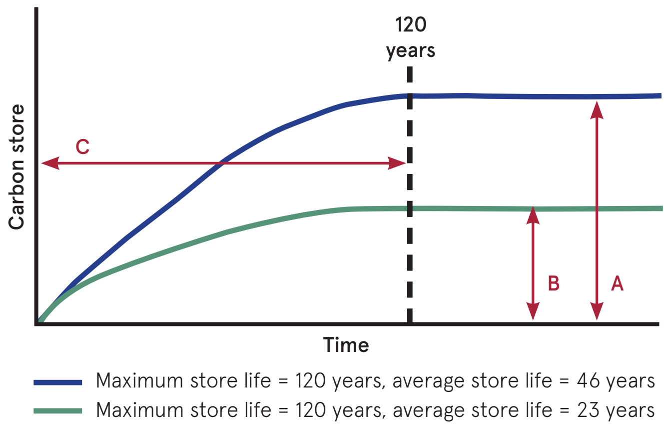

Figure 5: Influence of service life on size of overall carbon store. Image from BM Trada Wood Information Sheet (12). "A and B: the maximum carbon store in the built environment is equal to the average lifespan of timber products multiplied by the carbon in the timber introduced to the store each year. C: The carbon store levels off at the maximum life of any product in the store". Increased average service life means delaying the inevitable carbon emissions from end-of-life treatment, helping to alleviate pressure on supply and allowing the forest carbon stock to grow.

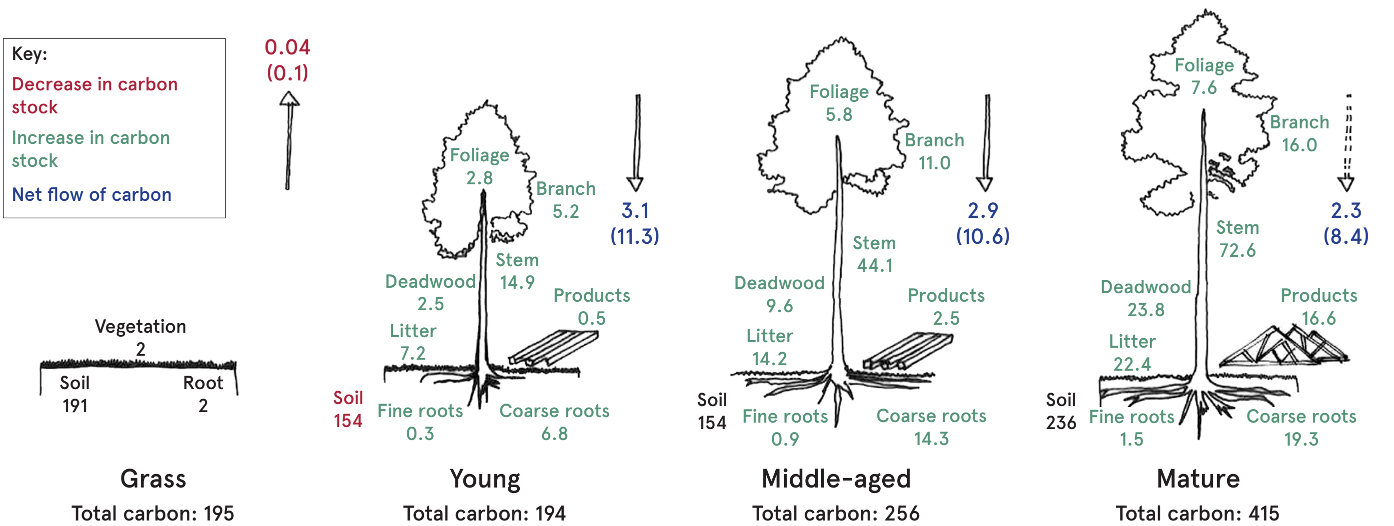

Figure 4: Carbon stocks in a Scots pine forest stand over a rotation period. Image edited from a Forestry Commission research report (11). Units are tC ha^{-1} yr^{-1} (and tCO_2 ha^{-1} yr^{-1} in brackets)

2. 60 years is the LCA definition of working life of the building, before its first major structural refurbishment or demolition. It is not a prediction of how long a building will last, but a time constraint to facilitate the calculation of whole life cycle carbon.

3. There are many other requirements for a forest to be considered sustainably managed that consider the impact on the wider ecosystem. The extraction rate limit is one of the main protections from supply being significantly increased.

To increase the service life of a HWP it should be used in a timber product with a long service life, such as a structural element. These should be designed to be reused where possible and if not, recycled down into smaller elements to create new products in a cascading principle as illustrated in Figure 6.

This is where the current practice can be restrictive as the reuse and recycling of timber products are not incentivised. Table 1 shows the embodied carbon associated with the four current end-of-life scenarios for a cross laminated timber panel. In each case the embodied carbon associated with the end-of-life activity is kept separate from the emission of the sequestered carbon, and a net total is provided for comparison. Positive numbers represent emission of carbon into the atmosphere, and negative numbers represent removal of carbon from the atmosphere. The upfront sequestered carbon is -762 kgCO_2/m^3 in all cases.

As the figures in Table 1 show, there is little difference in the Stage C emissions between reuse, recycling and incineration for energy recovery as the LCA system does not differentiate between embodied carbon "transferred" and "emitted". If Stage D is taken into consideration, then energy recovery may look like the best use case for waste wood due to the benefits of offsetting against fossil fuel energy generation. With a grid that will be decarbonised within 30 years this benefit will never be realised for long life harvested wood products. And equally importantly, Stage C and D emissions are only possible emissions – they may happen in fewer than 60 years or far longer. It is clear to see that the way the current system accounts for timber is not incentivising the most effective behaviour and there should be greater emphasis on reuse and recycling, as well as the timing of emissions. It can be argued that a circular economy statement should fill the void and influence positive design decisions, but in the absence of robust circularity metrics and under the current accounting method it is hard to distinguish between good practice and business as usual.

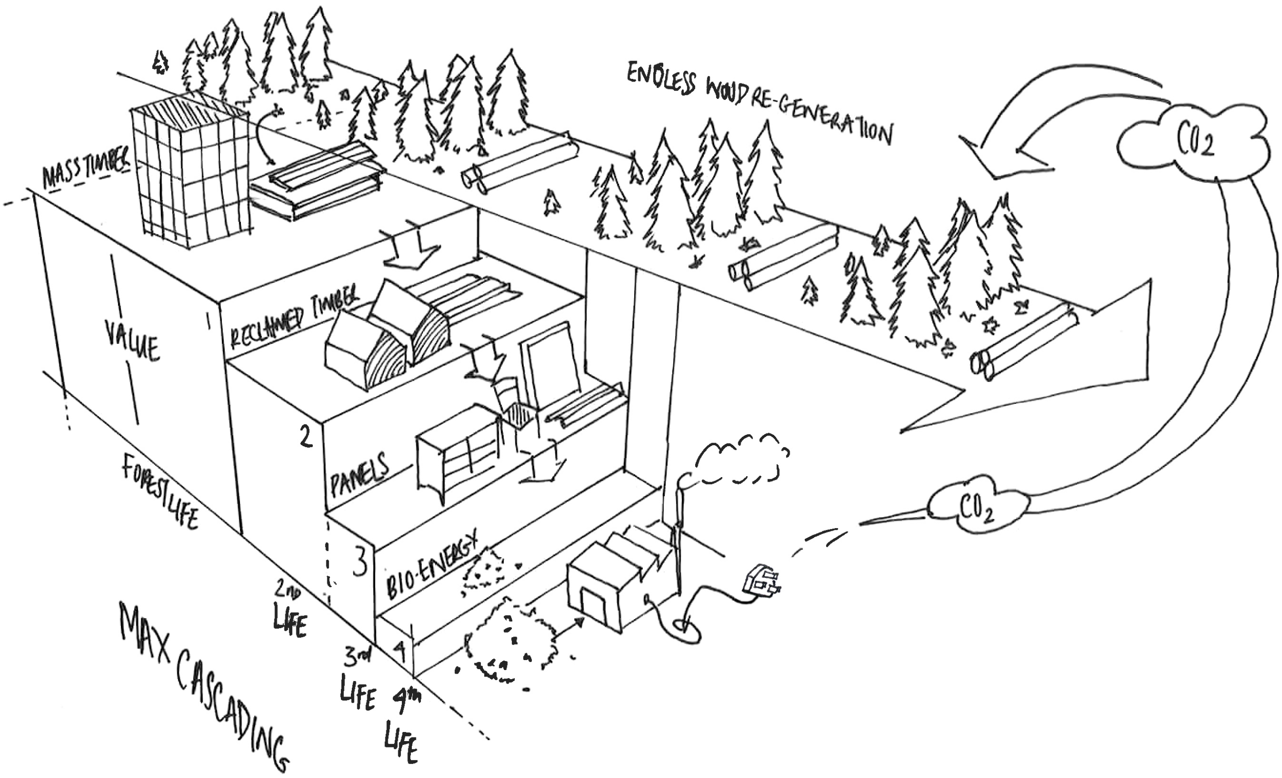

Figure 6: Timber cascade. Image from Tomorrow's Timber (13)

End-of-life scenario	100% Reuse	100% Recycling	100% Incinerated for energy recovery	100% Landfill
Stage C	2.6 emitted + **762 transferred**	8.2 emitted + **762 transferred**	38.2 emitted + 762 emitted	290.6 emitted + 762 emitted
Stage D	-52	-58.5	-365	-3.9
Net Stage C + D	+713	+712	+435	+1049

Table 1: Current end-of-life Stage C and D values for a Stora Enso CLT panel, from (7). All units are kgCO_2e/m^3 of timber

A partial improvement: dynamic life cycle assessments

One of the main limitations of the LCA methodology in EN 15978 (2), is that there is no weight given to the relative timings of carbon emissions. A 60-year timeline is generally taken for a LCA to suit the design life of the building, with the upfront emissions having the same weighting as those at the end of the building's life. In a climate emergency that needs to be addressed now, this does not make sense.

The use of a dynamic life cycle assessment (DLCA) has been proposed by the academic community (14) to accurately reflect the climate effect of the timings of emissions. Research has shown that a DLCA is the more comprehensive method for accounting for the impact of the time and type of greenhouse gas emissions when comparing biogenic vs fossil-based products with long lifespans (15).

It would be a progressive step for the UK to adopt the use of DLCA, as has already been done in some European countries such as France (16). However, while DLCAs more accurately account for the benefits of biogenic materials, they do not address the incentive issues regarding the reuse of these materials.

An alternative approach

Life cycle assessment

Accounting for the sequestered carbon in timber being "emitted" in Stage C doesn't intuitively make sense if the timber is to be reused or recycled. This shows that the -1/+1 system doesn't follow the true flow of carbon emissions. If we follow the actual release of the stored carbon within the timber, then a life cycle methodology can be created that incentivises timber to be used and reused, helping to increase the carbon stored within the built environment.

At the point that a stand of softwood trees is harvested there is specific product that the timber is designated for. It will be the demand of specific products that dictate the use of the sawn timber. To incentivise the use of long-life timber products the sequestered carbon carried out during the growth of the tree should be associated with that first product. When timber is reused or recycled it hasn't further sequestered carbon, so there is not a necessity to communicate that it has sequestered carbon if it has been attributed to the first product, but it should be understood there is stored carbon within this product.

At the end of the timber's life, having been used through cascading uses, the timber will be burnt for energy generation emitting the stored carbon[4], which should then be accurately reflected in the accounting. This system can create a duty of care that incentivises actions that keep carbon stored in timber products and punishes decisions leading to carbon being pre-emptively released by burning or decomposing in landfill.

This proposed alternative methodology incentivises reuse and recycling of timber by the current owner making the decision in the present, not the future, to ensure that the stored carbon is kept out of the atmosphere. The stored carbon will only be emitted when the product is burnt or landfilled, therefore incentivising the initial owner and any subsequent owner to keep the timber at its highest carbon value. The flow of sequestered carbon in this alternative approach is shown in Figure 7.

To ensure that material is used efficiently, sequestered carbon should be reported alongside the upfront carbon, as is current practice. In the future, a limit on upfront carbon emitted in Stage A would further disincentivise inefficient use of all material, including biogenic. In the short term, sustainably managed timber is not of infinite supply (17) therefore its use should be prioritised for long life products that substitute materials with high embodied carbon.

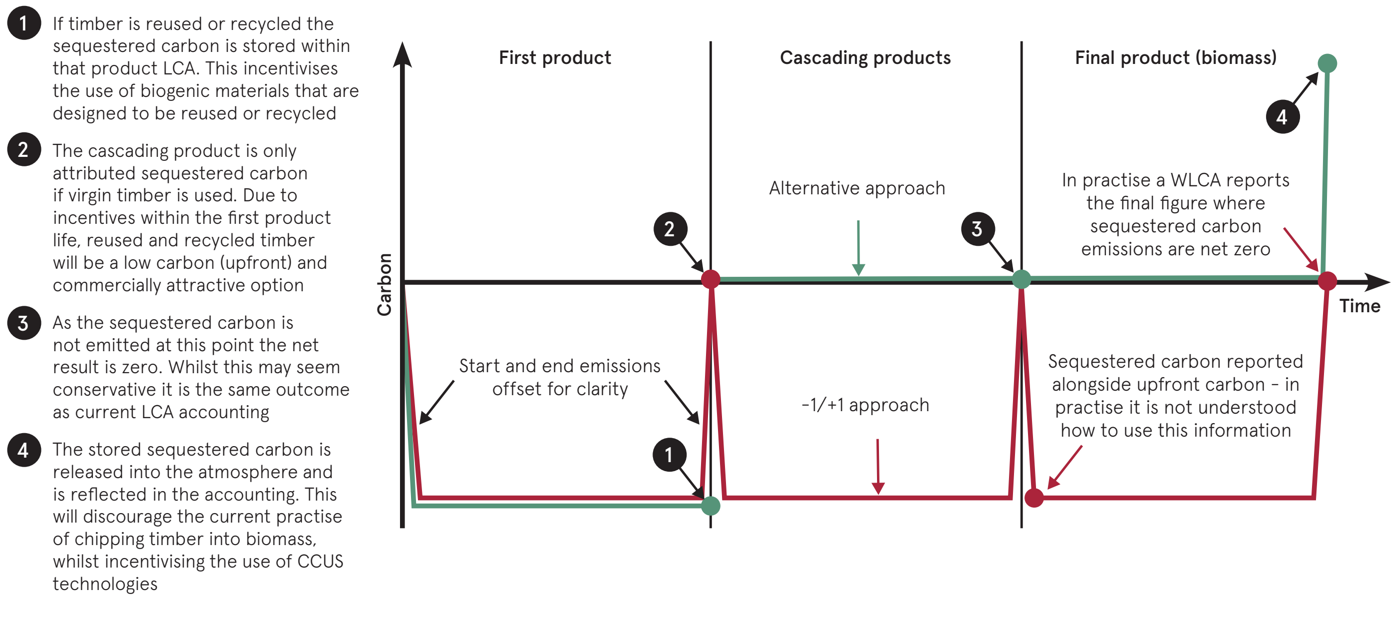

Figure 7: Annotated illustration of the life cycle flow of the -1/+1 approach (red), and the proposed alternative (green). Life cycle idealised to show only sequestered carbon for simplicity.

4. Or hopefully not. In the future there is potential for these emissions to be captured through carbon capture technologies, which could make timber products carbon negative over their life cycle. Whilst these technologies should not be relied on now, at the point a long-life HWP is burnt for biomass, carbon capture is forecasted to be commercially available and part of decarbonisation routes.

Information flow

The end-of-life assumptions need be clearly defined when carrying out a whole life cycle assessment (preferably at post-construction) to include knowledge of what materials have been procured and installed. This documentation needs to be kept throughout the building's life and made available at the point the building is being considered for redevelopment. This may seem like an unrealistic expectation but there is widespread support for better communication and storage of building information to both facilitate ease of refurbishment and material reuse. Within the London Plan (18), a notifiable project must carry out and submit both a whole life carbon assessment and circular economy statement, so this data is already being collected.

A building is likely to change ownership between its construction and its decommissioning. At the point of sale, the availability and content of its as-built information should be considered by the buyer to ensure they understand their requirements regarding end-of-life material treatment should they need to refurbish or deconstruct the building. To ensure that the owner meets their obligations, there would need to be sufficient and suitable penalties in place. This duty of care would benefit the built environment at all stages of a development.

The forest?

Within this alternative approach the forest has been disconnected from the built environment as it is purely a one-way system. A whole life cycle assessment will drive the demand for sustainably sourced timber but will have little influence upstream. Policy and responsible sourcing requirements are the systems to ensure that our forests are managed in a sustainable and regenerative way, that both increase the carbon within the forest system and promote biodiversity. Certification schemes such as FSC, PEFC etc. have been in used widely within the industry before it became commonplace to carry out an LCA. These schemes are reviewed constantly to ensure they reflect the latest best practise knowledge and new certification schemes are emerging to fill any gaps in the existing schemes, such as Grown in Britain.

Land-use change has been a major driver of greenhouse gas emissions and still is in regions across the world. Environmental and social responsibility should help to shift behaviour change but there is a responsibility of the specifier to ensure that chain of custody of any procured timber can be proven. As land-use change shifts to prioritise ecosystems that can store and sequester the most carbon, there needs to be thought on how best to develop a diverse and resilient system in an increasingly punishing climate. The necessity of extracting sequestering materials should be considered as there is an opportunity cost of further sequestering carbon and manufacturing emissions of turning the timber into a product.

Conclusion

Whole life carbon assessments have allowed design teams to interrogate and target carbon reductions within their buildings. While this may lead to the use of biogenic materials due to their lower upfront carbon emissions, it is not widely understood that there are additional benefits of delaying the emission of sequestered carbon at the end-of-life stage. Ultimately a whole life carbon assessment should be incentivising behaviour that will help address the climate emergency. The current accounting system has been developed to prevent mischaracterisation of biogenic materials against other fossil-based materials, but as a result the benefits are not fully acknowledged, and this restricts designs that could be comparatively better for our climate. This article sets out an alternative approach that allows for the benefits of biogenic materials to be more accurately accounted for and incentivises behaviour for the reuse and recycling of these materials. This approach would help to maximise the carbon stored in timber products with a corresponding climate mitigation impact.

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