Embodied carbon performance gaps in timber production for the UK built environment: A brief review.

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Abstract: The built environment contributes to nearly 40% of global carbon emissions. It is vital that the carbon footprint of building materials is accurately understood. Mass timber construction is widely assumed to be a sustainable approach to the building due to the regenerative and carbon sequestrating capacities of timber among others and is being increasingly employed to reach Net Zero by 2050. Performance Gaps are a widely accepted phenomenon in the Built Environment, with a strong focus on reducing operational gaps but far less consideration for embodied carbon gaps. Several studies have demonstrated shortfalls in the available carbon footprinting methods for analysing the full carbon flux at the point of extraction and the climate change potential of timber production. We highlight three key areas of performance gaps in the static life cycle assessment methods and realistic climate impacts. Firstly, sustainable forestry certification is opaque in its reliability and capacity to deliver regenerative forestry. Secondly, emissions from peat and the forest floor are not considered in static LCA models, yet contribute considerably to woodland carbon flux, and aerosol transfers. Thirdly, the radiative forcing of surface albedo change caused by landcover modifications. We propose further analysis to enhance the capacity of the construction industry to employ dynamic LCA modelling to limit its carbon emissions and recommend forestry activities.

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1. Introduction

The global built environment contributes approximately 39% of the planet's carbon dioxide (CO_2) emissions through embodied carbon and operational emissions of buildings (UN, 2021). Construction continues to increase in the UK with private industrial, residential and commercial construction driving annual growth (ONS, 2022). Within this, demand for new timber construction has also continued to grow significantly in the UK in recent years. 2021 saw timber imports grow 15% on the previous year, with concerns of demand-supply gaps emerging as a result of global supply-chain issues (Timber Development UK, 2022).

Calls to further increase the implementation of timber as a building material are growing. Aiming to expand carbon storage threefold, timber construction is seen to be a tool for mitigating climate change and a key component in the journey to Net Zero Carbon 2050 (CCC, 2019). CO_2 is absorbed by trees from the atmosphere as they grow through photosynthesis. This captured carbon element is retained in the wood until it reaches the end of its life, offering an opportunity to lock carbon in the material while the land is used for further carbon sequestration. Figure 1 shows the globally agreed approaches for calculating the sequestered carbon in timber (Hawkins, 2021), illustrating the lumped approach that is normally used in Life Cycle Assessments (LCA) for buildings. However, several studies have shown that the available LCA methods do not consider the full carbon flux and climate change potential of timber production. With continuing uptake of timber for UK construction, this brief review highlights the performance gaps that exist in measuring whole-life carbon performance of timber. The review focuses particularly on the gap between the carbon and greenhouse gas balance of forests and those calculated through standardised Intergovernmental Panel on Climate Change IPCC guidelines (IPCC, 2006) which could result in an overstatement of performance.

Figure 1. Approaches for calculating the sequestered carbon in timber (adapted from Hawkins, 2021)

2. Life Cycle Assessment Performance Gaps in the UK Built Environment

Performance Gaps are generally accepted (in varying capacities) within the Built Environment. The term categorises the inherent discrepancies which arise between the performance of the designed 'idealised' building, and that of the building realised onsite when in its operational phase (AHMM, 2022). Performance Gaps in building operational energy have been discussed in the industry for decades, with Post Occupancy Evaluation and detailed commissioning processes aiming to capture, record and rectify many gaps during the handover and occupation phases. However, a building's operational impact accounts for one key component of a building's life-cycle performance, the other element being its embodied carbon performance (Fig 2). It is anticipated that the embodied component will become incrementally more critical with grid decarbonisation and wider uptake of onsite renewables reducing operational energy emissions.

The concept of Performance Gaps is now being applied to Embodied Carbon too. When combined with the operational gap this provides the whole-life performance gap. A multitude of factors contribute to various project and building life stages, from material extraction and production to initial design stages through to operation (Fig 3). This review focuses on the indirect and hidden gaps present in the A1 Raw material supply phase for timber products, concerning the IPCC approach. However, this is just one small component of a larger issue facing the built environment industry in accurately assessing life-cycle carbon impacts in the move to Net Zero Carbon by 2050.

3. Life Cycle Performance Gaps in Timber

Quantifying the full environmental impact of natural regenerative materials such as timber is inherently complex and has significant scope for uncertainty. Calculations for embodied carbon in construction materials draw upon the methodology that has been developed by the IPPC (2006), and EN15804:2012+A2:2019, which sets out the requirements for developing Environmental Product Declarations (EPD) for construction products. In the UK construction industry, softwood and hardwood products are primarily imported from the European Union (Sweden, Latvia, Finland, Germany) and North America, with UK forests supplying around 31% of our total sawn wood demand (TDUK, 2022; Forest Research, 2022). With such high levels of imported timber sourced from areas with differing forestry practices, EPDs provide a critical source of information for life cycle assessors and wider practitioners. However, current EPD assessment methods for timber have a series of limitations (as outlined below) meaning the embodied carbon performance we are predicting is likely to be better than the true scenario.

3.1. Sustainable Forestry certifications

Amid growing discontent towards the forestry industry in the late 20th Century as a result of high deforestation and other resource management concerns, sustainable forestry certifications emerged from the private sector to recognise foresters that employ practices which limit harm to natural resources and nearby communities. Forestry Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), Sustainable Forestry Initiative (SFI) and Canadian Standards Association (CSA) are several of many certifications for forestry approaches.

There are many criticisms of sustainable certifications implementation efficacy and capacity to protect indigenous communities (Earthsight, 2021; Greenpeace, 2021). It is also essential to consider the impact of certified forests on carbon sequestration and emissions. The biogenic carbon stored in tree cells is only incorporated into LCA if the timber has been sustainably sourced (RICS, 2017). In a wide-ranging study across geographic regions, Dietz et al (2022) found that scholarly research into sustainable certifications across agriculture, forestry and aquaculture has a mixed performance at the producer level. Meanwhile, Tritsch et al (2020) found that FSC is one of several factors affecting lower deforestation levels, and is not necessarily the most significant. This uncertainty suggests that it cannot be guaranteed that plots are replanted, or that the same tree is planted after a tree is extracted, questioning the validity of biogenic carbon sequestration and storage calculations dependent on this assumption.

3.2. Emissions from Peat

Peatland is a terrestrial wetland ecosystem in which anaerobic conditions related to the water table elevation prevent the rapid decomposition of plant matter. This results in the long-term storage (millennia) of sequestered carbon from plant photosynthesis and the capture of nitrogen. The intricate interactions with the ecosystem include the release of methane (CH_4) into the atmosphere when the water table is high (Sloan et al., 2018), further contributing to the complex dynamics between the soil and plant composition, the water table and greenhouse gases.

Forestry practices, as with conventional agriculture, require drained land. This impacts the carbon efflux as a result of several processes. Firstly, if the disruption of the vegetated layer of the peatland prevents it from being able to photosynthesise, it is significantly limited in its capacity to sequester carbon into the soil over time (Sloan et al., 2018). This stops the build-up of plant matter in the soil, and the sequestered carbon with it. Secondly, the lowered water table influences the oxidation of organic matter and causes the carbon transfers in the soil to alter. This is due to greater oxygen levels being available to the organisms on the forest floor, which increases the rate of organic-matter decay (Leitner et al., 2016) and causes significant instabilities in GHG balances (Minkkinen et al., 2002). Thirdly, when carbon is carried from the soil by drainage to water bodies, it can be released from the water as CO_2 emissions (Härkönen et al., 2023).

Considerable tracts of large-scale forestry and afforestation occur on peatland landscapes. For instance, in the UK, it is predicted that 18% of peatland is beneath forestry (Evans et al., 2014). Such new planting or tree replacement on peat soil transfers carbon processes from secure storage in the below-ground material, to reliance on the aboveground storage of capacity of trees, limiting the carbon life-cycle to the end use of timber in addition to the carbon lost from the peat into the atmosphere. In most cases, this leads to a considerably shorter storage term (years to decades), together with an overall decline in soil-carbon storage, than if it were locked in the undisturbed, waterlogged peat soil (IUCN UK Peatland Programme, 2020).

3.3. Albedo change

The change to albedo from disturbing forests causes a radiative forcing that can be traced as a source of global warming (O'Halloran et al., 2012). Albedo is an important controlling factor which impacts land surface temperature and subsequent evapotranspiration and release of aerosols (Pielke et al., 2011). Surface albedo is viewed as a crucial area of research for understanding and improving climate change mitigation and adaptation (Bright and Lund, 2021), particularly in the context of forestry products and carbon dioxide sequestration strategies (Boysen et al., 2016; Bright and Lund, 2021).

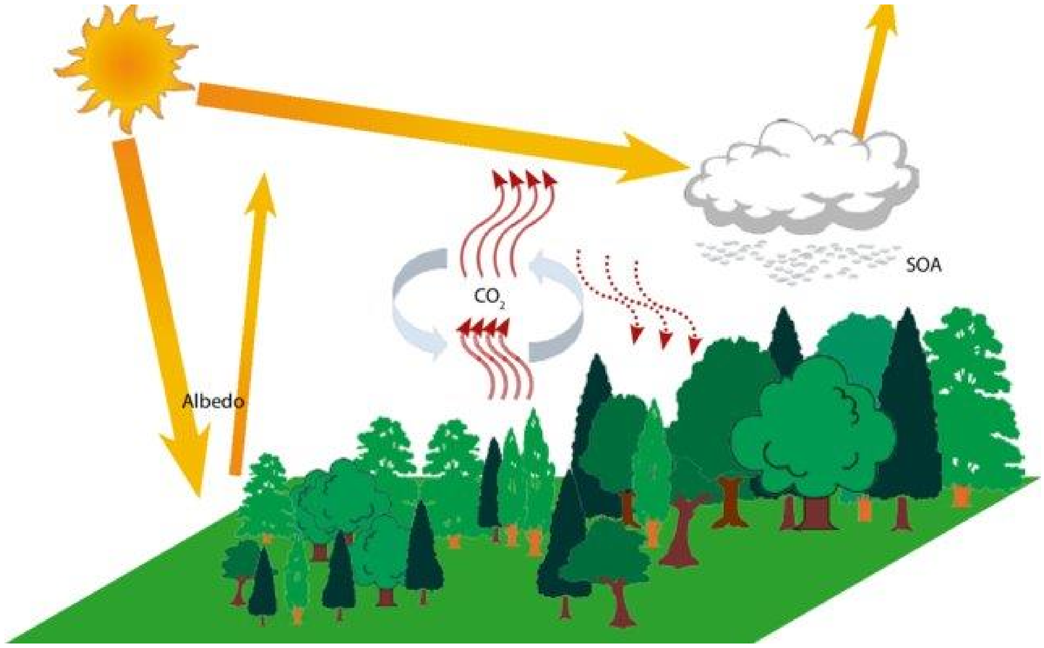

Figure 2. Illustration of the processes influencing radiative forcing: surface albedo, CO_2, and secondary organic aerosols (SOA) (Berndes et al., 2016).

It has been increasingly recognised that surface albedo is not considered in carbon calculators for wood products. The reason may be that the topic presents too many complex dynamics to be interpreted within the scope of most calculations. For instance, the Forest Research report 'Quantifying the sustainable forestry carbon cycle' (Matthews et al., 2022) omits the detail of surface albedo from their modelling scenarios presented. Holtsmark (2015) found that when surface albedo change after harvesting was accounted for in simulations, it was no longer possible to consider biofuels as a carbon-neutral product. Radiative forcing is a highly geographically and climatically specific biogeochemical and biophysical process. For example, albedo values are very different for areas of bare earth compared with areas covered by fresh snow (Weihs et al., 2021), meaning that seasonal changes alone can add complexity to the process of assessing any one product. In another study, Otto et al (2014) studied the effect of species variation and thinning strategies on summertime forest albedo. They found that both variables have a considerable impact on forest albedo, and consequently climate variability, therefore recommending the incorporation of such calculations into Earth System models. Although the IPCC's Sixth Assessment Report (Intergovernmental Panel On Climate Change, 2021) explicitly refers to the biogeochemical and biophysical effect of radiative forcing from surface albedo in changes to forested land, it is not directly included in modern LCA calculations.

Dynamic modelling is understood as an enhanced approach to estimating the carbon footprint and global warming potential of materials through analysing the atmospheric dynamics and heat-trapping ability of GHGs (Hawkins et al., 2021; Wang et al., 2022). This is largely due to the static nature of LCA's methodologies' interpretation of carbon emissions as neutral, referred to as the 0/0 or -1/.+1 approach (Andersen et al., 2021). However, dynamic LCAs offer a temporal analysis of the effects of land use changes over time (Cordier et al., 2022). This consideration of timing is crucial for accurately establishing the varying conditions of change in forest albedo and peat carbon emissions from water table changes. A previous study has demonstrated through dynamic LCAs the need for increased growing periods in forests to achieve climate neutrality, if at all (Wang et al., 2022).

Lately, fast-growing crops such as hemp, straw and sugarcane are increasingly being studied to address problems of carbon forcing in forestry (Caldas et al., 2019). These biomaterials are assumed to be fully regenerated within one year of harvesting in contrast to timber which takes longer to regenerate in the forest (Pittau et al., 2018). In addition, improved sequestration of carbon can be facilitated due to higher annual yields, therefore offering a potentially superior option for achieving Net Zero objectives in comparison to wood products (Lahtinen et al., 2022). Furthermore, such crops present an opportunity for raising the water table through 'paludiculture' to reduce the emissions associated with peat decomposition and subsequently, enhance the capacity of peatlands to behave as carbon sinks (Mulholland et al., 2020; Ziegler, 2020).

4. Conclusion

The carbon flux of forests is a complex mosaic of variables which in many cases are not yet fully understood, particularly in terms of both the interactions between forest and soil carbon and the radiative energy balance. The built environment is shifting towards employing mass timber construction as a method of limiting the carbon footprint of buildings and construction. Whilst this is a broadly positive turn away from other anthropogenic materials, not enough is yet known about the precise impacts on the environment through associated emissions from the extraction of timber and the industry must ensure any benefit is correctly attributed. LCA has been used as a satisfactory calculation of carbon emissions from wood, but research has proven that the methods used do not cover the detail necessary to establish the full, true, sustainability of forestry products. Sustainable forestry certification has contributed to improving environmentally sustainable woodland management, however it cannot be guaranteed that the conditions of certified forests and re-planting restore the biogenic carbon sequestered in trees that have been extracted. Forestry land is commonly drained in much the same way as agricultural land, leading to low water tables and carbon emissions from peaty soils beneath trees. Thirdly, when trees are removed from forests, the surface albedo of the planet changes, thus causing shifts in the radiative forcing of a forested area. Further research is needed to enable the wider improvement and implementation of time-dependant dynamic modelling to close the performance gap of LCAs and understand the true environmental impacts of forestry.

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