# Building a global carbon sink? A reality check on its feasibility limits

Francesco Pomponi[1,2,*], Jim Hart[1], Jay H. Arehart[1,3], Bernardino D'Amico[1]
[1] Resource Efficient Built Environment Lab (REBEL), Edinburgh Napier University
[2] Cambridge Institute for Sustainability Leadership (CISL), University of Cambridge
[3] Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder
* f.pomponi@napier.ac.uk

## Summary

The built environment is hard to decarbonise but has a pivotal role in meeting global climate targets. We reflect on global timber availability and carbon storage. New timber buildings can store 0.215 Gt $CO_2$ in 2020-2050 but global forests cannot deliver the floor area required by mid-century.

---

The building and construction sector accounts for ~ 40% of global final energy use and energy- and process-related emissions [1]. The efficiency of buildings while in operation has received great attention over the past four decades, embodied greenhouse gases (GHG) emissions linked to material manufacture, transportation and construction activities, and end of life disposal have only recently received global attention. These emissions are of great concern because (i) construction is a hard to decarbonise sector [2] and (ii) global urbanisation and population growth will add 230 billion $m^2$ of new buildings by 2060 [1]. A continued use of conventional building materials would pose significant carbon lock-in challenges. This is because emissions linked to the manufacture of, say, steel and cement, are incurred now on carbon-intensive energy sources and then locked into buildings and their assemblies for the whole, long lifespan of these built assets.

One of the most effective strategies to mitigate embodied emissions in buildings is through interventions at the material level [3,4]. These can be broadly clustered into material efficiency (using less of the same material) and material substitution (using alternative materials with lower embodied emissions). When substituting conventional materials, a further opportunity exists if the choice falls on so-called bio-based materials that can store carbon. The transition to post-carbon cities will require the use of carbon storing materials due to both their storage potential and reduced life cycle carbon emissions. It has been recently estimated [5] that between 0.037 to 2.49 Gt $CO_{2e}$ per year can be stored in buildings between 2020 and 2050 with aggressive adoption of bio-based structural materials.

## Which materials can store carbon?

Carbon storage in construction materials can be classified into two categories, based upon the mechanism through which they uptake carbon. Bio-based materials (*e.g.*, timber or bamboo) convert carbon dioxide into biomass through photosynthesis during the growth of the plant before being processed and used as a construction material. Cementitious materials (*e.g.*, concrete or mortar), on the other-hand absorb carbon through the carbonation of hydration products. A portion of the globally significant carbon emissions released during manufacturing (from the calcination of limestone) are reabsorbed as the concrete ages. This carbon uptake process is slow and depends upon a variety of factors, such as the surface area exposed, and the diffusion rate of $CO_2$ through the material. While cementitious materials are ubiquitous in construction, the amount of carbon absorbed is a fraction of the carbon emissions required to manufacture the concrete, thus while they store some carbon, they are not net carbon-storing materials.

Carbon storing materials are most commonly used in building envelopes, as insulation, and as building structure. Timber, as dimensioned or engineered lumber, has been used for centuries as a structural material, having become more prominent as a solution to midrise and highrise buildings as global urbanisation drives buildings to be taller. Bamboo is a fast growing bio-based structural material that can be grown around the world, with the potential to meet the growing demands of the global South building stock in addition to storing carbon. In building envelopes, insulation materials such as blown cellulose, cork, and hempcrete, are materials each of which reduces the energy required to heat and cool a building while also providing carbon storing services. Figure 1 compares the “cradle-to-gate”, or manufacturing, emissions (red) against the carbon uptake of various carbon-storing materials on a per-mass basis (kg $CO_2$e/kg material). Note that this figure should not be used to make comparisons between materials, since there is no functional equivalence between each material’s usage.

The comparison between carbon uptake in a bio-based product and carbon emissions is not always one-to-one. The timing of emissions, harvest cycle, management practices, and end-of-life scenarios all have an impact on the amount of carbon that is eventually stored in both the ecosystem, and the bio-based product that is removed from it. As a result, a more nuanced approach, such as using dynamic life-cycle inventories, must be taken when considering how to treat the uptake of carbon in the environmental accounting of buildings.

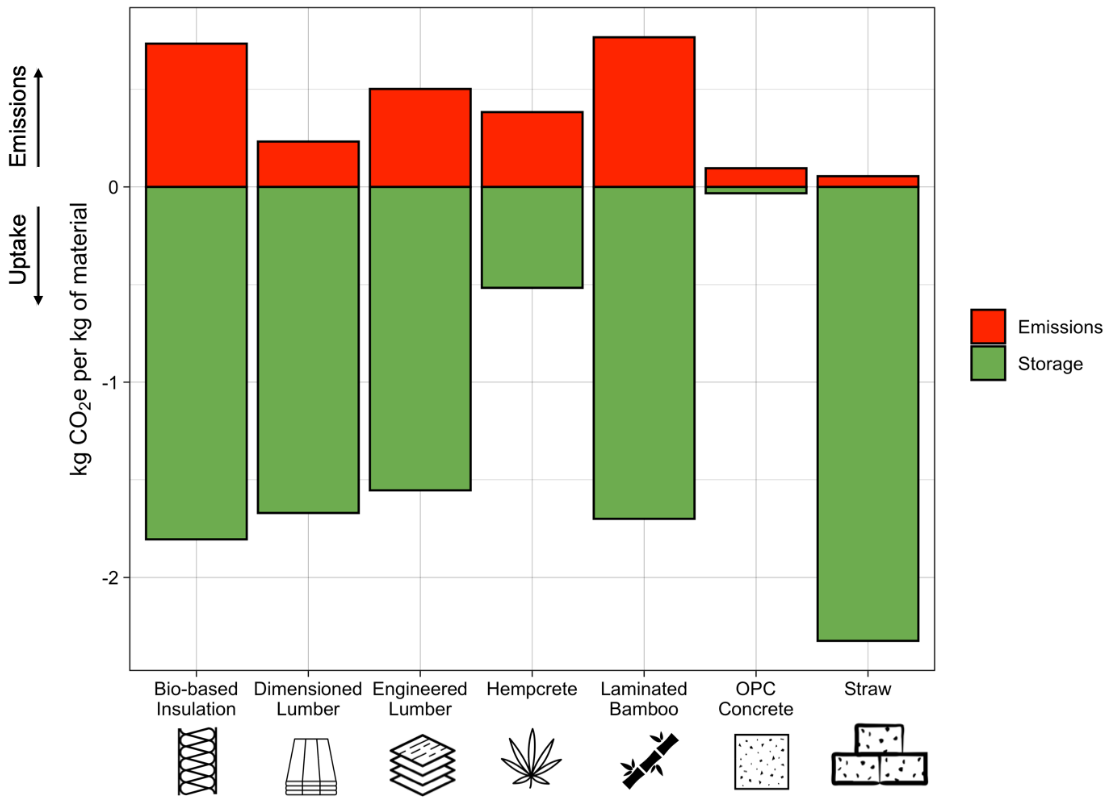


*Figure 1. The carbon storage potential (green) compared to the cradle-to-gate emissions (red) associated with manufacturing the material per kilogram of material.*

Of all these materials, timber is the one that has received the most global attention for its increasingly acknowledged potential to compete with steel and reinforced concrete in building structures [5]. We explore challenges of, questions about, and global potential for timber buildings in the next sections.

## Timber buildings: panacea or extra burden on the fragile global ecosystem?

Three broad strategies can be used to meet a growing demand for timber in building construction whilst attempting to meet climate change objectives. Firstly, we can plant new areas of forestry, managed to maximise productivity. Secondly, we can extract more timber from existing forests, and reforest as we go. Thirdly, we might attempt to divert timber from uses which offer little climate benefit to uses that best capitalise on the emissions displacement and carbon storage capabilities of timber products. All three strategies have potential, but also have their limitations. Afforestation projects can only help us to meet

demand for construction products in the long run (i.e. after the trees reach maturity), but in the long run the displacement benefits from using timber are likely to be reduced or even eliminated as a result of decarbonisation of industry generally. Increased extraction from existing forest may be a reasonable option in places, but is risky in terms of the damage that might be done to ecosystems, from soil and groundwater to the forest canopy. And in and around regions prone to deforestation, increased extraction should of course be avoided, as it should be in regions where the rate of extraction is already at or near the rate of growth. Whilst the aggressive structural timber scenario referred to above [5] can result in up to 2.49 $GtCO_2e$ of annual storage in buildings between 2020-2050, it should be noted that even at current rates of consumption and harvest, carbon stored in the world's forests has reduced at an average rate of 0.73 $GtCO_2e$ per year since 1990 [6], a number that might increase if demand increases.

The final strategy – using timber more wisely – may have the most potential in theory, but would involve mobilising the construction industry, globally, to understand and to act on how to use its share of the world's timber resources most effectively. Industry and Governments can work together by eliminating incentives to burn wood, whilst developing markets for products that can make good use of lower grades of timber and by-products: wood fibre insulation being a case in point. With every year that passes, the carbon intensity of energy displaced by biomass is reduced, and any argument for continuing to support its use is diminished.

Intensively managed plantation forestry, in suitable contexts, can easily generate sufficient timber to produce sawnwood at a rate of $4m^3$/ha (approx. 2 t/ha). However, if we look at timber productivity across whole landscapes or regions, then we see much lower numbers: for the EU the corresponding figure is around 0.35 t/ha and globally it is just 0.06 tonnes of sawnwood per hectare. Many factors contribute to this difference. For instance, according to 2020 Global Forest Resources Assessment of the Food and Agriculture Organization (FAO) of the United Nations [6], more than a quarter of global forest area is still primary forest, and is therefore untouched by commercial activities; additional areas are protected for other purposes including biodiversity and social amenity; and whilst more than a quarter of the world's forest area is identified as being valued primarily for production, only 3% has been physically planted and is intensively managed for the purpose. Many forest economies rely on a more extensive model, involving natural regeneration, which is likely to offer advantages for biodiversity, and probably soil carbon stocks, but not for maximising timber production.

One approach to promoting the sustainability of forests is to ensure that on average in each region, extraction is exceeded by growth, and it has been suggested that annual removals should not be more than 70% of the annual growth increment [7], partly to avoid putting pressure on forests in supplier countries. By this measure, the spare capacity in European forestry, for instance, is negligible. However, a modest relaxation of the target (but staying well below 100%) would result in spare capacity sufficient to produce 0.06 t/ha of sawnwood.

## Can supply match demand?

Deforestation and illegal logging rightly are of utmost concern [8,9] and should be fought and eradicated. Contrary to common belief some studies suggest global forest area is actually on the rise [10] whereas others report an increase in harvested forest area of 49% and an increase in biomass loss of 69% between 2011–2015 and 2016–2018 [11]. The World Bank [12] reports close to 40 million $km^2$ of global forests (2016 data), whose breakdown at country level as percentage of land area in each country is shown in Figure 2 (a). Studies on global urbanisation [13] have investigated where the hotspots of population growth and urbanisation are likely to be, with global figures shown in Figure 2 (b). If we combine these figures with recent estimates[14] for timber-based construction we can develop a simplified supply-demand model.

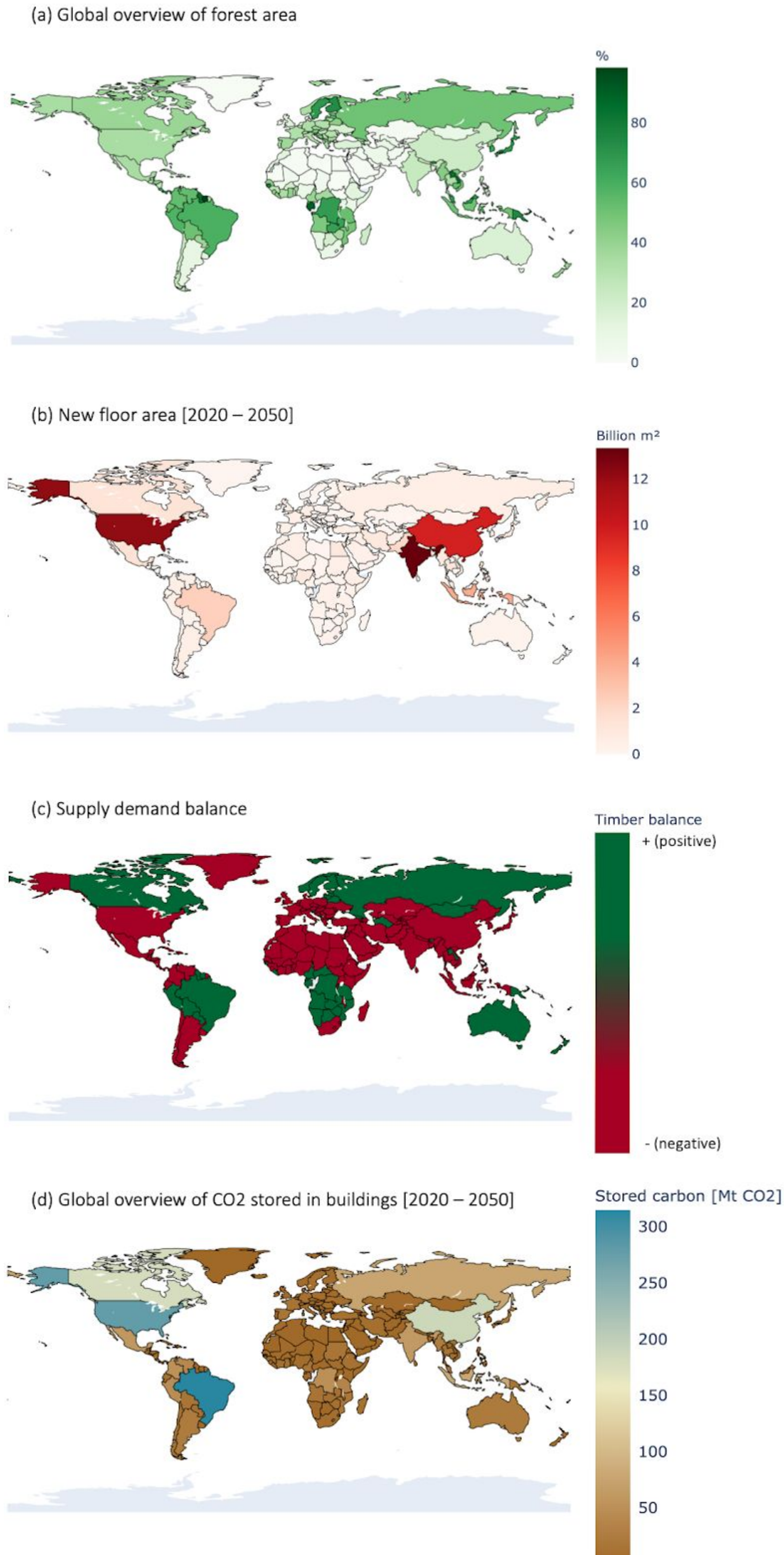


*Figure 2 - Global overview of forest area as percentage of land area based on data from the World Bank[12] for 264 countries (a), new floor area required for 199 countries in several world regions [13] in the three decades 2020 - 2050 using national population as*

*a criterion for allocation of regional figures in the original source (b), global overview (n = 199 countries) on supply/demand balance* *for construction timber (c) based on a recent analysis on average material intensities in timber buildings [14] averaging material intensity for timber-based structures at 80 $kg_{CLT}/m^2_{floor\ area}$, and global potential for stored carbon in buildings (d) if maximum possible timber floor area is realised through to 2050 based on the balance from figure (c). For the calculations behind Figure 2 (c) we consider a yield potential of 0.06t of sawnwood per hectare and 30% of the forest area in a country used for commercial purposes, which are realistic figures for global averages. Countries in green (n = 42) have commercial forest area left when all new projected floor area in the country is built out of timber whereas countries in red (n = 157) do not have sufficient commercial forest area to meet the demand driven by floor area increase. Globally, demand in 2020-2050 would exceed supply by ~ 6000 Mt with current figures for forest area. For the calculations behind figure (d) we have allowed for ~10% moisture content in above numbers, so 80kg of sawnwood or wood products store about 36kg of carbon, which we turn into $CO_2$ multiplying it by 44/12. In total we found that 0.215 Gt $CO_2$ can be stored in timber buildings between 2020-2050 which is significantly lower than recent estimates [5].*

The analysis shown in Figure 2 (c) assumes no increase in each country's forest area between now and 2050. Instead, we assume that the area cleared every year for construction timber is sustainably managed and replanted with similar species that will come to fruition in future decades. Clearly this is a simplified global model and there are some "buts". For instance, if the UK opted for an aggressive high-timber scenario for 200,000 UK homes per annum from domestically sourced wood, it would need over 1Mt of sawnwood per year. It would take around 1Mha of plantation forestry to sustain this, which is around three quarters of the existing area of productive coniferous forest. From looking at Figures 2 (b) and (c) it is evident that there are countries with limited demand for new floor area and an apparently abundant supply potential for construction timber. A fair bit of future global construction demand is likely to be in areas that have precisely the kind of timber that we need not to touch (i.e. tropical) and as such ensuring viable routes for timber construction is paramount to succeeding in its intended use as a sustainability catalyst for the built environment. However, several countries coloured in green have problems with the sustainability of their timber supply: Russia has deforestation issues in Siberia and for Brazil this goes without saying. Even Scandinavian countries have been losing standing biomass over recent years (i.e. timber is being harvested faster than it grows, as demand has increased); even if deforestation per se might not be the issue here this raises the question about 'net carbon sink or displaced carbon storage' that we address in the following section. Globally though, it seems that the supply - demand balance is unfavourable with more timber needed than actual forests can produce.

## Net carbon sink or displaced carbon storage?

Growing and felling trees, clearing up the land for the next plantation, sawing, milling and drying, and transportation and construction are all activities that require energy and incur emissions. Additionally, the carbon stored in timber eventually, however far into the future, will return to the environment. One might ask, is it still worth it? The answer is, as usual, "It depends.". Competition for land is high across all sectors of the global economy, with global demand for pulp and paper continuing to climb, and there is a fine balance to maintain between meeting immediate human needs whilst guaranteeing the capacity of the Earth to regenerate resources and provide goods and services in the future [15]. If trees are felled and not replaced then timber-based construction is simply an inefficient form of displacing carbon from forests to cities with the certainty that a mature living tree will continue, no matter how slowly, to store increasing amounts of carbon while a timber beam certainly will not. However, a rigorous approach to sustainably managing forest resources combined with policy interventions to promote increasing use of timber in construction and mandatory regulations to only use sustainable timber can actually increase the global amount of stored carbon by maintaining (or even better increasing) that stored in forests while incrementing the carbon stored in buildings. Our simplified global model contends glamorous claims on timber as a 'one-size-fits-all' solution[5] and shows that for most countries in the world a timber-only solution is neither possible to meet floor area demand nor desirable to maintain a healthy forest balance. Faster growing bio-based materials (e.g. bamboo and grasses) that have greater yields can be explored as an alternative solution which may be able to provide the demand by the built environment and should be explored. This requires an interdisciplinary approach to understanding how to build the floor area that the world needs in the next three decades since this might well be one of the pivotal choices upon which the future of us all rests.

## References


1. IEA, and UNEP 2018 Global Status Report - Towards a zero-emission, efficient and resilient buildings and construction sector.
2. CCC (2018). Biomass in a low-carbon economy - Committee on Climate Change.
3. Pomponi, F., De Wolf, C., and Moncaster, A. (2018). Embodied Carbon in Buildings: Measurement, Management, and Mitigation (Springer).
4. Pomponi, F., and Moncaster, A.M. (2016). Embodied carbon mitigation and reduction in the built environment – What does the evidence say? J Environ Manage *181*, 687–700.
5. Churkina, G., Organschi, A., Reyer, C.P.O., Ruff, A., Vinke, K., Liu, Z., Reck, B.K., Graedel, T.E., and Schellnhuber, H.J. (2020). Buildings as a global carbon sink. Nature Sustainability *3*, 269–276.
6. FAO (2020). Global Forest Resources Assessment 2020 – Key findings. Rome.
7. European Environment Agency (2017). Forest: growing stock, increment and fellings.
8. Carrasco, L.R., Nghiem, T.P.L., Chen, Z., and Barbier, E.B. (2017). Unsustainable development pathways caused by tropical deforestation. Science Advances *3*, e1602602.
9. Brancalion, P.H.S., Almeida, D.R.A. de, Vidal, E., Molin, P.G., Sontag, V.E., Souza, S.E.X.F., and Schulze, M.D. (2018). Fake legal logging in the Brazilian Amazon. Science Advances *4*, eaat1192.
10. Song, X.-P., Hansen, M.C., Stehman, S.V., Potapov, P.V., Tyukavina, A., Vermote, E.F., and Townshend, J.R. (2018). Global land change from 1982 to 2016. Nature *560*, 639–643.
11. Ceccherini, G., Duveiller, G., Grassi, G., Lemoine, G., Avitabile, V., Pilli, R., and Cescatti, A. (2020). Abrupt increase in harvested forest area over Europe after 2015. Nature *583*, 72–77.
12. World Bank Global forest area by country. Available at: https://data.worldbank.org/indicator/AG.LND.FRST.ZS.
13. Güneralp, B., Zhou, Y., Ürge-Vorsatz, D., Gupta, M., Yu, S., Patel, P.L., Fragkias, M., Li, X., and Seto, K.C. (2017). Global scenarios of urban density and its impacts on building energy use through 2050. PNAS, 201606035.
14. D'Amico, B., Pomponi, F., and Hart, J. (2020). Global potential for material substitution in building construction: the case of Cross Laminated Timber. Journal of Cleaner Production *(forthcoming)*.
15. Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., et al. (2005). Global Consequences of Land Use. Science *309*, 570–574.