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Carbon Credits for Mass Timber Construction

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Abstract

Due to concern over climate change, there is an increasing desire to limit new carbon dioxide emissions and to reduce atmospheric carbon dioxide levels. Specific efforts include taxing carbon emissions, capping carbon emissions and selling emissions allowances, and rewarding activities that avoid new carbon emissions or that capture and store carbon from the atmosphere. Cross-laminated timber (CLT) is a relatively new product that enables mass timber construction to replace traditional construction materials in mid-to-high-rise buildings. Wood materials offer substantial “carbon benefits” by storing carbon in the product and by avoiding the large amounts of new carbon emissions associated with the use of fossil carbon-intensive material options (e.g., concrete and steel). In this analysis, we propose that the carbon benefits of mass timber construction could be valued as a carbon offset, much in the same way that the carbon savings of building a wind farm or solar power plant are currently being marketed for avoiding fossil-fuel electricity generation, or how additional forest growth is being sold as carbon storage. Using a range of carbon prices, we calculate the potential carbon offset values of some mass timber construction projects located in the United States. The estimated total carbon benefit, including avoided emissions and carbon storage in wood materials from those mass timber construction projects, averaged 0.38 tCO₂e/m² of floor space, representing carbon values for projects ranging into the millions of dollars. Future trends in carbon prices will greatly affect the practical implications of any carbon offset program for mass timber construction.

Keywords: mass timber building, cross-laminated timber, carbon offset, carbon credit, avoided emissions, carbon sequestration, carbon storage

1. Introduction

There is interest in increasing the use of low-carbon footprint, renewable, and sustainable wood products in construction. Such interest is driven in part by concern over climate change; almost 13% of global greenhouse gas (GHG) emissions result from mate-

rials for buildings and infrastructure construction (United Nations Environment Programme 2022).

To mitigate climate change related to the building industry, new building materials and new building practices are being investigated, including cross-laminated timber (CLT) and mass timber construction (Dawson et al. 2022). Cross-laminated timber is manufactured by joining solid pieces of wood (structural lumber) in alternating layers. The resulting large panels have good properties and can be used as the primary structural elements in building construction (Ding et al. 2022, Karacabeyli & Gagnon 2019). Cross-laminated timber is a relatively new product that joins other wood products such as glued-laminated timbers (glulam) and heavy timbers under the general category of “mass timber” construction

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Key Policy Insights

- Mass timber construction offers potential carbon benefits through both carbon storage and avoided carbon emissions.
- Carbon offsets from mass timber construction would provide permanent, non-leaky, and additional carbon benefits.
- A carbon offset credit for mass timber construction would recognize the dual carbon advantages of mass timber and would incentivize the transition to mid- to high-rise construction based on renewable materials.

materials (Fernholz et al. 2022, Jakes et al. 2016, Stark & Cai 2021). Prior to the development of CLT panels, wood was excluded from use in mid-to-high-rise (greater than four story) construction (Stegner & Fotheringham 2022). Because of its unique structural capabilities, the advent of CLT has opened the possibility of using wood for mid- to high-rise buildings, which are currently dominated by steel and concrete (Ahmed & Arocho 2020, Brashaw & Bergman 2021, United Nations Environment Programme 2022). For example, the International Building Code of 2021 allows mass timber use in buildings up to 18 stories (ICC 2021).

A life-cycle assessment (LCA) is an internationally accepted method to evaluate the environmental impacts of a product, process, and service (ISO 2006a, 2006b). A large body of LCA literature has shown that wood products consume much less fossil-based energy to produce than functionally equivalent, non-wood products (Sathre & González-García 2014, Werner & Richter 2007). This means that using wood materials in construction avoids large amounts of fossil-based emissions – the substitution with wood reduces the CO_{2e} emissions that would result from the production of the fossil-based and fossil fuel-intensive materials, such as concrete and steel. In addition, biogenic carbon, which was sequestered from the atmosphere during tree growth, is stored in durable wood products (Bergman et al. 2014; Nepal et al. 2016, Skog 2008). The *avoided emissions* associated with wood products substitution for other materi-

als, combined with their *carbon storage* role, suggest that increasing wood use in buildings would result in substantial carbon benefits. The carbon benefits of mass timber construction specifically (including CLT) have been documented in multiple reports (Bowers et al. 2017, Buchanan et al. 2012, Chen et al. 2019, Liang et al. 2020, Milaj et al. 2017, Pasternack et al. 2022, Puettmann et al. 2021, Puettmann et al. 2019).

To achieve climate mitigation goals, policy makers around the world are introducing different carbon pricing mechanisms to promote activities that encourage reductions in greenhouse gas (GHG) emissions and/or increase carbon removal from the atmosphere (carbon sequestration and storage). Carbon pricing allows the external costs of GHG emissions (e.g., cost of damages related to climate change) to be internalized by those who are responsible for it, usually in the form of a price on the carbon dioxide (CO₂) emitted. The three common types of carbon pricing mechanism include (i) carbon taxes, (ii) emissions trading systems, and (iii) carbon offsets (World Bank 2021).

Carbon taxes are paid by the carbon emitter/producer (e.g., companies that use fossil fuels), and thus encourage switching to alternative technologies or products that emit less carbon. Many countries have implemented some form of a carbon tax, with prices (tax rates) in 2021 ranging from as low as US \$ 0.08 (Poland) to as high as \$137.24 per ton of CO₂ (World Bank 2021).

Under emissions trading systems (ETS), regulators establish emission targets for polluters, who can then either reduce their emissions to comply with the target or purchase unused emissions allowances from other polluters. Thus, an ETS establishes a market price of carbon by creating a demand and supply for emissions allowances (Environmental Defense Fund 2021). A cap-and-trade system is a common type of ETS, where a cap or an absolute limit on emissions is specified. The total amount of such cap is then split into allowances and distributed to emitters, usually for free or through auction. The given allowance sets the limit to what an emitter can emit, and penalties are imposed for any violations. The cap typically declines over time, providing an incentive for emitters to reduce their emissions efficiently and cost effectively (Environmental Defense Fund 2021). Entities that emit fewer emissions than

their allowance permit can save their “surplus allowances” for future use or can sell to other companies that emit more than their allowances. Example of ETS include the Joint Implementation (global), EU Emissions Trading System (regional), China National ETS (national), and California Cap-and-Trade Program (sub-national). Some ETS also allow use of carbon offset credits to meet the regulated entities’ emissions reduction targets.

Carbon offsets are issued for activities such as renewable energy projects, e.g., wind or biomass; energy efficiency improvements; reduction of methane emissions from a landfill site; reduction of industrial process emissions; and forestry or other practices to store carbon, e.g., afforestation or reforestation (Fernholz et al. 2021). Credits from carbon offset mechanisms can be sold or bought to comply with regulations or to meet voluntary GHG reduction goals by industry or businesses (World Bank 2021). In the United States, the most popular (reported volume) and valuable (total dollar value) carbon offset credits are those involving forests, with consideration of the carbon storage in standing trees (Forest Trends’ Ecosystem Marketplace 2021). These programs usually do not award credits to harvested trees or resulting wood products (Climate Action Reserve 2019).

Several countries, states, and local governments around the world have already implemented or are considering policies that directly or indirectly recognize mass timber as a means of mitigating building sector emissions. For example, the 2017 Buy Clean California Act requires the Department of General Services to set the maximum acceptable global warming potential (GWP) for various construction materials (California Department of General Services 2021). This provision will reward manufacturers of wood materials that have lower levels of *embodied carbon emissions* or the carbon emissions from materials manufacturing, transportation and construction (ThinkWood 2021). Similarly, the Australian government is planning to invest \$300 million in a program to encourage mass timber construction, with an aim to finance eligible projects that use low-carbon impact engineered wood products in nonresidential and residential buildings (PFA 2022). Recently, the U.S. government has announced funding for millions of dollars to advance climate-smart mass timber construction and expand wood products

markets through the U.S. Department of Agriculture’s Partnership for Climate-Smart Commodities Program (USDA 2022, NEFF 2022).

Recently, the carbon benefits—higher carbon storage and lower embodied carbon emissions—of using wood in place of other materials (Figure 1) are being recognized. For example, voluntary credits for the carbon benefits of using wood in place of other materials are currently being sold as “CO₂ Removal Certificates” (CORCs) through Puro.Earth (Puro.earth 2022). The U.S. state of Georgia passed House Bill 1015 that, when fully implemented, will enable developers to generate carbon offsets from using wood in buildings, for both the carbon stored in the wood and the embodied carbon emission savings from using wood in place of other materials (Totten 2020).

The purpose of this study is to illustrate the potential value of such carbon offsets, using available data on the summarized carbon benefits from some existing mass timber projects within the United States and a range of carbon prices on the current market and policy indicated.

2. Methods

We used publicly available data from mass timber projects located in the United States to quantify the total carbon benefits, including the carbon stored in the wood materials and the avoided fossil-fuel carbon emissions from using mass timber in place of traditional construction options. We then calculated the value of these carbon benefits, using a range of carbon prices. Finally, we put these carbon values into perspective by comparing the carbon values to the project construction cost.

Simonen et al. (2017) collected the embodied carbon emissions values from over 1,000 building projects. They reported a range of 0.200 to 0.500 tCO₂e/m² of embodied carbon for commercial office buildings, with a median of 0.384 tCO₂/m² for traditional concrete and steel buildings. A recent, multipart series of LCAs on mass timber buildings reported reductions in the embodied carbon emissions varying between 22% and 50%, when compared to functionally equivalent buildings made with traditional materials (Gu et al. 2021, Pasternack et al. 2022, Puettmann et al. 2021). We chose the midpoint of this range (36%) as a single, simple reference value to calculate the avoided emissions from the CLT

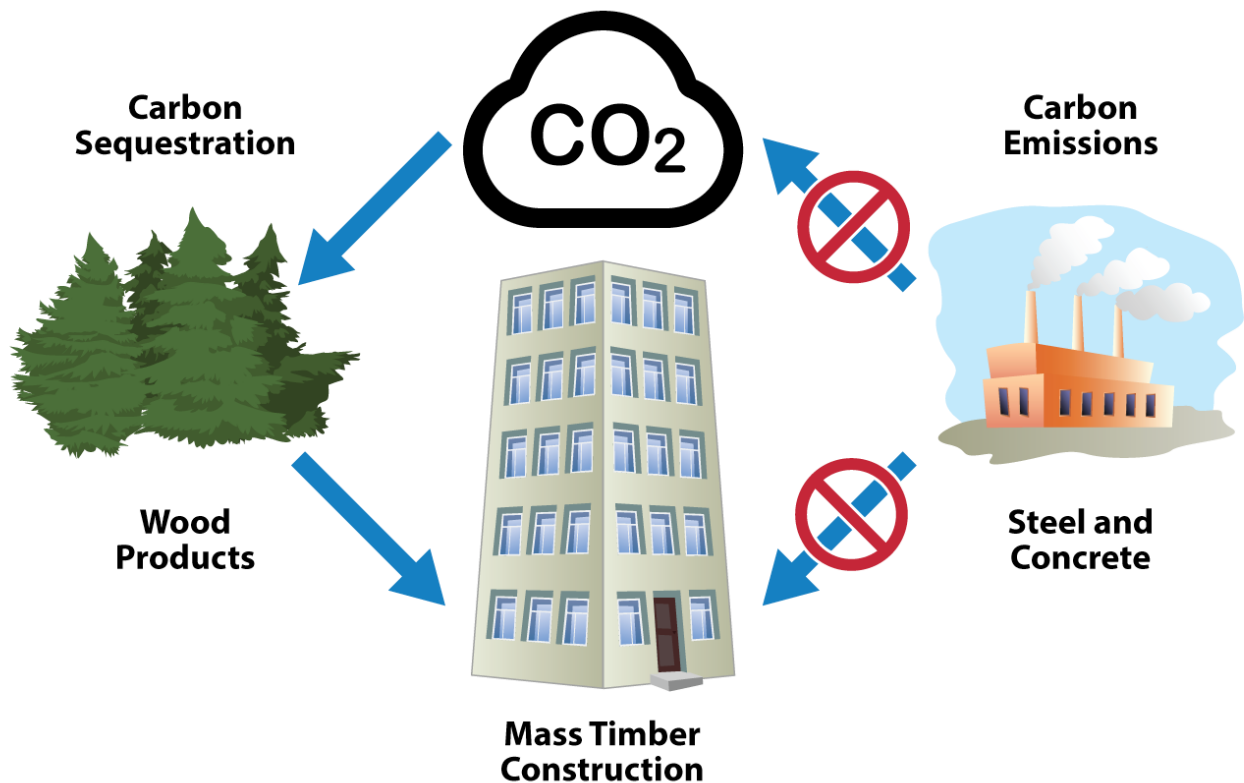


Figure 1. A simplified illustration of the dual potential carbon benefits of mass timber construction: (1) storing sequestered carbon in the wood building materials and (2) avoiding carbon emissions associated with production of alternative materials.

buildings included in this study. This simplification fails to capture the range of possibilities for specific projects, but it did allow us to include and compare many projects. Based on these reference points, the calculation we developed was as follows:

$$[1] \text{ Avoided emissions (tCO}_2\text{e)} = \text{emission reduction factor (36\%)} \times \text{traditional building embodied carbon per unit area (0.384 tCO}_2\text{e/m}^2) \times \text{building floor area (m}^2)$$

Carbon storage by these mass timber products in the buildings during their service life used a simple calculation based on the reported volume of wood materials:

$$[2] \text{ Carbon storage (tCO}_2\text{e)} = \text{volume of wood (m}^3) \times \text{density of wood (t/m}^3\text{)}^a \times \text{carbon content of wood}^b \times \text{molar ratio of CO}_2 \text{ to C}^c$$

a Assumed to be 480 kg/m³, an average density value for oven-dried Douglas-fir, with volume measured at 12% moisture content (Senalik & Farber 2021). Douglas-fir is commonly used in CLT in the United States; however, the wood species used in the projects was not consistently reported.

b Assumed to be 50% (Shmulsky & Jones 2019).

c 44/12.

Sixteen case studies of recent mass-timber buildings designed or built in the United States were included in this study because they contained consistent and sufficient data for the calculations (Gu et al. 2021, Hemmati et al. 2022, Liang et al. 2020, WoodWorks 2021). The case studies chosen are identified by their project name in Table 1. For a subset of five of the case studies, the total project costs data were reported (Table 2); for those five projects, the cost data were compared with the potential carbon offset values calculated in this study.

The price of carbon offsets around the world ranges widely and is very dynamic. In this analysis, we chose a few values to represent a possible range, but we recognize that the specific values chosen will be out-of-date soon, even by the time of publication of this work.

In their most recent review of global forest carbon offset prices, Forest Trends' Ecosystem Marketplace (2021) report 2019 prices as high as \$21.74/tCO₂e for compliance credit in the New Zealand ETS. The mean voluntary price was \$4.33/tCO₂e, but ranged to values as low as \$0.56.

Table 1. Carbon benefits and offset value of some mass timber projects.

Building project	Location	Reference	Building floor area (m ²) *	Volume of mass timber (m ³)	Avoided carbon emissions (tCO ₂ e)	Carbon storage (tCO ₂ e)	Total carbon benefit		Total carbon value (\$) at specified carbon price			
							Avoided + storage (tCO ₂ e)	By floor area (tCO ₂ e/m ²)	Low (\$4.33/tCO ₂ e)	Medium (\$49.80/tCO ₂ e)	High (\$137.00/tCO ₂ e)	
1	8-story mass timber building	U.S. Northeast	Gu et al. (2021)	9,476	3,519	1,310	3,124	4,434	0.47	19,201	220,833	607,513
2	12-story mass timber building	U.S. Northeast	Gu et al. (2021)	14,214	5,729	1,965	5,087	7,052	0.50	30,537	351,208	966,176
3	18-story mass timber building	U.S. Northeast	Gu et al. (2021)	23,321	7,324	3,224	6,503	9,727	0.42	42,119	484,418	1,332,635
4	University of Arkansas Adohi Hall	Fayetteville, AR	Hemmati et al. (2022)	18,768	4,082	2,595	3,625	6,220	0.33	26,931	309,732	852,075
5	Framework	Portland, OR	Liang et al. (2020)	8,361	2,376	1,156	2,110	3,266	0.39	14,140	162,625	447,382
6	Candlewood Suites Hotel	Redstone Arsenal, AL	Woodworks (2021)	5,824	2,208	805	1,961	2,766	0.47	11,976	137,738	378,916
7	Catalyst	Spokane, WA	Woodworks (2021)	15,236	3,310	2,697	2,939	5,636	0.37	24,405	280,685	772,167
8	Crescent Terminus	Atlanta, GA	Woodworks (2021)	25,548	7,316	3,532	6,497	10,028	0.39	43,423	499,413	1,373,886
9	Franklin Elementary School	Franklin, WV	Woodworks (2021)	4,199	1,932	580	1,716	2,296	0.55	9,942	114,345	314,564
10	Hacker District Office	Portland, OR	Woodworks (2021)	8,398	2,342	1,161	2,080	3,241	0.39	14,031	161,377	443,949
11	Nez Perce-Clearwater National Forests Supervisor's Office	Kamiah, ID	Woodworks (2021)	1,486	379	205	336	542	0.36	2,346	26,977	74,213
12	Stella	Marina del Rey, CA	Woodworks (2021)	60,428	5,424	8,354	4,817	13,170	0.22	57,027	655,879	1,804,327
13	The Bullitt Center	Seattle, WA	Woodworks (2021)	4,831	695	668	617	1,285	0.27	5,564	63,993	176,045
14	The Crossroads	Madison, WI	Woodworks (2021)	4,831	400	668	355	1,023	0.21	4,430	50,947	140,156
15	The Long Hall	Whitefish, MT	Woodworks (2021)	452	148	62	131	194	0.43	839	9,655	26,561
16	University of Massachusetts Design Building	Amherst, MA	Woodworks (2021)	8,129	2,190	1,124	1,945	3,069	0.38	13,287	152,815	420,396
Averages				13,344	3,086	1,882	2,740	4,662	0.38	20,012	230,165	633,185

*As reported. Not specified whether this represents gross floor area or net leasable area, etc.

Table 2. Carbon benefits and values for projects with reported areas and construction costs.

Project and location	Project cost (\$)	Building floor area (m ²)	Volume of mass timber (m ³)	Total carbon value (\$) at specified carbon price			Potential carbon offset values (%) relative to project cost at specified carbon price		
				Low (\$4.33/tCO ₂ e)	Medium (\$49.80/tCO ₂ e)	High (\$137.00/tCO ₂ e)	Low (\$4.33/tCO ₂ e)	Medium (\$49.80/tCO ₂ e)	High (\$137.00/tCO ₂ e)
The Long Hall, Whitefish, MT	705,135	452	148	839	9,655	26,561	0.12%	1.37%	3.77%
Stella, Marina del Rey, CA	65,000,000	60,428	5,424	57,027	655,879	1,804,327	0.09%	1.01%	2.78%
The Bullitt Center, Seattle, WA	30,000,000	4,831	695	5,564	63,993	176,045	0.02%	0.21%	0.59%
University of Massachusetts Design Building, Amherst, MA	36,000,000	8,129	2,190	13,287	152,815	420,396	0.04%	0.42%	1.17%
University of Arkansas Adohi Hall, Fayetteville, AR	79,600,000	18,768	4,082	26,931	309,732	852,075	0.03%	0.39%	1.07%

The most recent review of global generic carbon prices (including emissions trading and carbon taxes) reports an even wider range: up to more than \$137/tCO₂e in the case of Sweden's carbon tax (World Bank 2021). However, the most important market segment, in terms of volume and value, is the European Union's ETS, which has generated \$22.5 billion at \$49.80/tCO₂e. The current estimate for the "social cost of carbon" in the United States (GAO 2020), is \$50/tCO₂e, which is similar to these carbon tax and emissions trading values in Europe.

Based on the range of values identified in these references, we chose to use values of \$4.33/tCO₂e (low), \$49.80/tCO₂e (medium), and \$137/tCO₂e (high) for our analysis. These correspond to the average forest carbon offset value globally in 2019, the EU's emissions trading value in 2021, and Sweden's carbon tax in 2021, respectively. We recognize that a carbon tax is not practically equivalent to a carbon credit, but we include it as a reference value because it implies a value for carbon.

3. Results and Discussion

The added value attributed to estimated carbon benefits of mass timber construction can be substantial (Table 1). The size and type of the building, of course,

drives the quantity of wood used, which in turn affects the quantity of carbon stored in the wood materials *and* the amount of non-wood, fossil fuel-intensive alternative materials whose use is avoided. The total carbon benefit (avoided carbon emissions and carbon storage) per unit floor area averaged 0.38 tCO₂e/m². Because of the range of building sizes and potential carbon values, the calculated value of carbon offsets from the projects included in this study range from hundreds to millions of dollars.

The *avoided carbon emissions* by substituting mass timber products for the non-wood option was generally less than the carbon *stored* in the mass timber materials (Table 1). The avoided carbon emissions averaged 40% of the total carbon benefit, but ranged from 25% to 65%, indicating that building area (the basis for the avoided emissions calculation) does not necessarily correspond to the volume of mass timber used (the basis for the stored carbon calculation.)

The current wide range of carbon prices means that the potential value of the carbon benefits in these projects also ranges widely; however, at a high carbon price, the carbon savings of these projects could be about 1% to 4% of the total cost of the project (Table 2). This suggests that, if carbon prices increase, the potential carbon offsets from

mass timber construction could make a modest but meaningful contribution to a project's financing.

Mass timber construction that includes CLT is relatively new, and thus the cost of this construction type, relative to traditional options, is uncertain. Reports vary, suggesting that mass timber construction may be either more expensive than, similar in price to, or less expensive than existing alternatives (Ahmed & Arocho 2021; Gu et al. 2020, Kremer & Ritchie 2018). As the use of mass timber becomes more common in the United States, and the domestic manufacturing of CLT components increases, it is expected that mass timber construction costs will decrease, relative to conventional options. Given the uncertainty of the cost of mass timber relative to traditional options, it is difficult to predict if or at what carbon price a carbon payment would provide sufficient financial incentive to steer a developer toward choosing wood. Future research could explore the use of scenarios to examine this uncertainty. It may be that in many cases, the choice to use mass timber will be motivated by other considerations than the potential value of carbon credits (e.g., speed of construction, aesthetics, renewable resource use); however, this is difficult to predict, given that CLT has only recently become building code-approved and commercially available.

The choice of mass timber may also be discouraged by real or perceived disadvantages, such as lack of established supply chains and personnel familiar with the material (Ahmed and Arocho 2020). Mass timber buildings must satisfy the same requirements for safety (e.g., fire, seismic) and comfort as other buildings and are expected to provide similar service life; however, the true performance characteristics of mass timber are not yet known, given that it is a new technology (Ahmed and Arocho 2020). Potential carbon payments may help offset reluctance to try what is currently a less common material choice. Where carbon payments help make mass timber more attractive, we argue that constructing buildings with mass timber can result in additional carbon benefits.

The carbon benefit of mass timber construction projects, as calculated in this study and expressed on a per-floor area basis, averaged $0.38 \text{ tCO}_2\text{e/m}^2$. As noted above, we assumed single, average values for the embodied carbon emissions of traditional building types and for the avoided emissions factor associated with the substitution of mass timber. As average

values, they will be over- or under-estimates for most specific projects. These assumptions could also vary if they are meant to account for structural elements only or for the whole building (e.g., including trim and flooring), by the choice of baseline of comparison, and by the assumed reduction in embodied carbon emissions by using mass timber. Furthermore, some of our examples are hypothetical designs (e.g., projects 1-3 in Table 1) and thus do not reflect the actual construction practices. Our assumption of baseline embodied carbon emissions ($0.384 \text{ tCO}_2\text{e/m}^2$) is low, compared with some other estimates, e.g., up to $0.720 \text{ tCO}_2\text{e/m}^2$ (Carbon Leadership Forum 2017), thus our estimates of avoided carbon emissions are potentially conservative. Likewise, Skullestad et al. (2016) reported a range of embodied carbon emission savings for mass timber structures of from 34 to 84%; using the midpoint of this range (59%) would greatly increase the calculated avoided-emissions carbon benefits, compared to our assumption of a 36% reduction. Furthermore, the methods for calculating embodied-carbon baselines, and the savings associated with mass timber, are under continuing development (e.g., Carbon Leadership Forum 2022). The law in the U.S. state of Georgia requires the use of U.S. Department of Energy's Commercial Prototype Building Models for baseline comparison; however, the embodied carbon estimates of these models are still being developed (Georgia Forestry Association 2022). Clearly, any program that seeks to develop carbon credits with mass timber buildings would have to specify the scope of the building materials included and the baseline building embodied-carbon reference, based on the most current data.

If the carbon benefits of mass timber projects were to be sold as offsets, calculations of carbon savings would be needed, which could require a precise and project-specific LCA study that is compliant with the internationally recognized standards. Fortunately, several whole building LCA tools already exist that could assist with carbon benefits quantification (e.g., Tally, the Athena Impact Estimator for Buildings, OneClick LCA, and EC3). To date, the carbon storage and avoided carbon emissions benefits of wood construction have not been monetized in the form of carbon credits. However, most carbon offset programs provide opportunities to develop new protocols for their review and approval. This

suggests that, if there were interest in the concept, there is a pathway for carbon offsets generated from substituting mass timber products for non-wood materials in buildings to be certified and traded in the marketplace.

The potential carbon benefits of increased use of mass timber in buildings should be evaluated in the context of *additionality*, *permanence*, and *leakage*, three common criteria that are used by carbon offset programs to judge the overall effectiveness of a carbon offset project (Beane et al., 2008). The carbon savings of mass timber buildings could be *additional* because – assuming the building were to be built and the value of the carbon credits resulted in the choice of mass timber – the only other material options (i.e., steel and concrete) do not sequester carbon and are associated with much greater fossil-carbon emissions.

Similarly, the carbon savings due to substitution would be *permanent* – the emissions avoided by not using steel and concrete would last forever. The carbon stored in the mass timber materials would be “durable” but not truly permanent; rather they would last for the many decades of the service life of the building (Skog 2008). The carbon offsets for carbon storage in forest growth are of similar scales of permanence, e.g., 100 years (Climate Action Reserve 2019, GHG Management Institute and Stockholm Environment Institute 2021). The carbon storage benefit of mass timber construction could be extended, depending on the reuse or disposal options at the end of the buildings’ life (Liang et al. 2021, Skog 2008). Therefore, it may be that the temporary nature of carbon storage in mass timber buildings could disqualify it from consideration in some programs. Similarly, if the sequestration had already been credited during forest growth, it may be necessary to exclude the storage benefit of mass timber to avoid double-counting.

Finally, the carbon benefits (avoided emissions) of using wood in place of non-wood materials in these buildings would not result in *leakage* – greater carbon emissions elsewhere, as an unintended consequence – because the demand for other materials would be reduced. The carbon storage benefit could result in a leakage effect, depending on how the use of mass timber is assumed to impact forest

harvests and growth. In this analysis, we assume sustainably sourced wood products from net-neutral forest carbon stocks. This is a common, but controversial, assumption (Law & Harmon 2011, Lippke et al. 2011). The United States is the largest source of wood products in the world, at the same time that its forests are continually increasing in wood volume (FAO 2021, Oswalt et al. 2019). This suggests that U.S. forest carbon stocks can be a sustainable source for building materials that store carbon and avoid fossil carbon. A recent study by Nepal et al. (2021) suggested that even a very large increase in demand for mass timber globally (leading to about 4% increase in global timber harvest, compared to the baseline case, by 2060) would reduce global timber inventory only slightly (less than 0.3%), because most of the depleted forest inventory would be recovered over time, due to forest regrowth. Some studies have modelled very long “payback times” for the carbon benefits of harvested wood products (more than 100 years) because of the carbon emissions in the forest due to harvest disturbance. These carbon “debits” could be included in calculations of forest products’ carbon credits; however, there is much uncertainty about payback times (Bentsen 2017, Hurmekoski et al. 2020, Nabuurs et al. 2017). In addition, carbon debt analyses related to forests tend to be limited because they do not take a broader system perspective, where these changes, if any, in forest carbon stock can be seen in context (McKinley et al. 2011, Skog et al. 2014). Thus, we chose to assume net neutrality for forest carbon stocks for this study. Carbon neutrality is not the only indicator of sustainable or responsible forestry, and a potential carbon credit program could include requirements relating to the wood supply chain, such as forest certification or verification of legality. This may be particularly important in circumstances where local forest resources are threatened, or where imports are required to meet local wood product demand.

It is unlikely that the potential carbon sequestration value of mass timber could ever lead to the perverse situation of providing an incentive to use excess mass timber in a structure simply to earn carbon credits. At the highest carbon value considered in this paper (\$137/tCO₂e), the sequestration value of the carbon in wood would be about \$250/m³, while

current CLT prices are on the order of four times that amount (personal communication with Reinhart Sauter, owner of Sauter Timber, 2022).

This analysis shows the dominant role of carbon price on the potential value of a carbon credit for mass timber use. The great range, and future uncertainty, of carbon prices makes it difficult to predict if carbon credits could play a substantial role in motivating a shift to mass timber construction. However, carbon prices have been trending upwards in the recent past. In addition, the higher cost of mass timber construction, relative to the non-wood alternatives, can be expected to decline if the use of mass timber increases. These two trends, which would narrow any upfront price premium for mass timber, could ultimately make the role of a carbon credit for mass timber construction more important (Gu et al. 2020, Liang et al. 2021).

Wood-based construction is dominant in residential housing in the United States, while mass timber use has the potential to increase in non-residential and mid-to-high-rise construction, due to favorable building codes, coupled with the availability of CLT and other mass timber materials. To date, carbon offset programs do not reward the carbon benefits of using this carbon-storing and energy-efficient material. Issuing carbon credits for mass timber construction could provide the incentive to avoid the use of steel and concrete construction and increase carbon storage in buildings. There are many important details and assumptions to consider when developing a carbon offset program for buildings, and methods that include such consideration are being developed (Srubar et al. 2022).

4. Conclusions

The advent of mass timber is opening new opportunities to use wood in the built environment. This can provide two carbon benefits: storing sequestered carbon in long-lived wood products and avoiding the carbon emissions associated with the use of other materials. In this analysis, we quantified these carbon benefits in several actual mass timber buildings and determined their monetary value, using a range of carbon prices. This analysis used average values taken from the literature to estimate carbon benefits. Future analyses, making use of whole-building LCA

tools, could be more specific and detailed to provide more precise carbon benefits values.

The carbon storage and avoided carbon emissions benefits of mass timber buildings are large and could be of significant value, depending on the price of carbon. Some carbon credit programs for building with wood exist or are in development; however, it is uncertain whether such carbon offset programs could provide sufficient financial reward to overcome resistance to working with a relatively new building method or its potentially higher costs. Carbon credits for mass timber have the potential to provide additional, durable, and non-leaky carbon benefits; however, many uncertainties exist that policymakers should consider.

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