Tracking Carbon Emissions across the Wood Product Supply Chain:

Carbon Associated with Wood Product Imports into California and China

Research Brief

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INTRODUCTION

As the largest terrestrial carbon sink, forests are essential to prevent, mitigate, and adapt to climate change, and to regulate rainfall and water cycles. Global deforestation and forest degradation contribute 11% of global greenhouse gas emissions.[1] According to an Intergovernmental Panel on Climate Change assessment on climate change and lands, all pathways that limit warming to 1.5º Celsius (C) or well below 2°C, require significant reductions in deforestation.[2]

Forest products are a global commodity worth more than $600 billion and growing. Wood products that are part of these global supply chains can begin with deforestation of native forests, and thus incur large climate and biodiversity costs, or with supply chains that support sustainable, working forests. For jurisdictions that import and export large volumes of wood products and are active climate leaders, such as California and China, having an accounting system that quantifies this embodied carbon is important to build effective climate policy. Past research has found significant embodied carbon emissions associated with global trade in general,[3] and land use in particular.[4] Previous research on embodied emissions in China's wood products trade has focused on a production-based carbon accounting framework.[5] In this study, we estimate the carbon associated with wood product imports into California and China, using a consumption-based approach that quantifies emissions and sequestration from all stages of the wood product supply chain.Policy efforts to connect global trade to deforestation have recently been developed in some regions. For example, in 2022, the European Union agreed to a new law that will require companies to demonstrate that supply chains are not contributing to deforestation. California has also put forward legislation to encourage deforestation-free commodities. In order to produce sustainable supply chains effectively and reduce leakage, understanding the true costs of the carbon embodied in wood product supply chains is essential.

China is the largest consumer of wood in the world while demand in California is at an all-time high. The trade between the two countries is intertwined and goods imported into California reach markets across the United States. Given California's and China's ambitious climate goals and their history of climate policy collaboration, understanding the emissions associated with their wood products, is an important step in building more sustainable supply chains globally. Jointly developed trade policies of carbon-intensive products across jurisdictions that have quite different import and export characteristics can also serve as a model that can be applied to other regions that are tightly integrated into global wood product markets.

As part of these complex global supply chains, forest products are often consumed in different regions than where the forests are harvested and the products are manufactured. This can make tracking the embodied carbon in these traded products difficult to quantify and is often missed in a production-based carbon accounting framework. In order to address this gap, we estimate the carbon emissions associated with the imports of wood products in California and China. Our novel approach introduces a methodology that captures emissions and sequestration from forest carbon fluxes associated with forest growth and harvest, emissions from product manufacturing,

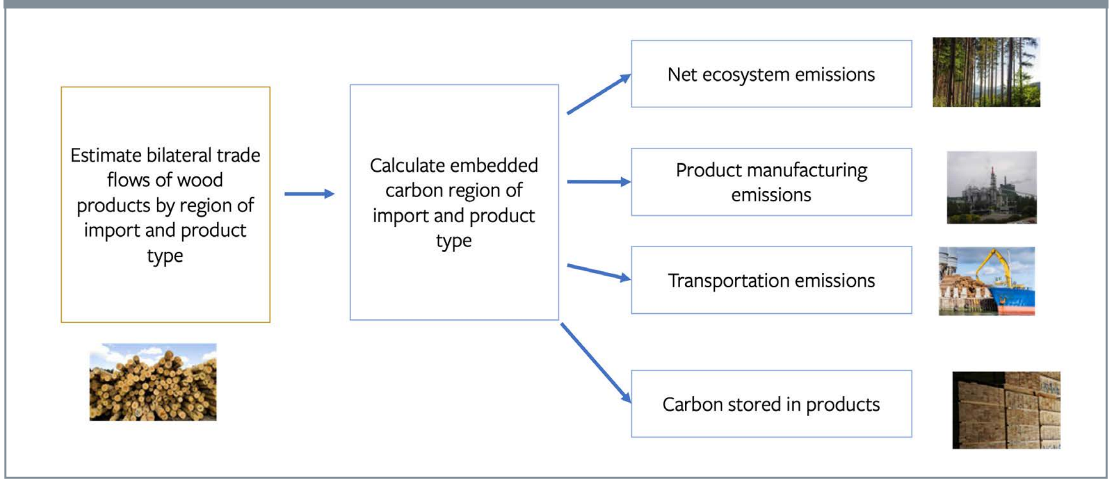
1 UNEP, 2022
2 IPCC, 2019
3 Peters and Hertwich, 2008
4 Hong et al. 2022
5 Liu et al. 2020

emissions from transportation of products around the globe, and the storage and decay of carbon in the product itself. Overall, this represents cradle-to-gate (or store) fossil and biogenic emissions, as well as the release of biogenic carbon emissions at the end of the product's life.

Methodology

The methodology for calculating the embodied carbon in imported wood products involved a two-step process (Figure 1). First, official trade data, disaggregated by detailed product type and country of origin, was compiled to create a time series of traded physical product volumes into California and China. Second, based on the source of these products and the product type, we then developed four carbon accounting modules to estimate the carbon footprint associated with (1) net changes of carbon in managed forest ecosystems (defined as the fraction of a nation's forest carbon flux attributable to exported wood products), (2) manufacturing emissions, (3) transportation emissions between the export country and the destination country, and (4) biogenic carbon emissions due to the decay of wood products. These carbon accounting modules are used to estimate the primary sources of emissions and sequestration along the global wood product supply chain. The methodology is able to capture regional heterogeneity based on the forest management and manufacturing practices that vary globally. Detailed descriptions of the methodological approach and data sources for each of these emissions and sequestration categories is discussed in the Appendix.

Figure 1 | Stylized overview of carbon quantification methodology



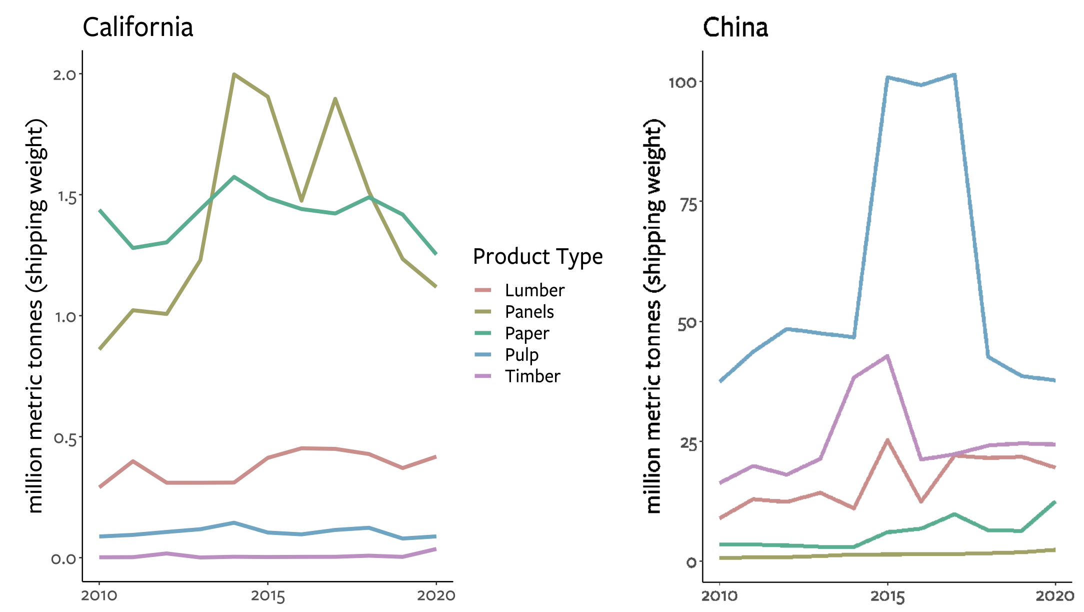
Results

Trade Results

The composition of wood product imports differs substantially between China and California. While both regions are large importers of wood products, given their relative population size, the specific products they are importing reflects the fact that California's economy is driven much more by consumption of finished wood products, while China still has a very large wood product manufacturing economy. Figure 2 shows the imports from 2010-2020 by major product category, including industrial roundwood (timber), lumber, panels, pulp, and paper. California imports primarily finished mill products, such as paper products, manufactured panels, and composite boards. China imports primarily raw and intermediate products, such as roundwood and pulp, that it then processes domestically into intermediate and finished products. These different wood product import patterns affect the embodied carbon content of the imports.

Primary trading partners for imported products differ substantially for California and China by product type. For example, China's primary trading partner for industrial roundwood products is New Zealand, with substantial quantities imported from Russia, North America, and Germany (Figure 3, panel a). Most of these imports are softwood species, although some tropical hardwood species are also imported. Pulp imports, which account for the largest volume by weight of imported wood

Figure 2 | Wood product imports into China and California (2010-2020)



products into China, come primarily from North America, South America (Brazil and Chile), and Indonesia (Figure 3, panel b). California panel and paper imports are shown in Figure 3, panels c and d, respectively. Canadian panels are the primary source of imports into the California market, followed by China and Chile. China is the largest source of California's paper imports, followed by Canada and Australia.

In California, Canada is by far the state's primary source of international wood product imports. This is true for all product categories except industrial roundwood (California imports trivial amounts of roundwood), and paper, where China is California's main import source and Canada is the next largest trading partner.

A breakdown of imports per capita by product category further illustrates the structural differences between China and California in terms of wood product demand (Figure 4). California's

Figure 3 | 2019 primary trading partners for top product categories for China (top panel) and California (bottom panel). California figures exclude imports from Canada to show scale amongst other countries of origin.

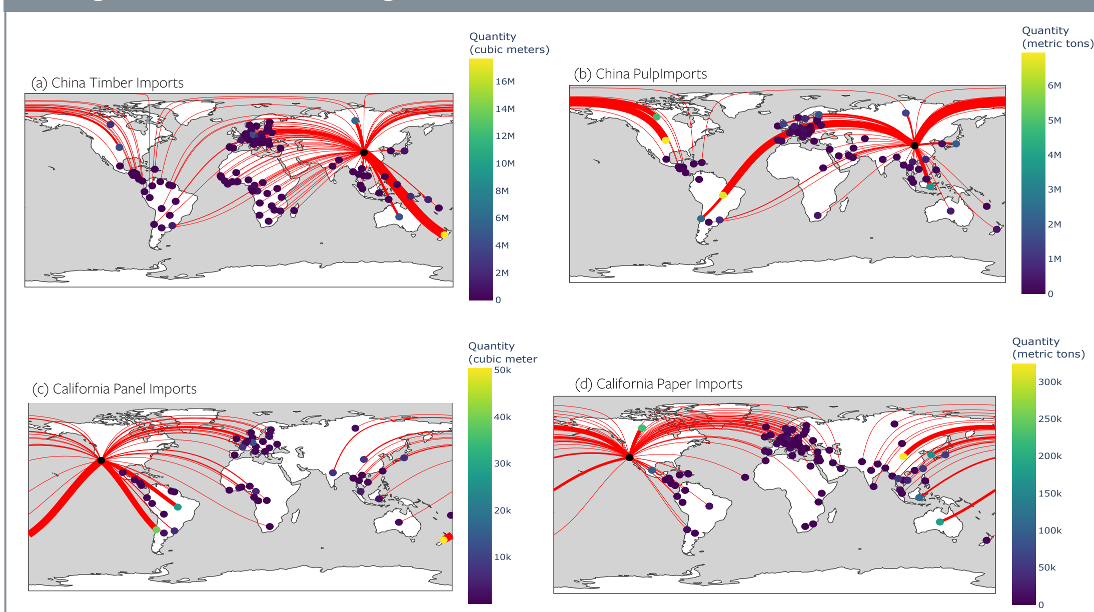
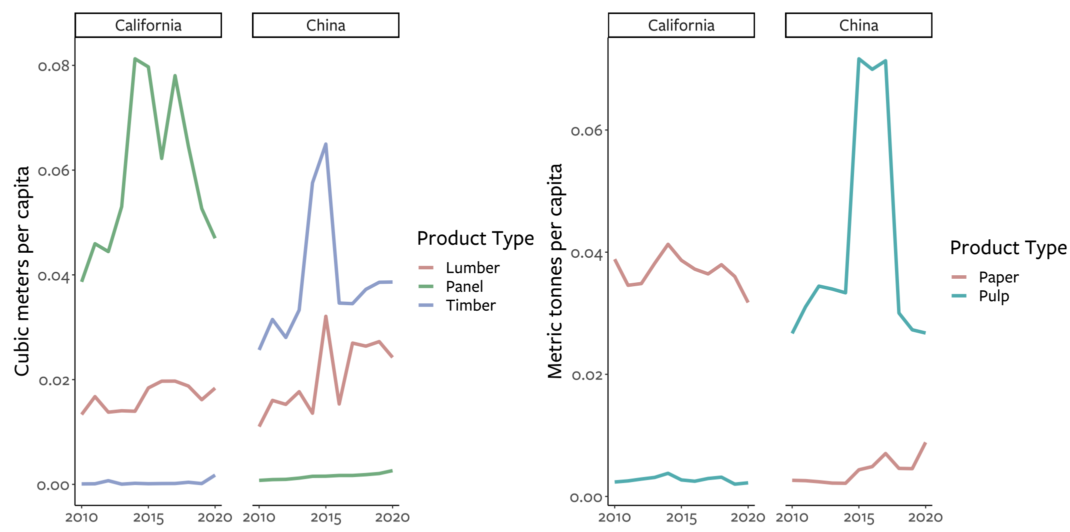


Figure 4 | Per capita imports for China and California by wood product category, 2010-2020.

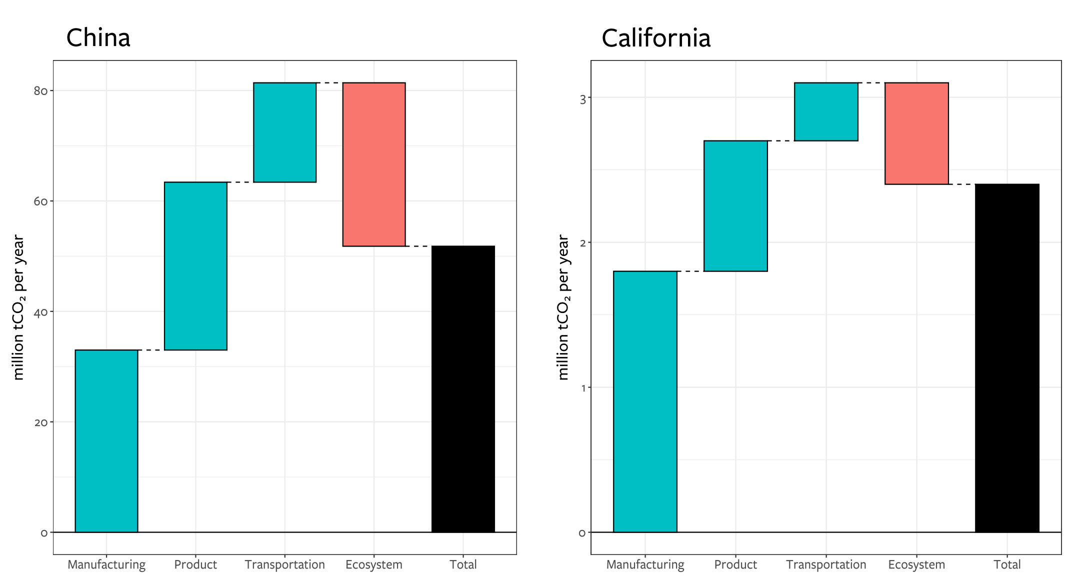


consumption-driven economy is importing more processed products per capita (panels/boards and paper) as opposed to China's value-added economy, which is importing more roundwood and intermediate products materials per capita.

Emissions Results

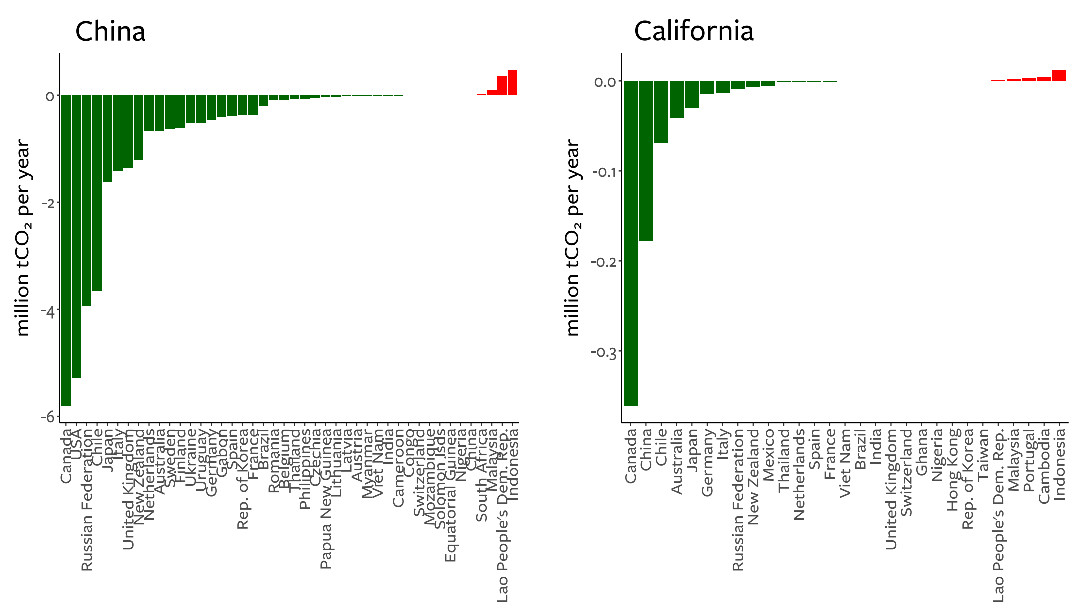
Each of the four wood product categories has an associated sequestration and emissions content based on where the world in the product was harvested, where it was manufactured, and how far it was shipped. These emission/sequestration categories, in addition to the carbon stored in the product itself, are shown in Figure 5. For both regions, manufacturing emissions account for the bulk of the total embodied carbon emissions. It is a slightly higher fraction of the carbon footprint for California imports because of the large volume of paper (an emission-intensive product) that is imported into the state. The emissions from product decay are the second largest contributor to the emissions footprint of embodied wood products. For short-lived products such as pulp, paper, and composite boards, this carbon is only stored for a small fraction of time in the product before being released into the atmosphere. Transportation,

Figure 5 | Average annual emissions from imported wood products



primarily via maritime shipping, is the smallest contributor to the embodied emissions. For both regions, net ecosystem carbon from harvest and forest management (defined in Appendix equation 2 as the forest carbon flux attributable to wood product exports) is a net sink in the product life cycle. While products imported from some regions are net sources of emissions, in total, these ecosystems are removing carbon from the atmosphere, offsetting some of the other emissions sources. However, it is clear that, without considering product and energy substitution effects of wood, currently, this offset does not fully reduce the emissions from manufacturing, transportation, and product decay.[6]

Figure 6: Total 2010-2020 ecosystem emissions associated with wood product imports. Negative emissions represent net forest-based sequestration and positive emissions represent net forest-based emissions.



Embodied emissions of imported wood product are small relative to the size of each region's total annual emissions from all sectors. In both regions, these embodied emissions from 2010-2020 account for approximately 0.6% of annual emissions.[7]

One novel contribution of this analysis is the estimation of net ecosystem emissions associated with imported wood products. These ecosystem fluxes can be either positive (net source) or negative (net sink). Figure 6 shows the net forest-based emissions of imported wood products, breaking down by trading partners. The result suggests that, except for regions with high net deforestation rates and severe natural disturbances, the managed forest ecosystems in most trading partners of California and China acted as net carbon sinks. . However, this was estimated using the Global Forest Watch data and should be interpreted with some caution. Other data sources, such as the National Inventory Reports submitted to the UNFCCC, indicated some countries to have much smaller sinks, or even as net sources. This discrepancy may result from a number of factors including the uncertainty associated with wildfires and insect outbreaks. While the Global Forest Watch data allowed us to estimate the contribution of forest ecosystem to embodied emissions of imported wood products, future work should assess the uncertainty associated with different data sources.

[6] Product substitution effects would include replacing energy-intensive building materials with structural wood products. Energy substitution effects include replacing fossil fuels with wood energy.

[7] California emissions inventory data is from the California Air Resources Board. From 2010 through 2019 California emissions were 4.24 gigatonnes of CO_2e. Emissions data for China is from the Global Carbon Project. China's emissions from 2010 through 2019 were approximately 98.6 gigatonnes of CO_2e.

Conclusions and Implications

The objective of this research was to estimate the emissions associated with wood products imported into California and China. To answer this question, we analyzed import patterns into each of the two jurisdictions and developed an accounting methodology that estimated emissions and sequestration along the global supply chain. Here we summarize the key conclusions and implications.

Conclusion 1: Import trade patterns of California and China are quite different both in product type and trading partners.

- California primarily imports lower value but more highly processed wood products from international markets, such as panels and paper products. The carbon stored in most of these products is relatively short-lived. California imports almost no industrial roundwood (ie, timber or raw logs) for processing.
- China's wood product imports are primarily in the form of industrial roundwood, which it then processed domestically for both domestic consumption and for export of value-added wood products into the global market. Data suggests that these logs are often converted into products with relatively short-lived carbon storage.

Conclusion 2: A global supply chain accounting framework allows for the major emissions and sequestration categories to be explicitly identified, which can help target policy interventions appropriate to a given emissions source.

- Process emissions from product manufacturing are the largest source of emissions in the accounting framework for both California and China. This source of emissions is driven largely by the high volume of pulp (China) and paper (California) imports, which are an emissions intensive manufacturing process. This suggests that decarbonizing the wood product manufacturing sector is critical for reducing the global emissions footprint of traded wood products.
- Emissions arising from the decay of wood products are the second largest sources. As with manufacturing emissions, this is driven by the high volume of pulp and paper imports which store carbon for only a few years. In California, many of the composite boards that are imported are also used for relatively short-lived purposes. Emission reduction of this category requires a shift in consumption behavior to more long-lived end use applications, as well as the adoption of a circular economy.
- If the forest ecosystem acts as a sink, it can significantly reduce the carbon footprint of imported wood products. Ecosystem emissions results vary considerably across trading partners and are sensitive to whether emissions associated with natural disturbances are included and attributed to the traded products. The magnitude of the net ecosystem sink was approximately equal to the emissions from the decay of wood products. However, the validity of these results depends on the reliability of the ecosystem carbon dynamics data, as well as the assumption that these sinks can be attributed to the traded wood products. The economic value of forest products has been considered an important driver of tropical deforestation. A wide range of initiatives, ranging from corporation pledges to industry certification standards, as well as government-led forest product protocols, are in place to reduce the rate of deforestation.[8] While these approaches have had mixed success in the past,[9] continual efforts to improve these initiatives are needed.

Future work should continue to refine the methods and data used to track emissions from carbon-intensive products along their global supply chains. Two specific areas are particularly important. First, regional-specific process emissions based on national electricity mixes could improve the estimation of manufacturing emissions, which are an important contributor of the embodied emissions of imported wood products. Second, net ecosystem emissions estimates could be improved using better data based on ecosystem models, which are more comprehensive than

[8] Lambin et al. 2018

[9] Lambin et al. 2018; Wolff and Schweinle, 2022

the satellite-based emissions estimates using Global Forest Watch data. Continual improvement in emissions tracking of globally traded products will both improve transparency in the carbon footprint of various products, but also help identify decarbonization policies and initiatives that are relevant to emissions sources along various points in the supply chain.

APPENDIX: DETAILED METHODOLOGY

The analysis time frame for this study is 2010-2020, prior to the COVID-19 pandemic. Physical quantities of traded wood products were gathered from two sources. China's imported wood product volumes were obtained from the United Nations Comtrade database. Comtrade reports traded quantities at the HTS-6 classification level. California imported wood product volumes were obtained from the U.S. International Trade Commission (ITC) Dataweb. California imports from Canada often through a non-Californian port of entry. For these trade flows, we used data from the Canadian International Merchandise Trade Statistics (CIMT) database, which reports exports to specific U.S. states by final destination. One important limitation of the ITC data (used for non-Canadian imports) is the possibility that wood products enter through a California port but then leave California to another final destination state. In these cases, a product would be incorrectly counted as a California import in our analysis. Finished wood products, such as furniture, were excluded from the analysis due to insufficient data availability. Comtrade and ITC reports this data in numbers (ie. 10 tables), making it difficult to determine physical volumes that can be converted into units of embodied carbon. Future work could focus on large product categories and determine average wood volumes in order to provide a first approximation of embodied carbon.

Total embodied carbon was estimate as:

$$E^{total} = \sum_r \left[E_r^{Ecosystem} + E_r^{Transportation} + E_r^{Manufacturing}\right] + \sum_i E_i^{Product} \qquad (1)$$

where

$E_r^{Ecosystem}$	are total embodied ecosystem emissions in wood products imported from country r
$E_r^{Transportation}$	are total transportation emissions associated with imports from country r
$E_r^{Manufacturing}$	are total manufacturing emissions associated with processing of wood products in country r.
$E_i^{Product}$	are biogenic emissions from product I due to decay.

Equation (1) was estimated separately for California and China, and are reported in metric tonnes of CO2e. Each component of the total emissions is described below.

The ecosystem emissions module is a method developed for allocating some fraction of a nation's total forest-based CO2 fluxes to their wood product exports to China and California (Equation 2). We allocated these emissions according to the following formula:

$$E_r^{Ecosystem} = \frac{HA_r}{FA_r} * \frac{RE_r}{RH_r} * NEE_r \qquad (2)$$

Where HA is the total timber harvest area in country r[10]; FA is the total forest area in country r[11]; RE is the total roundwood export from country r to China or California;[12] RH is the total roundwood harvest in country r;[13] and NEE are the net forest-based ecosystem emissions in country r (Harris et al. 2021). As noted about, the net ecosystem emissions are changing due to wildfire and pest outbreaks. Future work should compare results using GFW data to alterative data sources. There

10 Global Forest Watch; Curtis et al. 2018

11 FAO Global Forest Resource Assessment 2020

12 Comtrade/USITC

13 FAOStat

are some important limitations of this method, which are likely to underestimate the emissions attributable to exported wood products. For example, our approach is not able to distinguish actual forest management. We use net carbon fluxes as indicative of overall management, but it could be the case that forests harvested for wood products are being deforested and not replanting, while other areas are reforested for conservation purposes. In this case, assuming the two fluxes offset each other, our approach would show no ecosystem emissions attributed to the wood product when clearly it is a driver of deforestation and is unconnected to any reforestation efforts. In countries where this occurs at a large scale, we would be failing to attribute emissions for deforestation to their appropriate drive (forest products). Future work should either identify or develop datasets that can make this distinction. Until then, the ecosystem emissions results should be interpreted as a likely underestimate of emissions attributable to wood product trade.

Emission from country-to-country transport of the wood products was estimated as:

$$E_r^{Transportation} = \sum_i w_{i,r} * d_r * er \qquad (3)$$

Where w are total product i imports from country r; d is the nautical distance from country r;[14] er is the emissions factor for one nautical tonne-kilometer for international shipping.[15]

Emissions associated with the manufacturing of wood products are measured by region and product. Aggregate regions were used since manufacturing emissions data was not available at the country-level for most countries. We attempted to match countries to an appropriate emissions reference based on likely fuel mixes at the facility. We assume that the country from which a product is exported is also the country where it was manufactured. While this may not be the case for some products with more complex global supply chains, it is a reasonable assumption for approximating emissions. Product- and region-specific emissions are derived from life-cycle assessments in the academic literature. For lumber, panels, and boards we used the manufacturing emissions component of the LCA emissions factors from the CORRIM database. Pulp/paper manufacturing emissions factors are derived from McKetchnie et al.[16]

Finally, carbon stored in the wood products themselves was estimated according to the methodology in Smith et al.[17] This approach considers how much carbon is stored in the carbon vs. released into the atmosphere over a 100-year analysis horizon. We assume that any carbon left in the product after 100 years can be considered permanent storage. We use IPCC decay functions for specific product categories. Primary product ratios, for roundwood imports only, are taken from Smith et al.[18] for California and Manley and Evison[19] (2018) for China. Chinese primary product ratios are an important area of uncertainty and require additional research.

14 Bertoli et al., 2016
15 GHGenius V5.0d database
16 McKetchnie et al. 2014
17 Smith et al. 2006
18 Ibid.
19 Manley and Evison 2018

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