International Symposium on Life Cycle Assessment and Construction
July 10-12, Nates, France, 2012. pp. 318-325

Developing a dynamic life cycle greenhouse gas emission inventory for wood construction for two different end-of-life scenarios

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Abstract

Static life cycle assessment does not fully describe the carbon footprint of construction wood because of carbon changes in the forest and product pools over time. This study developed a dynamic greenhouse gas (GHG) inventory approach using US Forest Service and life-cycle data to estimate GHG emissions on construction wood for two different end-of-life scenarios. Biogenic and fossil GHG emissions sources included a growing forest, logging slash, softwood lumber manufacturing, residue decay and combustion, and product in the landfill. The two scenarios focused on 1) disposing of old wood and logging forests for new construction wood and 2) reusing the old construction wood instead of making new and landfilling the old wood. GHG emissions covered a 100-year time-period and were allocated to 1.0 m^3 of softwood lumber produced for two different forests and harvesting rates. Reusing old construction wood had lower GHG emissions initially. However, using new wood would eventually have lower GHG emissions because logged forests regrow and absorb carbon faster and for a longer time than unlogged forests. The paper shows the critical time delay in forest carbon re-accumulating from logging forests may be problematic in mitigating climate change in the short-term but unlikely in the long-term.

Keywords: carbon, forest, building products, new, recovered, dynamic Life Cycle Assessment (LCA)

1. INTRODUCTION

Accounting for greenhouse gas (GHG) emissions over the life of harvested wood products (HWPs) typically does not consider emission changes over time whether positive or negative. These changes involve: 1) forest carbon re-accumulating after harvesting, 2) cradle-to-gate life cycle emissions for product production, 3) carbon emitted with and without energy recovering from product combustion and residue decay, and 4) GHG emissions from HWPs leaving service and being stored a landfill. . Therefore, accurately detailing temporal aspects of GHG emissions in conjunction with life cycle assessment requires assessing emissions over time for the various stages of the whole life cycle.

In 2005, the US Forest Service (USFS) provided projections of forest growth which focused on afforestation and reforestation for six site-specific regions of the United States involving the Pacific Northwest (PNW) and Southeast (SE) regions. By volume, the PNW and SE are by far the two largest wood-building product regions in the United States [2]. Carbon factors were estimated to show carbon flows from the forest carbon pools into harvested carbon pools after harvesting. Rates of carbon accumulation in the forest and ultimately in HWPs were highly dependent on forest types, site productivity, and management intensity (i.e. forest harvesting rates).

GHG emissions from the building industry are a major focus of life cycle assessment (LCAs) mostly because of climate change implications. In the current LCA framework, building product systems are evaluated statically to develop a GHG profile. Additionally, traditional LCAs only record the total amounts of carbon emitted over the whole life cycle without addressing the timing of carbon emissions, a significant shortcoming [3]. Furthermore, standard LCA practice only considers fossil carbon emissions when calculating Global Warming Potential (GWP), not biogenic CO_2 emissions that are emitted during HWPs production [4]. Given the focus of the US Environmental Protection Agency on how to categorize biogenic carbons, research into this area will provide some context for decision-makers [5]. Therefore, a more accurate timing of all GHG emissions estimates including biogenic carbon will provide a more complete picture of a building product's environmental performance. Recently, temporal aspects of carbon accounting have been examined for biofuel studies to aid researchers and policy-makers on determining whether biofuels are less carbon emitting than fossil fuels [6, 7, 8, 9]. These studies note that timing of carbon release and reabsorption matter over several decades. In fact, delays of offsetting emissions may cause rapid and irreversible warming [10, 11]. In addition, the delayed release of GHG emissions affects the level of radiative forcing seen by the environment differently than considering all GHG emissions occurring a single time. Some methods have been proposed to consider delayed GHG emissions for building materials [12, 13]. However, this study proposes a GHG inventory approach to include carbon re-accumulation in the forest and different forest harvesting rates.

Determining the timing of GHG emissions correctly for HWPs offers new insights into describing and mitigating building environmental impacts including climate change [14]. For example, during the life cycle of a product, GHGs are emitted during harvesting, transportation, manufacturing, and disposal. GHGs from disposal may happen 100 years after the initial harvesting of raw materials for construction wood which occur outside the typical 100-year time-period for calculating GWP This study did not consider leakage that may occur due to lower lumber prices from reusing wood in construction and the resulting higher demand for new wood products.

The goal of the study was to develop a dynamic GHG inventory approach by incorporating standard estimates of forest and harvested forest carbon data with cradle-to-gate LCI data on new and recovered wood products. The scope covered a single harvest cycle to estimate GHG profiles for two forest types in the US PNW-West and SE regions. Softwood framing lumber is the primary building material used in residential housing construction in the United States. Therefore, examining how recovering wood for reuse changes the carbon pool will provide policy-makers sound scientific data necessary for developing the best building policies with respect to GHG emissions including biogenic CO_2. This study will evaluate two scenarios over a 100-year time period assuming no future harvesting will occur after year 0 although harvesting would normally occur prior to 100 years. Future harvestings were not included to introduce and illustrate the dynamic inventory through simple scenarios and then conduct scenarios that are more complex later on in future work.

2. METHOD

Using forest carbon data compiled by the USFS [1] and cradle-to-gate LCI data on new and recovered softwood framing lumber [15], we developed a dynamic GHG inventory approach for two different end-of-life (EOL) scenarios for wood construction. The dynamic GHG inventory approach demonstrated what happens to GHG flows when recovered softwood lumber from old buildings is reused (recovered wood scenario) instead of landfilling it with a comparison to harvesting new wood from PNW-West and SE forests (new wood scenario) for construction. PNW-West will be referred to as PNW for the remainder of the paper. In addition, the USFS report [1] is available as supplementary material [S1]. Description of supplementary material is available in the Appendixes. This study focused on clear-cut reforested not afforested stands. The study recorded total emissions for the new and recovered wood scenarios on an annual basis. Figure 1 shows the GHG product pools present and tracked within the system boundary. All biogenic and fossil GHG emissions were allocated to a functional unit of 1.0 m^3 softwood lumber produced for wood construction. Because softwood lumber is the driver that causes the forest to be logged, all emissions were assigned to softwood lumber.

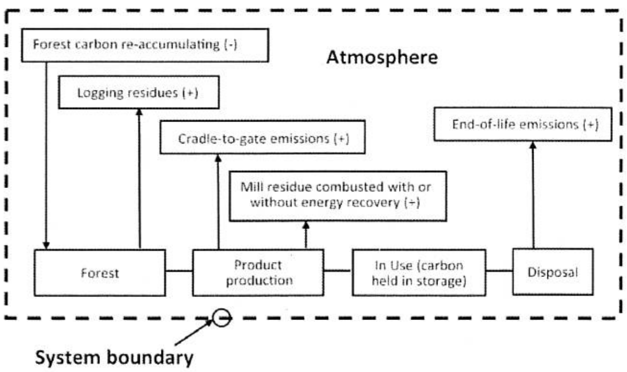

Figure 1: System boundary for GHG pools tracked for construction wood

Total emissions included the carbon emissions reabsorbed by the forest, the carbon emitted with and without energy recovery for the four industrial categories mentioned below, and the GHGs released from the old lumber breaking down in the landfill with and without energy recovery. The industrial categories included softwood sawlog, softwood pulp, hardwood sawlog, and hardwood pulp.

2.1 Waste Treatment of Old Lumber

This study modeled the old lumber waste treatment based on the same assumptions used in the other portions of the USFS analysis. These assumptions included that 24% of the wood in landfill decomposed with a half-life of 14 years and 25% of carbon was emitted with no energy recovery [1]. The recovered lumber product system did not include landfill emissions from the old lumber because the old lumber was reused in construction. The carbon factors for carbon emitted with energy recovery and without energy recovery were also taken from [1].

2.2 Forest Modeling

Forest carbon stock includes live trees, standing dead trees, understory, down deadwood, forest floor, and soil organic. We examined two forest types involving reforestation: a high-intensity managed, high-productivity Douglas-fir stand in the PNW [S1: Appendix A23] and a high-intensity managed, high-productivity loblolly-shortleaf pine stand in the SE [S1: Appendix A40]. Clear-cut harvesting occurred at year 0 for the PNW and SE stands and no subsequent forest harvesting occurred.

The amount of forest in hectares necessary to make 1 m^3 of softwood lumber was calculated. For the PNW and the SE, estimation were 0.00239 ha/m^3 for the 45-year and 0.01144 ha/m^3 for the 25-year harvesting cycles, respectively. The higher the value means more hectares are necessary to produce a cubic meter of construction wood. Note that the SE requires considerably more forest to produce a cubic meter of wood products, about five to one mostly because of its shorter harvesting cycle. The two conversion factors were used to convert from hectares to cubic meters for the carbon flows of the various forest carbon stocks.

Logging emissions differed for the new and recovered wood scenarios. For new softwood lumber production, we used logging emissions of 82.6 and 22.2 t carbon/ha for the PNW [S1: Appendix C12] and the SE [S1: Appendix C20]. For the recovered wood scenario, logging emissions were zero for both regions as no harvest took place.

2.3 Cradle to Gate Manufacturing

The fossil carbon emissions for the cradle-to-gate new and recovered softwood lumber are 118 and 76.4 kg/m^3, respectively [15]. Cradle-to-gate emissions for new lumber include from harvesting (cradle) through production to product transportation to the building site (gate) whereas recovered lumber emissions account for removing wood from old buildings (cradle) through storage to product transportation to the building site (gate). The biogenic emissions were assumed to be already accounted for the in-use category. Although the inventory approach is dynamic, this study simply used GWP 100-year static forcing factors.

2.4 Harvested Wood Product Sequestration

Following Example 4 [1], the carbon found at various times for the harvested wood products was estimated. Please see additional supplement S2 for our example.

3. RESULTS

This paper illustrated a dynamic GHG inventory approach from the forest through product production to the landfill for two different EOL scenarios for wood construction. The PNW and SE stands were examined over a 100-year period for a both new and recovered wood scenario with no additional harvesting occurring [S5]. Future harvesting cycles would typically occur at 25 and 45 years for the SE and the PNW stands, respectively. Results were reported in tonnes CO_2-e per cubic meter of softwood lumber.

Figures 2a, 2b, 3a, and 3b show the individual emissions and total GHG emission profile for the two wood scenarios for the PNW and SE stands, respectively. The pattern for both stands is similar with carbon re-accumulating eventually becoming the dominant force in driving total GHG emissions for new wood and somewhat less for recovered wood.

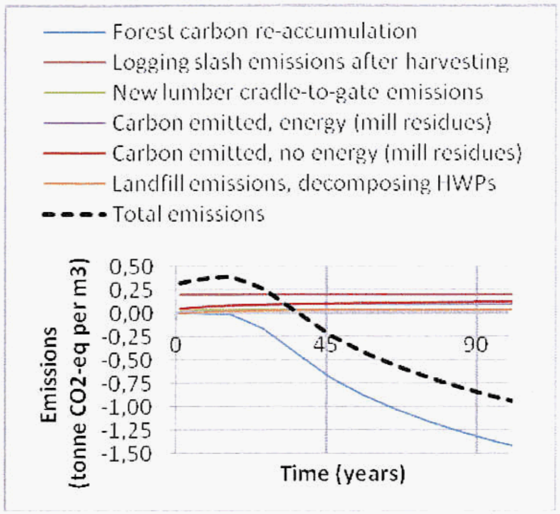

Figure 2a GHG emissions for the new wood scenario for the PNW stand

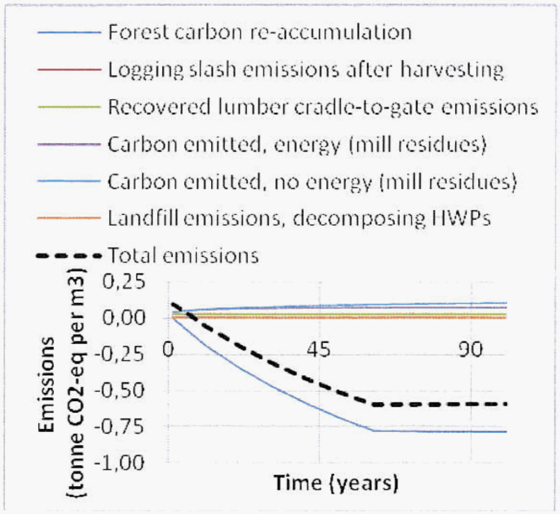

Figure 3a GHG emissions for the recovered wood scenario for the PNW stand

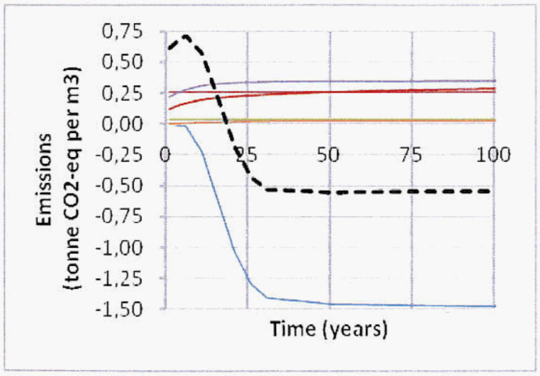

Figure 2b GHG emissions for the new wood scenario for the SE stand

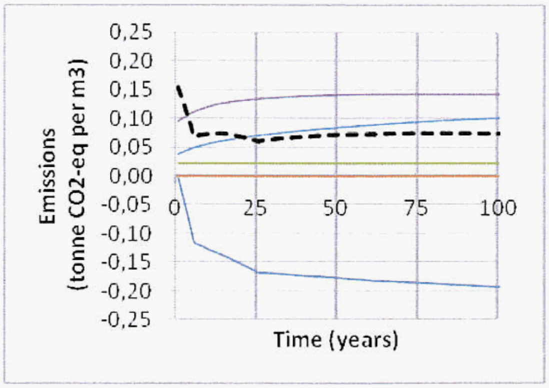

Figure 3b GHG emissions for the recovered wood scenario for the SE stand

Initially, total GHG emissions were considerably lower for the recovered wood scenario. For the recovered wood scenario, both stands continued to grow and absorb carbon through the various carbon stocks for a number of years even though no harvest had occurred. Live trees had the largest impact as they continue to grow and sequester carbon [S5]. Eventually, forest growth slowed and reached equilibrium around 60 and 5 years for the recovered wood scenario for the respective PNW and SE stands. For the new wood scenario, total GHG emissions started high and continued to increase for about 15 and 5 years after harvest for the respective PNW and SE stands. The increase in emissions resulted mainly from softwood lumber and pulp leaving service (in-use) and carbon emitted with or without energy recovery. In addition, the forests that were harvested had to be replanted and the small trees (i.e. saplings) did not begin to sequester large quantities of carbon until later. After 67 (PNW) and 17 (SE) years, total GHG emissions from new and recovered wood were about equal for the respective forest types. Furthermore, emissions continued to decrease for the new wood scenario as the forest was able to store more carbon in the not fully mature live trees. In these scenarios, no harvesting occurred at 45-year intervals for the PNW or at the 25-year intervals for the SE. A substantial difference was noted between the equilibrium for the recovered wood scenario for the PNW and the SE mainly due to the live trees reaching maturity at a much earlier time for the SE (~30 years) than the PNW (~105 years) [1]. However for the PNW, if just considering what happens at the 45-year point, recovered wood emissions were about twice as negative as new wood emissions. Future work would consider what would happen to emissions if harvesting occurred at the normal harvest cycle.

4. DISCUSSION

Accurately reporting how GHG emissions are affected on a temporal scale by various wood scenarios provides policy-makers, builders, and architects with insight into how to build our buildings, what products to build with, and provides a model for other life cycle analyses. Concerning forest policy, however, forests provide other benefits such as recreation, wildlife habitat, and other non-timber products and services that have to be considered besides the carbon benefits. Regardless based on our preliminary analysis, initially using recovered wood for reuse results in lower carbon emissions but eventually the harvested forests could overtake the recovered wood scenario primarily because of new tree growth. Recovered wood products definitely have an advantage with respect to lower cradle-to-gate life cycle emissions than new wood products [15]. However, the initial advantage of lower product manufacturing emissions may be offset eventually by the forest itself if no future harvesting occurred. Without harvesting, forests will continue to grow and sequester carbon until they reach an equilibrium point. This equilibrium point occurred much sooner in the un-harvested case than when harvesting occurred.

Limitations of the study include that only a single forest harvesting was studied. Adding subsequent harvestings for the two forest types could affect the global carbon balance given the different time-periods for the individual carbon flows of the HWPs and associated forest types.

5. CONCLUSIONS

This paper presented a dynamic GHG inventory approach incorporating life cycle analysis with USFS carbon data to report total carbon emissions over the life of a HWP. The paper shows the critical time delay in forest carbon re-accumulating from logging forests may be problematic in mitigating climate change in the short-term but unlikely in the long-term. Using our dynamic approach for the two high-productivity forest stands, this paper showed that harvesting increases forest carbon sequestration capacity after a short time results in large negative carbon emissions for new softwood lumber. Other forest types including low-productivity stands may not have the same long-term carbon benefit. Regardless, the concept is counter-intuitive. Reusing wood for construction has its benefits such as resource efficiency and lower cradle-to-gate carbon emissions. However, not harvesting well-managed forest stands for wood products would be counterproductive if our goal is to lower the US building industry's carbon footprint. By going back to the cradle (i.e. the forest), the methodology was able to provide a more complete picture on carbon emissions. Growing trees are an excellent way to sequester carbon but without harvesting, forests will typically reach equilibrium in total carbon emissions thus not providing maximum carbon benefits. Therefore, we must not only consider the forest but the forest products produced from them through a dynamic carbon analysis to show the real carbon benefit of wood building products. Future work dictates incorporating an update of forest inventory data and conducting scenarios that are more complex. In addition, a full LCA ought to be conducted to capture the full impacts of harvesting trees for construction wood missed including carbon flows concerning life organisms.

ACKNOWLEDGEMENTS

We thank the following individuals for their peer-reviews: Patrick Eagan (University of Wisconsin); Hongmei Gu (US Forest Products Laboratory), and Maureen Puettmann (WoodLife Environmental Consultants)

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APPENDIXES

[S1] 'Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States'

[S2] Example 4

[S3] Factors to calculate carbon growth in growing stock volume (S1: Table 4)

[S4] Regional factors to estimate carbon in industrial roundwood, bark on logs, and fuelwood for the two regions selected (S1: Table 5)

[S5] Individual and total carbon emission data for the new and recovered wood scenarios for the Pacific Northwest (PNW) and the Southeast (SE)