Temporal Considerations of Carbon Sequestration in LCA

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Abstract

Accounting for carbon sequestration in LCA illustrates the limitations of a single global warming characterization factor. Typical cradle-to-grave LCA models all emissions from end-of-life processes and then characterizes these flows by IPCC GWP (100-yr) factors. A novel method estimates climate change impact by characterizing annual emissions with the IPCC GHG forcing functions ($w/m^2/yr$), integrated over the same 100-year time horizon, and then relating the warming to the equivalent time-zero equivalent (TIZE) CO_2 emissions. Net life cycle carbon sequestration for lumber using TIZE and GWP 100 were -464, -557, -669 and -416, -462, and -552 kg CO_2eq/m^3 wood for a 25, 50, and 75 year service life, respectively. The spread between the two results is directly related to service life, with longer service lives exhibiting greater variation. The comparison exemplifies the need to harmonize carbon sequestration accounting methodology – particularly the temporal aspects.

Keywords: temporal, carbon sequestration, forest, dynamic, wood
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Introduction

In LCA, an implicit or explicit carbon dioxide "credit" is typically granted to bio-based resources that photosynthesize carbon as part of their natural growth cycle. An implicit credit is granted by ignoring the biogenic carbon emissions in the calculation of global warming potential (GWP). An explicit credit is granted by accounting forest growth as a negative carbon dioxide emission.

Several widely used carbon foot-printing standards (PAS 2050, 2011; WRI, 2013) and product category rules (FP Innovations, 2011; IBU, 2009; International EPD System, 2011) permit crediting based on explicit end-of-life emissions and key to the methodology for doing so is the decision of how to include the temporal dimension of carbon emissions (Reap et al., 2008; Levasseur et al., 2010; Brandão et al., 2013).

Carbon sequestration is accounted as a credit to the product system due to the recognition that the manufacture of durable wood products typically have lengthy service lives (>50 years) and the wood carbon is not immediately released back to the atmosphere at the end of the service life. The extended sequestration in the "in use" and landfill pools serve as carbon stock that is in addition to the forest from which the wood was sourced.

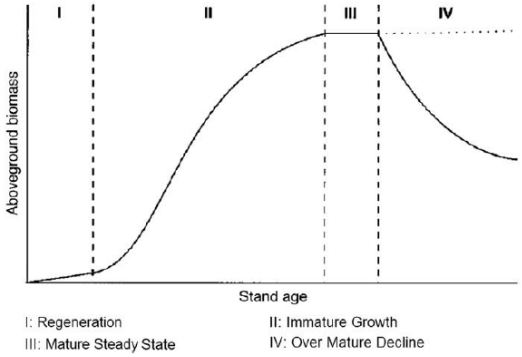
PAS 2050 (2011), WRI GHG Protocol for Products (2013) and the three most widely used wood product PCRs (FP Innovations, 2011; IBU, 2009; International EPD System,

2011) all base the carbon sequestration credit on the following logic: When a forest is logged, the natural cycle is reset. The wood that is removed from the forest is thus no longer subject to natural disturbances such as fire. The mature or near-mature forest is also replaced by a younger and faster growing forest that consumes carbon dioxide from the atmosphere at a greater rate than before the logging occurred. This time table for forests from seedling to maturity can be substantially altered by active forest management.

Accurately estimating GHG emissions for durable wood products provides insight into describing and mitigating climate change impacts (Werner et al., 2010). Bergman and others (2012) showed the forest regrowth of US commercial softwood species under intensive forest management for a logging and no logging scenario by reusing recovered durable wood from deconstruction. The study developed a dynamic greenhouse gas (GHG) inventory approach using life-cycle data and US Forest Service to estimate the temporal GHG emission inventory. The species examined were loblolly (*Pinus taeda*)-shortleaf (Pinus echinata) pine in the Southeast and Douglas fir (*Pseudotsuga menziesii*) in the Pacific Northwest. Using the dynamic GHG approach for the two high-intensity and high-productivity forest stands, Bergman and others (2012) show that harvesting increases forest carbon sequestration capacity after a relatively short time which results in large negative carbon emissions over 100 years. Other forest types including low-productivity stands may not have the same long-term carbon benefit.

Fig. 1 illustrates the growth (I and II), steady state (III), and eventual decline of biomass as a forest matures (IV) (Kurz and Apps, 1999). Removing trees late in phase II, after growth has slowed, and reinitiating phase I create an atmospheric carbon reduction as the forest returns to the pre-harvest level.

Figure 1: Four stages of forest growth



Crediting the product system with the carbon sequestration in the forest requires the tracking of the forest carbon after it leaves the forest. This is due to the recognition that the natural carbon cycle causes the carbon stored in wood to return to the atmosphere either through combustion or decomposition.

In the modeling presented in this paper, the LCI accounting accounts for all emissions that occur over 100 years after the logging process. The forest background in this model is assumed as a static baseline because the 100 year time horizon is longer than the rotation length of merchantable timber producing forests (CORRIM, 2013). The amount of carbon in the product thus serves as the initial credit from which the end-of-life emissions are accounted against. This assumption is in agreement with the two most common carbon footprint

standards (PAS 2050, 2011; WRI, 2013) and several widely used product category rules for wood products (IBU, 2009; International EPD System, 2011; FP Innovations, 2011).

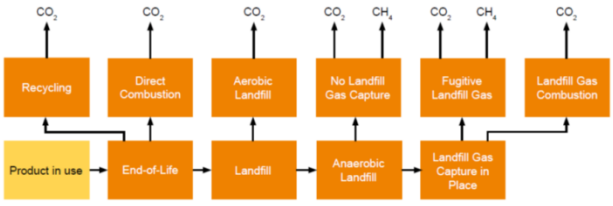
End of Life Carbon Modeling

After a product has reached its end of life, a portion is either recycled into new wood products, combusted, or disposed in landfills. A portion of the landfills that receive wood waste may be classified as aerobic landfills or dumps in that the material is left uncovered to decompose aerobically.

Anaerobic landfills that bury waste are subject to more strict regulations and typically employ landfill gas capture devices. The landfill gas that is captured in such devices is then either flared or combusted with energy recovery.

Average statistics have been aggregated from numerous sources to model the fate of biogenic carbon at the end of the product service life. This modeling is represented by Figure 2 and was developed by FP Innovations and the Athena Institute (2013).

Figure 2: End-of-Life Model Diagram



The various processes in the end-of-life model shown in Figure 2 were modeled as follows:

Product in Use: Three different service lives were selected, (25 years, 50 years, and 75 years) to test the differences of the two characterization models under various scenarios.

End-of-Life/Landfill: In both scenarios, 100% of the wood material was assumed to enter anaerobic landfills at the end of the service life.

Anaerobic Landfill: The anaerobic landfill is accounted as a first order decay with a 4% annual decay rate (k/yr) applied to the 23% of wood that decomposes (Skog, 2008). The carbon in the decayed wood is converted to both methane and carbon dioxide in equal portions (50% to each). A portion of the methane that is generated (10%) is oxidized to carbon dioxide before it reaches the landfill surface.

Landfill Gas Capture in Place: In the average landfill that was modeled, 82% of the landfill gas generated in the anaerobic landfill occurs in those that have landfill gas capture wells in place (Dymond, 2012).

Landfill Gas Combustion: The landfill gas that is captured is either burned for energy or flared without energy recovery. In both cases, 100% of the landfill gas carbon is emitted as carbon dioxide. The modeling did not account for any energy substitution effects.

Fugitive Landfill Gas: In the landfill modeling, the landfill gas generated in anaerobic landfills is directly emitted as 55% carbon dioxide and 45% methane on a molar basis (USEPA, 2012).

No Landfill Gas Capture: Of the landfilled wood, the landfill gas generated in the anaerobic landfill that have no landfill gas capture wells in place is emitted entirely to the atmosphere as 55% carbon dioxide and 45% methane (molar basis).

Aerobic Landfill: In the anaerobic landfill, the decomposition is accounted as a first order decay with a 4% (k/yr) annual decay rate (Skog, 2008) applied to the 23% of wood that decomposes (USEPA, 2012). The carbon in the decayed wood is 100% converted to carbon dioxide.

GWP Characterization

The present analysis compares the static GWP100 factors as developed by the IPCC, and a novel time-zero equivalent (TIZE).

The TIZE methodology demonstrates the time-dependent climate change impact using the concept of cumulative radiative forcing (CRF). The new approach is referred to as the time-zero equivalent (TIZE) uses the same reporting metric as GWP, kg CO_2-eq (Bergman 2012). Similar to the concept of net present value, TIZE generates a single value where future negative and positive impacts are brought back to year zero. In the Bergman (2012) study, TIZE values for the major (greenhouse gases) GHGs of fossil carbon dioxide, methane, and nitrous oxide were found for two flooring products, prefinished solid strip hardwood and prefinished engineered wood flooring. Results were reported in kg CO_2-eq per functional unit of wood flooring. The functional unit was one m^2 of installed wood flooring in service for 80 years.

Figure 3 illustrates the effect of delaying a pulse emission of CO_2 emission (Schwietzke et al., 2011). The emissions pulse pertains to the instantaneous radiative forcing (IRF) with units of W/m^2. Whereas CRF is equal to the area under the IRF curve from the time of the pulse until the end of the time-horizon, 100 years in this case ($W/m^2/yr$). Numerical integration was used to find the area under the curve. At time zero, the pulse emission (pulse 1) has the highest CRF (solid) because the effect of the pulse lasts over the whole time-horizon. The pulse emission at 50 years (pulse 3) has the lowest CRF (dashed) because the radiative forcing of the pulse is considered only for the last 50 years. The pulse at 25 years (pulse 2) falls in between the 0-year and the 50-year pulse and results in a CRF (dotted) smaller than from pulse 1 but greater than from pulse 3. The radiative forcing from pulse 1 corresponds to how GWP would be calculated over the 100-year time horizon.

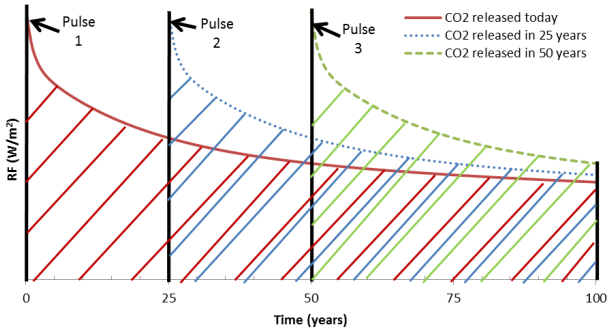


Figure 3: Instantaneous radiative forcing curves for a pulse emission of CO2 at different times

Infinite time horizon for analysis of GHG fluxes: The static LCA approach incorporates emissions regardless when released or removed from the atmosphere. Bergman (2012) considered the following approach when accounting for forest carbon

and biogenic CO_2 emissions. This approach underlies all static LCA as biogenic CO_2 is given a characteristic factor of zero when estimating the impacts on climate change. The forest carbon uptake during tree growth balances out the biogenic CO_2 emissions released regardless of the time they occur. Therefore, the forest is considered to regrow to its original state because time is not considered. This occurs even if the GHG fluxes from re-sequestering forest carbon occur outside the given time horizon for calculating the impact on climate change.

Static LCA time horizon : For the static LCA time horizon, calculating GWP for a given time horizon assumes the individual GHG emissions are aggregated to a single GHG and that the radiative forcing effect occurs over the given time horizon (from t=0 to t=given time horizon) regardless of when the GHG was released. The GHG may even be released after the given time horizon has expired but the GWP would be the same regardless whether the emission was released at time zero or after the end of the given time horizon.

Dynamic LCA time horizon: For a dynamic LCA time horizon, all emissions occurring within the given time horizons are accounted for. No emissions are accounted for outside the given time horizon unlike the static LCA approach.

Time zero equivalent metric time horizon: For the new TIZE time horizon, GHG emissions generate the radiative forcing effect at the time of emission to the end of the given time horizon. Therefore, GHGs emitted near the end of a given time horizon will have a smaller CRF for TIZE than when calculating GWP for the LCA time horizon.

GWP Characterization Comparison

The two GWP characterization models were compared by modeling all emissions from end-of-life processes identically and then characterizing these flows by IPCC GWP (100-yr) factors and by the TIZE method.

The carbon sequestration results were calculated using both methods for 400 oven dry kg of wood (roughly 1 m^3) over service lives of 25, 50, and 75 years. The results are shown in Table 1.

Table 1: Biogenic Carbon Sequestration Results for GWP 100 and TIZE Characterization

Service Life (years)	GWP 100 (kg CO_2-eq.)	TIZE[a] (kg CO_2-eq.)	Percentage Difference (%)
25	-415.9	-464	-10.9%
50	-462.13	-557	-18.6%
75	-552.21	-669	-19.1%

[a] TIZE= time-zero equivalent

The TIZE method showed less overall warming impact in terms of kg CO_2 time-zero equivalents relative to kg CO_2-eq (GWP 100). The values increased for both methods as service life increased. The results using TIZE and GWP 100 were -464, -557,-669 and -416, -462, and -552 kg CO_2-eq/m3 wood for 25, 50, and 75 years respectively. The difference in results is entirely attributable to the different characterization model that is employed.

The spread between the two results is directly related to service life, with longer service lives exhibiting greater variation between results.

Conclusions

The comparison between the two methodologies exemplifies the need to harmonize carbon sequestration accounting methodology – particularly the temporal aspects of the characterization models. The challenges of quantifying global warming impacts are also not unique to the problem of carbon sequestration. Indeed, any product that results in greenhouse gas emissions over an extended period is also subject to the same characterization model considerations.

Examples of potential applications for advanced greenhouse gas characterization include the consideration of use-phase and end-of-life impacts.

Use phase impacts of buildings: The trade-offs of increased cradle-to-construction impacts are often considered against improved energy performance during building occupancy. In absence of advanced global warming characterization, the impacts of an energy emission occurring in years 90-100 is modeled identically to manufacturing impacts. Applying the TIZE method would consider the shorter atmospheric presence of use phase emissions relative to manufacturing emissions over a given time horizon.

End-of-life impacts: Certain materials cause significant impacts at the end of their service life relative to their manufacturing impacts. When these materials are used in durable products that remain in service for many years, the LCA practitioner may wish to assess the relative global warming impacts of the manufacturing and end-of-life emissions over a fixed time horizon such as 100 years. In addition to the emissions of biogenic carbon from landfills as was addressed in this research, recycling and energy recovery may also cause significant credits to the product system. Applying the TIZE method would allow the equivalent impacts of end-of-life treatment relative to manufacturing impacts.

It is widely accepted that the impacts of greenhouse gases are rapidly approaching a "tipping point". While life cycle thinking can be credited for a more complete assessment of the environmental impacts of material selection and design decisions, static characterization of impacts does very little to address the urgency recognized by many climate change scholars (IPCC, 2007). Dynamic characterization methods such as TIZE allows decision makers to apply their own perspectives to weigh the trade-offs of global warming impacts as they occur.

References

Bergman, R.D. (2012): The effect on climate change impacts for building products when including the timing of greenhouse gas emissions. Ph.D. Dissertation. Madison, WI: University of Wisconsin. 278 p. May 30, 2012

Bergman R.D., Salazar J, Bowe S.A. (2012): Developing a dynamic life cycle greenhouse gas emission inventory for wood construction for different end-of-life scenarios. In: Proceedings, International Symposium on LCA and Construction 2012. French Institute for Transports, Development and Networks (IFSTTAR): Nantes, France: 318-325.

Brandão M., Levasseur A., Kirschbaum M.U.F., Weidema B.P., Cowie A.L., Jørgensen S.V., Hauschild M.Z., Pennington D.W., Chomkhamsri K. (2013): Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting. International Journal of Life Cycle Assessment, 18(1), pp. 230-240.

CORRIM (2013): Updates to CORRIM Phase 1 Report – January 2013. Available online @ http://www.corrim.org/pubs/reports/2013/phase1_updates/index.asp

Dymond, Caren (2012): Forest Carbon in North America: annual storage and emissions from British Columbia's harvest, 1965-2065. Carbon Balance and Management: (7)8. Table 9.

FP Innovations. (2011): Product category rules (PCR) for preparing an Environmental Product Declaration (EPD) for North American Structural and Architectural Wood Products. Available online @ http://www.forintek.ca/public/pdf/Public_Information/EPD%20Program/PCR%20November%208%202011%20Final.pdf.

FPInnovations and Athena Institute. (2013): Business-to-Business (B2B) Carbon Sequestration Tool for Wood EPD's as per PCR for North American Structural and Architectural Wood Products, Version 1.

IBU. (2009): PCR Wood Materials Institut Bauen und Umwelt e.V (IBU). November (2009) Available online @ http://bau-umwelt.de/download/C5e22a4e5X12a601a68dbX3b2f/PCR_Wood_Materials.pdf

International EPD System. (2011): PCR Builders joinery and carpentry of wood. Available online @ http://www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=8112#.UZaHubWmiAg

IPCC (2007): IPCC Fourth Assessment Report, The Physical Science Basis: TS 2.5. Section 2.2.3. Available online @ http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch2s2-2-3.html

Kurz, W., and Apps, M. (1999): A 70 year retrospective analysis of carbon fluxes in the Canadian forest sector. Ecological Applications. 9(2)526-547.

Levasseur A, Lesage P, Margni M, Deschenes L, Samson R (2010): Considering time in LCA: Dynamic LCA and its application to global warming potential. Environmental Science and Technology 44(8): 3169-3174.

PAS 2050. (2011): Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. British Standards Institute. Available online @ http://shop.bsigroup.com/en/forms/PASs/PAS-2050

Reap J, Roman F, Duncan S, Bras B (2008) A survey of unresolved problems in life-cycle assessment Part 1: goal and scope and inventory analysis. Int J LCA 13:290-300.

Schwietzke S., Griffins W.M., Matthews H.S. (2011): Relevance of emissions timing in biofuels greenhouse gases and climate impact. Environ. Sci. Technol. 45:8197-8203.

Skog K. (2008): Sequestration of carbon in harvested wood products for the United States. Forest Prod J 58:56–72.

USEPA (2012): Documentation for Landfilling Used in the Waste Reduction Model (WARM) Version 12. Documentation@ http://epa.gov/epawaste/conserve/tools/warm/pdfs/Landfilling.pdf

Werner F, Taverna R, Hofer P, Thürig E, Kaufmann E (2010): National and global greenhouse gas dynamics of different forest management and wood use scenarios: a model-based assessment. Environmental Science and Policy 13(1):72-85.

WRI. (2013) GHG Protocol: Product Life Cycle Accounting and Reporting Standard. Amended May (2013). World Resources Institute (WRI). Available online @ http://www.ghgprotocol.org/standards/product-standard

Salazar J, Bergman R. 2013. Temporal considerations of carbon sequestration in LCA. In: Proceedings from the LCA XIII International Conference, October 1-3, 2013, Orlando, FL: 136-142; 2013