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Calculating a Land Carbon Accounting Factor in the United States: an Example and Implications

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Abstract

Companies that produce and use wood for products and energy find it increasingly important to communicate the carbon balance and potential climate effects of these activities. Computing forest carbon stocks and stock changes, and emissions from operations, are often part of institutional reporting for environmental, social, and governance purposes. This article describes an example methodology to assess forest carbon changes associated with the harvesting of wood products and proposes metrics that could be used to allocate harvesting effects to individual organizations for their reporting purposes. We discuss boundaries (types of forests and carbon pools to include), spatially appropriate evaluations given uncertainty, temporal considerations, risk of reversals, and allocation of net sequestration to products sourced from the region. We also discuss the complex nature of the biogenic carbon cycle and warn about the appropriate interpretation of this methodology.

Study Implications: Purchasers of wood products are increasingly interested in the carbon effects of the wood they purchase. For example, are the forests from which this wood was harvested continuing to sequester carbon or are they in decline? One means of communicating this information would be a carbon accounting factor that expresses the net forest carbon change per unit of wood consumed. We describe an approach to develop such a factor and report results for regions of the conterminous United States. However, any single metric is unlikely to fully capture the carbon dynamics of wood sourcing, as illustrated by the carbon stock declines in the Rocky Mountain regions that cannot be attributed to forest harvesting or the very high factors for the Great Plains due to low harvest levels. We discuss several other metrics that can shed additional light on land carbon resiliency and land-use efficiency and could be considered in conjunction with net carbon stock change.

Keywords: forest inventory, carbon balance, GHG reporting

The History and Need for Carbon Reporting

The United States contains 8% of the world's forests, yet provides almost 20% of industrial roundwood, making it the largest contributor to wood products in the world (Food and Agriculture Organization 2021). Although wood products are often touted for their relatively low embodied carbon (e.g., the greenhouse gas [GHG] emissions associated with growing, harvesting, transporting, and manufacturing wood products)(Leskinen et al. 2018; Sahoo et al. 2019; Sathre and O'Connor 2010), the effects of harvesting on forest carbon have been difficult to assess.

Efforts to quantify the forest carbon effects of wood utilization have been undertaken for decades in applications including assessments by forest products companies, national-scale reporting, life cycle analyses of wood products, environmental product declarations (EPDs), regulatory assessments of biogenic emissions, and voluntary reporting of GHG emissions by corporations.

Carbon assessments by forest products companies are certainly not new. In an early carbon balance assessment for paper mills, Young et al. (2000) and Côté et al. (2002) used national forest inventory data to compute net carbon stock changes in a fiber sourcing region and allocated that change to mills based on their proportion of harvest within the region. The National Council for Air and Stream Improvement, Inc. (NCASI 2007) published a global forest industry carbon footprint assessment that used generally accepted calculation methods and available data sets at the time to understand the full contributions of the forest industry to atmospheric GHGs from forest sequestration to manufacturing to end-of-life. However, the demand for current, consistent, and more granular data to support these types of assessments is growing.

At a national level, the effects of forest harvesting on carbon stocks are addressed in the land use, land-use change, and forestry (LULUCF) portion of the international GHG reporting framework, outlined by the Intergovernmental Panel on Climate Change (IPCC). The IPCC approach tracks net flux among the land sector, either using the stock change method or gain/loss (IPCC 2006). This framework treats all harvested carbon that is not transferred into long-lived products as an immediate emission, and only the proportion of the harvest that remains stored in a wood product is tracked through time (IPCC 2019).

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Product life cycle assessments also follow the IPCC accounting methodology to determine how biogenic carbon is treated. For example, ISO 21930 (ISO 2017) considers country-level carbon stocks to determine whether the forest carbon can be conservatively not counted in the assessment. If fiber is sourced from a country with stable or increasing carbon stocks or from a certified forest, then the forest carbon impact is considered zero, even if the carbon stocks are increasing.

Although accounting at a country level may be acceptable for international reporting, there is desire to provide more granular information at smaller scales. For example, users of information from EPDs want more transparency in forest carbon effects so they can better understand the effects their choice of wood fiber has on forest carbon. The EPDs are focused on generic products (e.g., southern yellow pine lumber), but users want to be able to differentiate between suppliers of a given product based on factors such as carbon dynamics in different sourcing regions.

More granular biogenic carbon assessments have also been discussed in US regulatory frameworks, with little resolution. The most visible recent discussion was the Environmental Protection Agency's proposed Framework for Assessing Biogenic CO2 Emissions from Stationary Sources (EPA 2011), first drafted in 2011 in response to a petition for reconsideration of the 2010 final Tailoring Rule (EPA 2010), which, unlike the 2010 proposed version (EPA 2009), failed to differentiate between biogenic emissions and fossil-based carbon emissions for regulatory calculations.

The EPA then engaged their Science Advisory Board (SAB) to provide feedback on their initial proposed framework, and the SAB's analysis resulted in additional questions. Of particular concern for the SAB was how to isolate the carbon changes on land that occur as a result of biomass combustion from energy generation, which they said would require an "anticipated baseline approach" that would "model a 'business as usual' scenario along some time scale and compare that carbon trajectory with a scenario of increased demand for biomass" (EPA SAB 2012). The EPA released a second framework in 2014 (EPA 2014), which the SAB felt they could not endorse because there was no indication of how the framework would be used in regulation. Between the agency, the SAB, and stakeholder input, there was no consensus on how to assess the impact of burning biogenic carbon at a stationary source in a regulatory context and no framework was finalized.

The EPA framework concept was created in response to a regulatory need, whereas this article responds to the increasing market pressure for forest landowners and forest products manufacturers to voluntarily report the GHG emissions associated with the production, distribution, and use of their products. Buyers of wood products want to know what effects their purchase may have on forest carbon stocks, knowing that in some parts of the world, such purchases may lead to forest degradation. In addition, organizations that are setting net zero GHG emissions and other climate-based targets want to understand the effects that their management or wood purchases have on GHG emissions across their entire value chain. The GHG Protocol is an example of a widely used accounting framework for such voluntary reporting. The GHG Protocol (WRI 2023) is used by 92% of Fortune 500 companies to communicate the GHG impacts of their products and processes. Recently, the GHG Protocol published draft guidance (WRI/WBCSD 2022) for reporting emissions and removals (sequestration) from the land sector portion of supply chains (e.g., forests that supply wood to mills). The protocol defines scope 1 emissions as those that come from processes under the direct control of a reporting company. Scope 2 emissions are those arising from the generation of power purchased by a company. Scope 3 emissions come from a company's supply chain, such as upstream emissions from the production of raw materials used by a company or downstream emissions from the use and disposal of its products. In the forestry context, a decrease in forest carbon stocks might be reported as a scope 1 emission by a landowner harvesting timber, but those same emissions would be reported as scope 3 by a company using wood coming from that land.

Therefore, this article seeks to describe a way to comply with the GHG Protocol in reporting a company's land sector removals and emissions (from biogenic carbon stock changes in forests) and allocate net carbon stock changes to downstream fiber users. Other process emissions (from silvicultural activities and manufacturing activities, such as reported by Saud et al. 2013) are already addressed in other components of the GHG Protocol.

Accounting for forest carbon in a way that can inform and incentivize management to improve storage and sequestration can be complex. First, in assessing forest carbon, one must consider spatial and temporal dynamics. Landowners will have different carbon dynamics on the land, depending on how large an area they manage (Bowyer et al. 2012), and the carbon dynamics will change with the longevity of products produced (such as structural timber versus paper for packaging). Similarly, a forest products mill must assess carbon dynamics on a spatial scale that reflects not only forest stands from which they purchased fiber each year but also their future supplies, which are growing concurrently in the surrounding forest stands and among multiple landowners. Finally, forest health and resilience are important factors in understanding forest carbon longevity. We focus here on reporting forest carbon stock changes, although complete reporting of forest sector emissions would include emissions from fuel used in silvicultural activities, emissions from fertilizer use, etc. These emissions have been discussed elsewhere (Albaugh et al. 2019; Janowiak et al. 2017; Markewitz 2006; Saud et al. 2013).

Data for Forest Carbon Reporting

The most reliable source of data on carbon dynamics in the US forestry sector is Forest Inventory and Analysis (FIA) data from the USDA Forest Service. The publicly accessible FIA database (FIADB; Burrill et al. 2021) provides estimates of carbon stocks for all forest carbon pools. Tree-level measurements, such as species, diameter at breast height (DBH), and tree height, provide data for equations that estimate biomass and carbon in the aboveground portion of live trees (≥2.54 cm DBH).

Estimates of change in carbon stock over time (flux) are possible when plots are measured at two points in time. The FIA inventory design calls for remeasurement of all forested plots, with a portion of plots (termed a panel) measured each year. In the eastern United States, remeasurements occur on a 5- to 7-year cycle, depending on the state. In the western United States, the reinventory cycle is 10 years. By comparing measurements taken on the same plot at two points in time, it is possible to estimate gross growth (the total biomass increment on all living trees), mortality (biomass in trees that died between plot measurements), and harvest (biomass in trees removed from the forest). Remeasurement data are currently available for all states in the conterminous United States except Wyoming.

The FIA sample is designed to produce estimates that meet specifications for allowable error on state or substate regions. Because it takes 5 to 10 years to completely sample a state, only 10%–20% of all plots are current at any given time. This has profound implications for estimating change over time. On a 5-year cycle, each year 20% of plots are remeasured, meaning any estimates produced from the complete state sample share 80% of the data with the previous year's estimates (Coulston et al. 2020).

Estimates produced from a single panel (single year of inventory) have much lower precision, making the detection of a meaningful change over a short time period challenging. For example, Edgar et al. (2019) examined different combinations of FIA plot data (from single panels to full sets of panels) to assess damage from droughts and hurricanes in eastern Texas. The authors found that using single panels detected disturbances sooner, and tended to indicate higher magnitude of disturbance but with lower precision. Using multiple sets of panels (short of a full panel set) appeared to be a useful compromise between a full set of panels and a single panel. Subsequent efforts (Coulston et al. 2020) indicated that incorporating weighting adjustments based on observation year improved the ability to assess timing and magnitude of disturbances.

Objectives

The purpose of this article is to first summarize the carbon dynamics in aboveground live trees for regions of the United States. This includes computing gross growth (sequestration), transfers from the aboveground live tree pool through mortality and harvest, and computing net change. From this information, we can compute an accounting factor as the net change of carbon stocks per unit of harvested roundwood delivered to forest products mills. This information can form the basis for reporting an organization's share of the carbon stock change within a fiber sourcing region. Finally, we discuss uncertainties and implications of this type of mechanism for carbon reporting.

Methods

Analysis Scope

Our analysis was limited to a specific domain of forests in the conterminous United States: those that were defined as timberland at both the most recent and previous inventory cycles. The focus of stock change estimates was the aboveground live tree pool. Our reasoning for these choices follows.

Timberland is defined by the FIA program as forests that are not legally reserved from commercial timber harvest (e.g., national parks, wilderness areas) and capable of producing at least 20 cubic feet of wood annually. Restricting the focus of our analyses to plots classified as timberland avoided incorrectly attributing stock changes to timber harvest from areas where harvest was not likely to take place. Using plots that were timberland at both the current and previous measurement excluded those that were recently converted to timberland from some other land use and those plots that had been converted to nonforest land uses since the previous measurement cycle. Plots classified as timberland at current and previous cycles represent most of the managed forest land in the United States and provide the best insights into changes occurring in managed forests. This approach also is compatible with the Draft GHG Protocol Land Sector and Removals Guidance (WRI/WBCSD 2022), which separately addresses land-use change and requires the exclusion of areas unavailable for harvest.

Estimates of regional carbon stock changes were based on the most recent FIA data for the conterminous United States[1]. Our approach estimated carbon stock changes in the aboveground live tree carbon pool only (which includes trees at least 2.54 cm in diameter at breast height). Our reasoning for limiting the change estimates to this pool was that (1) it is the primary pool measured on every forested plot, (2) it is the carbon pool most influenced by forest management activities, (3) it is possible to estimate uncertainty for this pool, and (4) it captures the largest portion of carbon stock changes in areas where forest remains forest (80% of forest carbon fluxes reported by Domke et al. (2021) were from the aboveground and belowground live biomass pools). Furthermore, using tree-level dynamics, it is possible to distinguish carbon stock changes from growth, mortality, and harvest, lending more insight into causes of stock changes. Part of the goal of emissions reporting is to identify opportunities for improvement (emissions reductions). Therefore, the most effective metrics are those that relate to the resource under direct control of forest managers, which in this case is the aboveground biomass. Because FIA estimates of other carbon pools are coarse models that are strongly correlated with (even mathematically dependent upon) aboveground biomass, including them does not increase our knowledge about management effects on carbon stocks. In the case of soil carbon, for example, the pool is large (often greater than aboveground biomass), but current FIA estimates of soil carbon are just default values for geographic regions and forest cover types and do not reflect management effects. In 2017, estimates of aboveground live biomass came from tree measurements on 107,602 plots (USDA 2023) whereas Domke et al. (2017) report soil carbon measurements from only 3,636 plots. Forthcoming revisions to the FIA database will include improved soil carbon estimates from models described by Domke et al. (2017). In the meantime, using FIA soil carbon estimates can lead to false conclusions about harvesting effects on forest carbon balances.

We summarized our data at a regional level (figure 1), using regions defined in Hoover et al. (2014). We chose these regions because they generally distinguish forest ecosystem types but are large enough to be able to detect net carbon stock changes (see uncertainty discussion). These regions are abbreviated herein as: CENT: Central, GP: Great Plains, NE: Northeast, NLS: Northern Lake States, PNWE: Pacific Northwest-East, PNWW: Pacific Northwest-West, PSW: Pacific Southwest, RMN: Rocky Mountain-North, RMS: Rocky Mountain-South, SC: South Central, and SE: Southeast. Regions were generally split on state boundaries, except for the boundaries between PNWW and PNWE and GP and SC, which followed FIA survey unit boundaries (Burrill et al. 2021) within states.

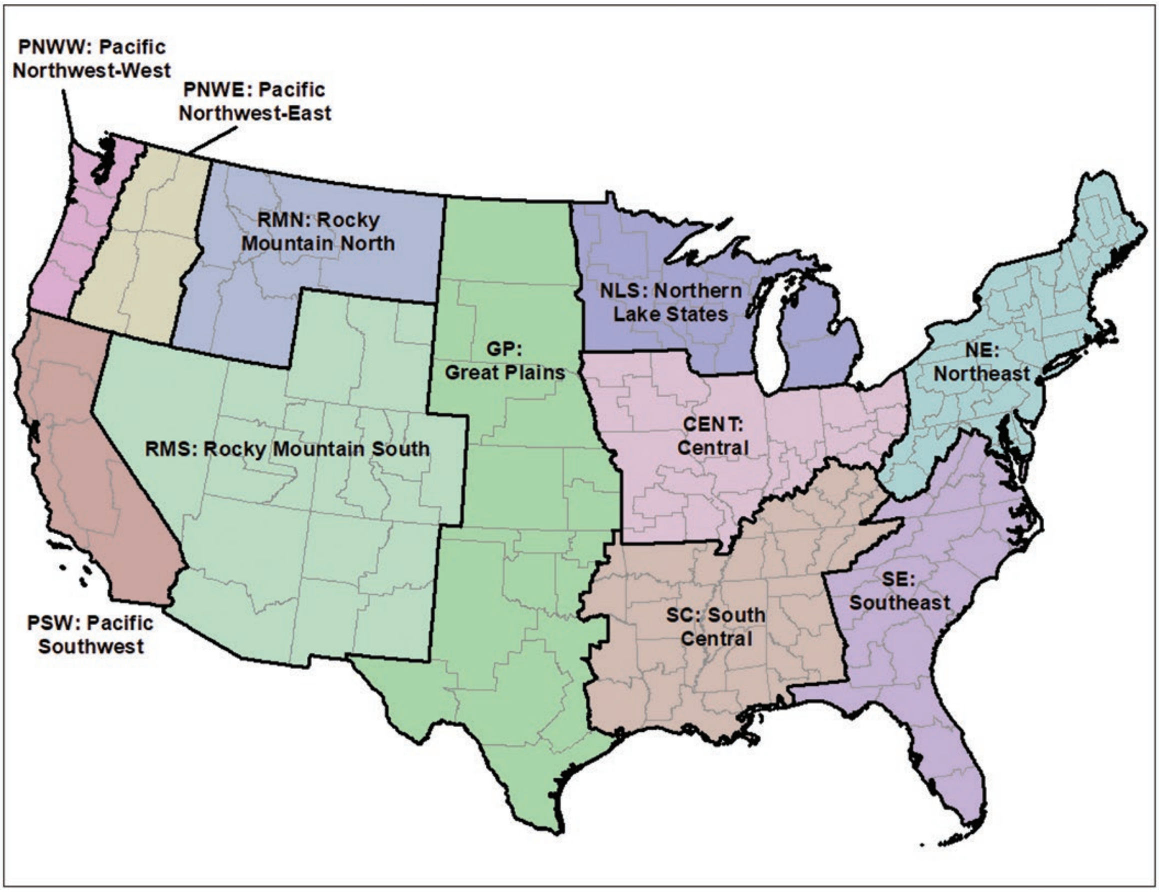

Figure 1 Regions used in this analysis. Light lines within regions are FIA survey unit boundaries. Adapted from Hoover et al. 2014.

Processing Overview

Our goal was to compute an accounting factor, the net carbon stock change in a region per unit of delivered roundwood, based on FIA data. To do this, we computed (1) annual forest carbon stock changes in the aboveground live tree pool as gross growth minus mortality minus harvest, (2) annual roundwood deliveries as total harvested biomass times a dry-weight-to-green-weight conversion factor minus the proportion of harvest left in the forest as logging residue, and (3) the accounting factors as annual forest carbon stock change divided by annual roundwood deliveries. These steps are detailed in the following sections.

Computing Annual Forest Carbon Stock Changes

There are several approaches available for estimating forest carbon stocks and fluxes based on FIA data. These include using tools such as EVALIDator (USDA 2023) or the Forest Vegetation Simulator (FVS; Dixon 2002), or direct analysis of downloaded FIA data from FIA Data Mart (https://apps.fs.usda.gov/fia/datamart/datamart.html). Although much of the information needed here could be retrieved using EVALIDator, it would take numerous queries for each region (separate queries for current carbon stock, growth, removals, and harvest). Using FVS would be appropriate for a plot level analysis but would be cumbersome for an entire region. We therefore chose to download plot data from FIA Data Mart and analyze it using R software (R Core Team 2020). Although there are powerful packages for analysis of FIA data in R such as rFIA (Stanke et al. 2020) and FIESTA (Frescino et al. 2022), we used programming code in hand that followed the standard FIA analysis procedures as documented by Bechtold and Patterson (2005), Burrill et al. (2021), and Pugh et al. (2018).

Net change in tree volume, biomass, and carbon between inventory cycles can be attributed to components of change (Bechtold and Patterson 2005), generally referred to as gross growth, mortality, and removals (harvest). Gross growth represents the total amount of carbon removed from the atmosphere by tree growth during an inventory cycle and is computed from tree measurements at two points in time. Mortality depicts the amount of carbon transferred from live tree to dead wood pools (standing dead, down dead, and litter) during a cycle, based on measurement of trees that were living at the previous measurement and were dead at the current measurement. Harvest is the amount of carbon removed from the live tree pool during harvesting operations computed from measurements of trees that were living at a previous measurement and had been harvested by the time of the current measurement. In FIA terminology, harvest is considered part of "removals," which may also include carbon removed from the forest category due to land-use change. Because we excluded land-use change from this analysis, all FIA removals were associated with harvest. In climate change terminology, "removals" are considered removals of CO_2 from the atmosphere, so we use "harvest" rather than FIA "removals" to avoid confusion.

We computed the net change in aboveground live tree carbon between inventory cycles as gross growth minus mortality minus harvest (as in Saud et al. 2013). We annualized net carbon stock change for each plot by dividing the net stock change for the plot by the time between plot measurements ("REMPER" or remeasurement period in the FIA database, reported in decimal years). Following this procedure, we computed annual net carbon stock change in aboveground live trees on timberland from the most recent complete inventory cycle for each state (except Wyoming, which lacked sufficient remeasurement data). For all stock and change estimates, we followed the standard for emissions reporting, which uses metric tonnes of carbon dioxide equivalents (MT CO_2e) rather than elemental carbon.

In addition to net stock change in aboveground live trees, we computed the growth-drain ratio commonly used as an indicator of forest resource dynamics. Here, the growth-drain ratio is computed by dividing net growth (gross growth–mortality) by harvest.

Computing Annual Roundwood Deliveries and Accounting Factor

For reporting purposes, it is useful to compute annual forest carbon stock change per unit of wood consumed by forest products mills. This factor, multiplied by the total roundwood consumption for a mill (in green tons), represents the "share" of forest carbon stock change associated with the organization's production from wood harvested from the region (per Young et al. 2000 and WRI/WBCSD 2022). In the United States, the most common unit of measure for roundwood transactions is green weight in short tons, although these weights are frequently converted to product-dependent units such as board feet or cords. Therefore, we summarized harvest quantities in green short tons per year. To accomplish this, we used FIA standard methodology described previously to compute biomass (tons dry weight) for harvested trees and converted to green weight using the dry-weight-to-green-weight conversion factor (by tree species) from the FIA species reference table (Burrill et al. 2021).

However, FIA harvest estimates represent carbon removed from the live tree pool through harvest; it does not equate to roundwood delivered to forest products mills, as some of this carbon is left in the forest as logging residues. From Oswalt et al. (2019; Table 40) we computed the proportion of harvest delivered to mills by Resources Planning Act region (Table 1). We then applied these proportions to harvest totals to estimate the corresponding roundwood deliveries (in green short tons per year) for each region. Finally, the accounting factor for each region was computed as the net carbon stock change divided by roundwood deliveries (expressed in MT CO_2e per green short ton).

Results

Regional Dynamics in Aboveground Live Tree Carbon

The gross growth, mortality, harvest, and net stock change for the aboveground live tree carbon pools by region (with associated sample sizes) are depicted in Table 2. We include the total current stock in the aboveground live tree pool for context. Positive net C stock changes represent net increases in the carbon stock; this differs from common usage of positive net sequestration (removals from atmosphere) being represented by negative numbers. Here, net C stock changes in the live tree pool do not equate with net sequestration or emissions to the atmosphere. Mortality and harvest are deductions from the live tree pool but are not necessarily emissions; they are simply transfers of carbon stock into other pools that will experience emissions from decay over time.

It is notable that the only regions in the conterminous United States with decreases in tree carbon stock are the RMN and RMS regions, which has been reported elsewhere and attributed to a range of natural disturbances (e.g., Birdsey et al. 2019; USDA 2019). The RMS region has the lowest harvest as a percent of growth in the nation, and mortality in this region is 27% higher than tree growth. Regions with the lowest mortality as a percentage of growth are PNWW, SE, and SC, which also contain the greatest amount of intensively managed forests; together they account for nearly three-fourths of all forest harvest nationally.

The national annual carbon stock net change is about 1% of stock, meaning aboveground live tree stocks are growing (net change) at approximately 1% per year. The only regions with net change higher than this average are SE (1.4%) and SC (2.0%).

Accounting Factors

Expectedly, net annual carbon stock change, annual delivered harvest, and the resulting accounting factor (change in live

Table 1. Computation of proportion of harvested wood delivered to mills. Logging residue and roundwood products quantities come from Table 40 of Oswalt et al. (2019) by Resources Planning Act (RPA) regions. Calculated proportions are applied to the regions in this study as indicated.

RPA region	Region for this study	Total logging residues (thousand cubic feet)	Total roundwood products (thousand cubic feet)	Proportion of harvested wood delivered
Great Plains	GP	12,625	69,429	0.8461
Northeast	NE	434,812	1,597,036	0.7860
North Central	CENT & NLS	529,232	1,784,712	0.7713
Pacific Northwest	PNWW & PNWE	494,766	2,017,956	0.8031
Pacific Southwest	PSW	107,649	470,554	0.8138
Intermountain	RMN & RMS	90,865	510,364	0.8489
South Central	SC	1,225,898	3,991,734	0.7650
Southeast	SE	831,962	3,493,204	0.8076
	CONUS	3,727,808	13,934,988	0.7889

tree carbon stocks in MT CO_2e per green ton of delivered harvest) varied by region (Table 3). The accounting factor is highest in the GP region, which has very low harvest (denominator), and lowest in the RMS, which experienced net carbon stock losses and very low harvest levels.

Discussion

The accounting factors in Table 3 could be used by organizations to quantify their contribution to carbon stock change in a wood sourcing region (Young, et al. 2000). For example, in the SC region, each green ton of roundwood delivered to a mill was associated with 1.3 MT CO_2e increase in the live tree carbon stock in the region. A forest products mill consuming one million tons of roundwood annually from that region therefore was associated with a positive net carbon stock change in live trees of 1.3 million MT CO_2e.

When estimates such as these carbon accounting factors are used in the context of reporting sustainability or environmental performance, it's important to understand the limitations of the quantification methodology and the proper contextual interpretations depending on the reporting use. Three considerations include uncertainty, discrepancies with allocation of land carbon change to the product unit, and permanence considerations for some reporting needs.

Uncertainty

A primary reason for considering uncertainty is to appropriately interpret changes over time or differences among regions. For example, comparisons such as carbon stock change in one region versus another, or at one point in time versus another, should consider uncertainty. If the difference between estimates (across regions or time periods) is less than our confidence in the estimates themselves (expressed, for example, by a confidence interval), then conclusions may not be supported by the data, as differences may be due to sampling error alone.

Estimates derived from FIA have quantifiable uncertainty based on the sampling design. This means that estimates

Table 2. Regional aboveground live tree carbon stock on timberland, with annual components of change.

Region	Carbon stock	Gross growth	Mortality	Harvest	Net C stock change	Number of plots	Growth/drain
	(10^6 metric tonnes CO_2e)		(10^6 metric tonnes CO_2e/year)				
CENT	2,879.7	81.3	44.0	19.2	18.1	7,458	1.9
GP	479.5	13.7	8.3	1.4	4.1	1,338	3.9
NE	7,913.6	199.5	80.7	57.5	61.3	14,554	2.1
NLS	3,272.1	105.5	45.2	32.7	27.6	18,966	1.8
PNWE	1,241.1	31.2	15.0	9.7	6.5	7,231	1.7
PNWW	4,035.3	112.3	25.3	59.2	27.9	6,799	1.5
PSW	2,252.3	47.6	21.9	11.8	14.0	2,814	2.2
RMN	2,242.4	50.4	43.7	11.7	-5.0	4,255	0.6
RMS	1,472.8	19.5	29.2	2.2	-11.8	3,072	-4.5
SC	9,674.5	472.3	101.0	178.5	192.8	27,523	2.1
SE	7,411.7	344.4	83.8	157.2	103.5	21,410	1.7
CONUS	42,875.1	1,477.9	498.0	541.1	438.8	115,420	1.8

Table 3. Annual carbon stock changes, delivered roundwood quantities, and accounting factors for US subregions. Positive stock changes represent increases in live tree carbon stocks.

Region	Timberland area (10^6 hectares)	Annual net C stock change in aboveground live trees (10^6 MT CO_2e/year)	Annual delivered roundwood harvest (10^6 tons green weight/year)	Accounting factor (net C stock change per green ton delivered)
CENT	13.3	18.1	15.4	1.174
GP	3.3	4.1	1.1	3.648
NE	31.1	61.3	46.7	1.313
NLS	20.3	27.6	27.5	1.002
PNWE	7.5	6.5	7.8	0.832
PNWW	9.2	27.9	43.8	0.637
PSW	6.5	14.0	10.4	1.354
RMN	14.3	-5.0	9.9	-0.509
RMS	8.5	-11.8	1.9	-6.171
SC	46.2	192.8	147.3	1.309
SE	33.7	103.5	136.7	0.757
CO-NUS	193.8	438.8	448.4	0.979

from larger areas, which include more sample plots, will tend to have greater precision and lower sampling errors (Table 4). For example, the 95% confidence interval on aboveground live tree carbon stocks in the PNWW region is ± 2.8%. Estimates at the FIA survey unit level for this same area (six survey units) have confidence intervals that range from about 5% to 7% with an average of 6.2%. For estimates at the county level, confidence intervals for the thirty-eight counties average 26.7%. The confidence intervals in Table 4 are for carbon stock estimates at one point in time. Estimates for carbon stock *change* are far more complex to compute, given the lack of independence between plot measurements at two points in time and the lack of independence in estimates of components of change. This makes comparisons of net stock change between counties even more difficult. Therefore, although it may be appealing to develop estimates for very small spatial scales such as counties, the uncertainty of these estimates may be high, making comparisons between counties less reliable. Further work is needed to be able to refine estimates at smaller spatial scales, and FIA scientists are actively engaged in research in small area estimation, which uses additional datasets to help improve precision of estimates developed from smaller samples of FIA plots (Westfall et al. 2022).

Similarly, to know (with statistical confidence) whether carbon stocks increased over a given time period requires testing whether the time 2 stock minus the time 1 stock is significantly greater than zero. This may rarely be the case for small geographic areas across short time periods because the stock change itself may be small relative to the uncertainty of the estimates. The key point, then, is that comparison of metrics should include attention to the uncertainty of those estimates, and this uncertainty will relate to both the spatial and temporal domains, which influence the number of plots upon which an estimate is based.

Allocation of Net Carbon Changes to Harvest Quantities

One of the difficulties in connecting the forest carbon assessments with the wood product and downstream assessments is converting to similar units. A product's unit of assessment is a unit of wood, yet carbon balance must be assessed at a landscape level. As described previously, one can connect the two by dividing the net carbon change across the landscape by the volume of wood that was used for wood products in that year, resulting in a land accounting factor of "net carbon stock change per unit of wood consumed." However, this allocation method is sensitive to the denominator, meaning that when the area has little harvest, the net carbon stock change (whether it is positive or negative) is amplified relative to a region with more harvest. The result is a metric that can be difficult to interpret on its own.

For example, figure 2 shows that the region with the highest land accounting factor is GP. This region has the third lowest net stock change (figure 3). Its land carbon factor is high because it has almost no harvest, leading to the net stock change being allocated across a very small

Table 4. Average 95% confidence interval width of aboveground live tree carbon stocks (in percent) for different spatial aggregates.

Spatial aggregate unit	Number of units	Average unit area (million hectares)	Range of 95% confidence intervals per spatial unit	Average confidence interval per spatial unit
PNWW region	1	10.97	±2.8%	±2.8%
FIA survey units in PNWW	6	1.83	±4.6% – ±7.2%	±6.2%
Counties in PNWW	38	0.29	±8.0% – ±72.1%	±26.7%

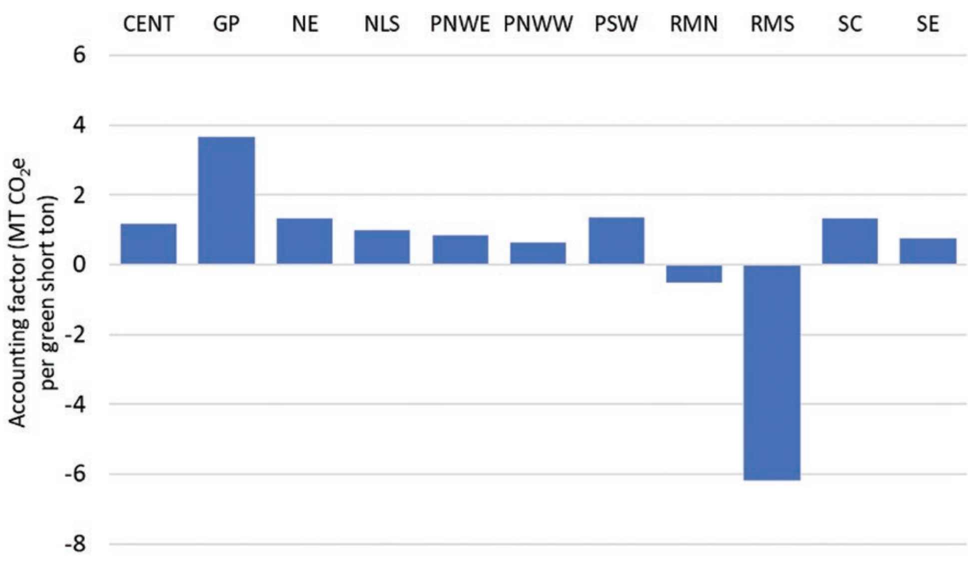

Figure 2 Landscape carbon accounting factor by region (net live tree C stock change in MT CO_2e per green short ton roundwood delivered).

number. The region with the highest net stock change, SC, has a land carbon factor that is similar to the NE, despite the fact that its net stock change is almost triple that of NE (figure 3). Finally, two regions have negative land carbon factors (RMN, RMS). These regions have very little harvest but high mortality relative to growth, which meant that over the last time period, net carbon stocks in live trees decreased. Because harvest is so low, this negative effect is amplified.

These examples demonstrate that the land accounting factor, on its own, does not provide a sufficient indication of the carbon balance effects of the forest harvest in a region.

Land Carbon Resiliency

Carbon sequestration in forests can be subject to reversals, where the sequestered carbon is released into the atmosphere through disturbances such as fire, drought, or insect outbreaks that result in tree mortality or through forests being converted to nonforest land uses. Biogenic carbon reversals are addressed in three ways:

1. Forest carbon offset protocols address the risk of reversal through a menu of mechanisms either by setting a contract length, such as is done in the California Forest Offset Protocol (CARB 2015), assigning discounts based on risk of reversal such as is done with the Verified Carbon Standard (Verra 2019), or even assigning temporary credits, such as was done with the Clean Development Mechanism of the Kyoto Protocol (UNFCCC 2013).
2. Annual carbon reporting (e.g., country level reporting to the IPCC) accommodates reversals by committing to report every year so that any future reversals will be reflected in that future year's report.
3. Product life cycle assessments accommodate reversals by implicitly or explicitly incorporating time, for example, either cradle to gate or cradle to grave (ISO 2006). For example, in North American wood products cradle-to-gate Environmental Product Declarations (EPDs), all biogenic carbon that leaves the gate is assumed to be immediately released (although it is known that some carbon is stored in products). In a cradle-to-grave EPD, emissions in use and end of life are tracked, resulting in the carbon permanently stored in landfills as the net removal (North American Wood Product Product Category Rule)[2].

The land carbon accounting factor can potentially be used for multiple purposes, such as for annual carbon reporting through the GHG Protocol, or as a supplemental indicator for a wood product EPD. The GHG Protocol is an organizational standard, which has a combination of annual and life cycle reporting, so the land carbon accounting factor could follow either of these methods. For wood product EPDs, for the land net carbon sequestration to be consistent with the product, forest sequestration would need to be modeled and discounted either (1) in perpetuity (as is the method used in current North American Wood Product Product Category Rule (ULE 2019) or (2) over 100 years (to be consistent with offset protocols and policy time horizon for GWP adjustment).

How would this be quantified? As with HWP end-of-life fates, a future carbon scenario could be modeled that incorporates natural disturbance risk profiles. Another option would be to divide mortality by the carbon stock in the region to understand the current health of the region. For example, the RMN and RMS regions are losing nearly 2% of their live tree carbon stock annually to mortality, indicating a high risk of reversal in that region (figure 4). More actively managed regions such as PNWW, SE, and SC have annual mortality near or below 1% of live tree carbon stock.

Suggestions for Reporting

Users of wood products are seeking a land carbon metric that can be included in corporate GHG reporting to reflect regional carbon consequences of their use of wood fiber. However, the land carbon factor on its own cannot be ranked in a way to identify carbon benefits of products. In addition to the difficulty of allocation, the land carbon factor on its own fails to address forest health and land-use efficiency.

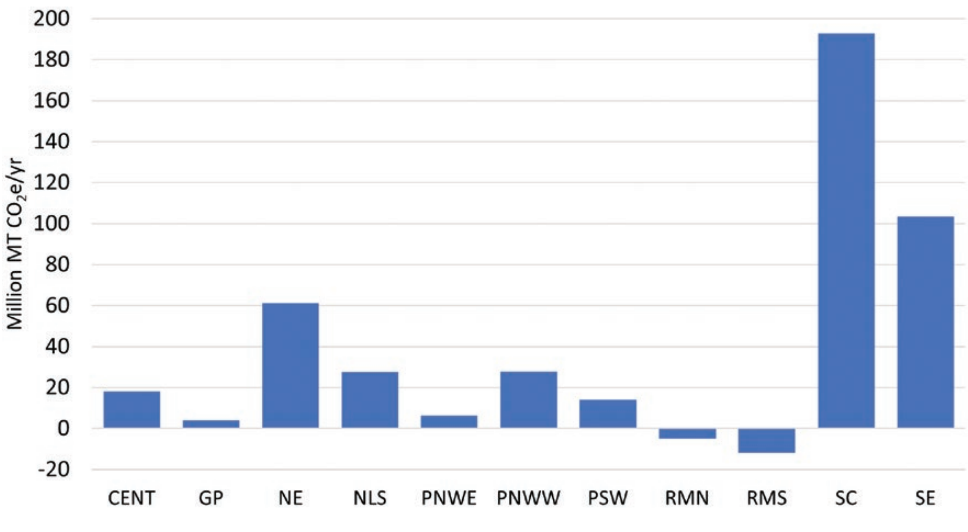

Figure 3 Annual net change in live tree carbon stock (10^6 MT CO_2e/year) by region.

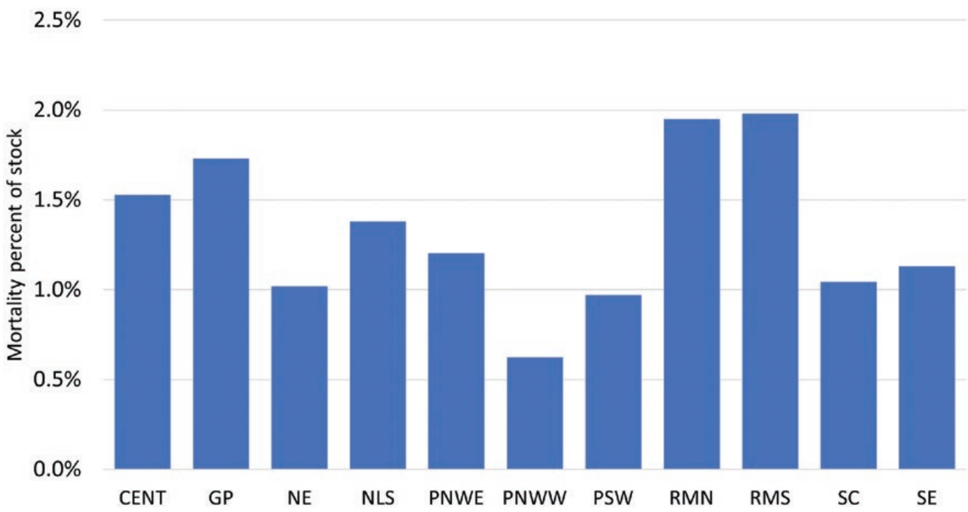

Figure 4 Annual mortality as a percentage of live tree carbon stock by region.

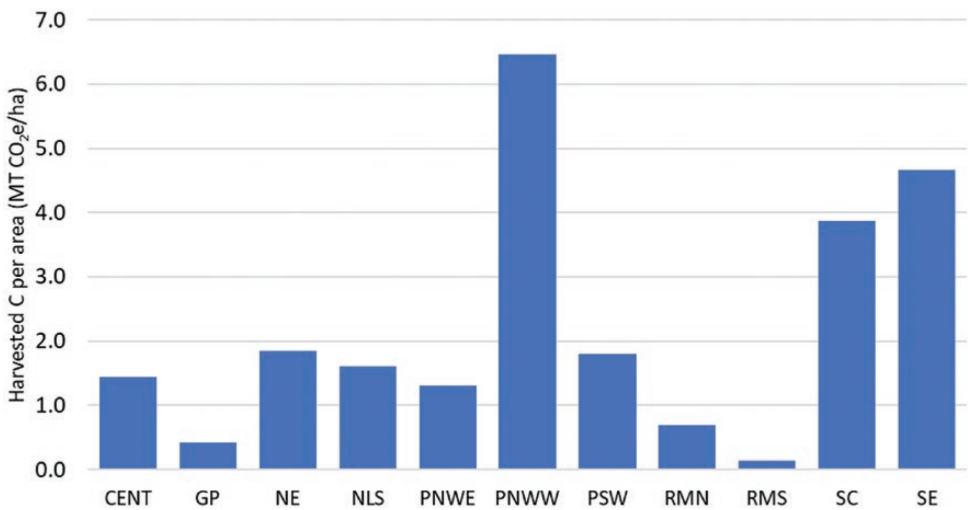

Figure 5 Average harvest (MT CO_2e) per timberland hectare by region.

Forest health is an indication of forest carbon resiliency as described above and could be quantified as mortality as a percent of live tree carbon stock. Given the many competing pressures on useable land, an indication of how much fiber is harvested per hectare can help provide information on land-use efficiency. This factor can be derived by dividing annual harvest per region by area (figure 5). Clearly, PNWW, SC, and SE are producing more fiber per unit of land area than other regions of the country.

Combinations of several metrics (Table 5) are needed to adequately express carbon dynamics in a wood products sourcing region. Using the Hoover et al. (2014) regions, one can understand more about the regions' forest productivity, health, and efficiency by looking all these metrics simultaneously. For example, although GP has the highest land accounting factor, it has one of the lowest net stock changes per hectare, low harvest per hectare, and one of the highest mortality rates. Collectively, these factors indicate the GP forests have poorer carbon performance than other regions but have not yet reached the point where they are losing more carbon than they are gaining, as is the case in RMN and RMS.

Conclusions

This article is intended to continue a discussion on how to meaningfully derive land carbon accounting factors, including the tradeoffs in appropriate spatial and temporal scale given data uncertainty. We show, for example, that although county-level resolution might be desired, the uncertainty of estimates derived from FIA data at that spatial grain are very high relative to regional estimates. Therefore, differences in metrics between counties may simply be due to sampling error.

A land carbon accounting factor computed as net carbon stock change in live trees divided by roundwood deliveries in a region follows early efforts to communicate harvesting effects on woodshed carbon balances (Young et al. 2000). However, the factor may be inflated in regions with low timber harvest, making interpretation difficult.

Furthermore, the land carbon accounting factor has little utility in assessing the best place from which to source fiber as it does not assess resiliency or efficiency. Pairing the land accounting factor with a resiliency and efficiency factor may provide a more robust set of information about the durability and efficiency of land carbon. In addition, information about

Table 5. Metrics describing regional carbon dynamics. Metrics in bold are better than the national average, metrics in italics are worse.

Region	Land carbon accounting factor (annual net C stock change per green ton delivered)	Annual net C stock change per hectare (MT CO_2e/ha/year)	Annual harvest per hectare (MT CO_2e/ha/year)	Mortality as percent of stock
CENT	**1.174**	*1.36*	*1.44*	*1.53*
GP	**3.648**	*1.21*	*0.42*	*1.73*
NE	**1.313**	*1.97*	*1.85*	**1.02**
NLS	**1.002**	*1.36*	*1.61*	*1.38*
PNWE	*0.832*	*0.87*	*1.30*	*1.20*
PNWW	*0.637*	**3.05**	**6.47**	**0.63**
PSW	**1.354**	*2.15*	*1.81*	**0.97**
RMN	*-0.509*	*-0.35*	*0.69*	*1.74*
RMS	*-6.171*	*-1.39*	*0.13*	*2.38*
SC	**1.309**	**4.18**	**3.87**	**1.04**
SE	*0.757*	**3.07**	**4.67**	**1.13**
National average	0.979	2.26	2.79	1.16

forest management sustainability can help provide assurance of other ecosystem service co-benefits.

There is clearly room for improvement and there are many unanswered questions related to the use of land carbon accounting factors to inform wood users about carbon consequences of their purchases. In the United States, users of roundwood cannot always track their purchase to a specific forest stand or tract, so accounting must occur at a coarser spatial grain, such as a region or woodshed. At this point, distinguishing carbon effects from different types of wood products (construction lumber versus paperboard for packaging, for example) is complicated because so many harvests produce wood for multiple products simultaneously, and there is no obvious way to allocate responsibility beyond total wood consumption, as is done here. Finally, natural disturbances such as storms, fires, and insect outbreaks clearly have a dramatic effect on forest carbon balances but are generally ignored in current carbon accounting frameworks. Improvements in forest carbon estimation and monitoring, combined with a more thorough understanding of the complex wood supply chain, will enhance future efforts as such accounting.

Endnotes

1 Data were downloaded from FIA DataMart on November 25, 2022. Most recent inventory years by state were 2018 (KY, LA, TN), 2020 (DE, GA, IL, IN, KS, MS, MO, NE, NH, PA, SC, SD, VT, VA), 2021 (AL, AR, IA, ME, NC, ND, TX, WI); all others were 2019.

2 Please note that some methods, such as those used in carbon offset protocols, set a time period and provide the ability to quantify the climate benefit of temporary storage using dynamic accounting or approximations thereof (CARB 2015; European Commission 2010).

Literature Cited

Albaugh, T.J., T.R. Fox, R.L. Cook, J.E. Raymond, R.A. Rubilar, and O.C. Campoe. 2019. "Forest Fertilizer Applications in the Southeastern United States from 1969 to 2016." *Forest Science* 65 (3): 355–362. https://doi.org/10.1093/forsci/fxy058.

Bechtold, W.A., and P.L. Patterson. 2005. *The Enhanced Forest Inventory and Analysis Program — National Sampling Design and Estimation Procedures*. USDA Forest Service General Technical Report SRS-80, 85. Asheville: US Department of Agriculture, Forest Service, Southern Research Station.

Birdsey, R.A., A.J. Dugan, S.P. Healey, K. Dante-Wood, F. Zhang, G. Mo, J.M. Chen, A.J. Hernandez, C.L. Raymond, and J. McCarter. 2019. *Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks of U.S. National Forests*. USDA Forest Service General Technical Report RMRS-GTR-402, 116 (plus appendices). Fort Collins: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Bowyer, J., S. Bratkovich, M. Frank, J. Howe, S. Stai, and K. Fernholz. 2012. "Carbon 101: Understanding the Carbon Cycle and the Forest Carbon Debate". Minneapolis: Dovetail Partners. Available online at https://mail.dovetailinc.org/upload/tmp/1581622918.pdf.

Burrill, E.A., A.M. DiTommaso, J.A. Turner, S.A. Pugh, J. Menlove, G. Christiansen, C.J. Perry, and B.L. Conkling. 2021. "The Forest Inventory and Analysis Database: Database Description and User Guide Version 9.0.1 for Phase 2". US Department of Agriculture, Forest Service, 1026. Available at https://www.fia.fs.usda.gov/library/database-documentation/current/ver90/FIADB%20User%20Guide%20P2_9-0-1_final.pdf. Last accessed September 12, 2021.

California Air Resources Board. 2015. "Compliance Offset Protocol: U.S. Forest Projects". Adopted June 25, 2015. Available online at https://ww2.arb.ca.gov/sites/default/files/cap-and-trade/protocols/usforest/forestprotocol2015.pdf.

Côté, W.A., R.J. Young, K.B. Risse, A.F. Costanza, J.P. Tonelli, and C Lenocker. 2002. "A Carbon Balance Method for Paper and Wood Products." *Environmental Pollution* 116 (Suppl 1): S1–S6. https://doi.org/10.1016/S0269-7491(01)00240-8.

Coulston, J.W., C.B. Edgar, J.A. Westfall, and M.E. Taylor. 2020. "Estimation of Forest Disturbance from Retrospective Observations in A Broad-Scale Inventory." *Forests* 11 (12): 1298. Available at: https://www.mdpi.com/1999-4907/11/12/1298.

Dixon, G.E. comp. 2002. *Essential FVS: A User's Guide to the Forest Vegetation Simulator*. Internal Report, 226, revised August 24, 2022). Fort Collins: US Department of Agriculture, Forest Service, Forest Management Service Center.

Domke, G.M., C.H. Perry, B.F. Walters, L.E. Nave, C.W. Woodall, and C.W Swanston. 2017. "Toward Inventory-Based Estimates of Soil Organic Carbon in Forests of the United States." *Ecological Applications* 27 (4): 1223–1235. https://doi.org/10.1002/eap.1516.

Domke, G.M., B.F.Walters, D.J. Nowak, J.E. Smith, M.C. Nichols, S.M.Ogle, J.W. Coulston, and T.C. Wirth. 2021. *Greenhouse Gas*

Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the United States, 1990–2019. USDA Forest Service RU-FS–307, 5. [plus 2 appendixes]. Madison: US Department of Agriculture, Forest Service, Northern Research Station. https://doi.org/10.2737/FS-RU-307.

Edgar, C.B., J.A. Westfall, P.A. Klockow, J.G. Vogel, and G.W. Moore. 2019. "Interpreting Effects of Multiple, Large-Scale Disturbances Using National Forest Inventory Data: A Case Study of Standing Dead Trees in East Texas, USA." *Forest Ecology and Management* 437 (January): 27–40. https://doi.org/10.1016/j.foreco.2019.01.027.

Environmental Protection Agency Science Advisory Board (SAB). 2012. "SAB Review of EPA's Accounting Framework for Biogenic CO_2 Emissions from Stationary Sources" (September 2011). US EPA.

Environmental Protection Agency (EPA), Office of Air and Radiation Office of Atmospheric Programs, Climate Change Division. 2014. *Framework for Assessing Biogenic CO_2 Emissions from Stationary Sources*, 69. Available at: https://19january2017snapshot.epa.gov/sites/production/files/2016-08/documents/framework-for-assessing-biogenic-co2-emissions.pdf.

Environmental Protection Agency (EPA). 2009. [PROPOSED RULE] *Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule*, 75 Federal Regulation 55,292. (October 27, 2009).

Environmental Protection Agency (EPA). 2010. [FINAL RULE] *Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule*, 75 Fedederal Regulation 31,514 (June 3, 2010).

Environmental Protection Agency (EPA). 2011. *Draft Accounting Framework for Biogenic CO2 Emissions from Stationary Sources*, 140. Available at: https://19january2017snapshot.epa.gov/sites/production/files/2016-08/documents/biogenic-co2-accounting-framework-report-sept-2011.pdf.

European Commission Joint Research Centre. 2010. *Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook: General Guide for Life Cycle Assessment- Detailed Guidance*, 417. Luxembourg: Publications Office of the European Union. Available at: https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf.

Food and Agriculture Organization (FAO). 2021. "Forestry Production and Trade. Food and Agriculture Data." Available online at http://www.fao.org/faostat/en/#data/FO/visualize. Last accessed July 1, 2020.

Frescino, T.S., K.S. McConville, G.W. White, J.C. Toney, and G.G. Moisen. 2022. "Small Area Estimates for National Applications: A Database to Dashboard Strategy Using FIESTA." *Frontiers in Forests and Global Change* 5 (May): 1–18. https://doi.org/10.3389/ffgc.2022.779446.

Hoover, C., R. Birdsey, B. Goines, P. Lahm, G Marland, D. Nowak, S. Prisley, E. Reinhardt, K. Skog, D. Skole, J. Smith, C. Trettin, and C. Woodall. 2014. "Chapter 6: Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems." In *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*, edited by M. Eve, D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar. Technical Bulletin 1939, 606. Washington, DC: US Department of Agriculture, Office of the Chief Economist.

Intergovernmental Panel on Climate Change (IPCC). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use*, edited by S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Kanagawa, Japan: Institute for Global Environmental Strategies.

Intergovernmental Panel on Climate Change (IPCC). 2019. "Chapter 12: Harvested Wood Products". In *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use*, edited by E. Calvo Buendia, K. Tanabe, A. Kranjc, J. Baasansuren, M. Fukuda, S. Ngarize, A. Osako, Y. Pyrozhenko, P. Shermanau and S. Federici. Switzerland: IPCC.

International Organization for Standardization (ISO). 2006. *Environmental Management- Life Cycle Assessment- Requirements and Guidelines*, 46. International Organization for Standardization. (ISO 14044:2006).

International Organization for Standardization (ISO). 2017. *Sustainability in Buildings and Civil Engineering Works- Core Rules for Environmental Product Declarations of Construction Products and Services*, Second edition, 80. International Organization for Standardization. (ISO 21930:2017-07).

Janowiak, M., C.Swanston, and T. Ontl. 2017. *Management of Forest Carbon Stocks*. US Department of Agriculture, Forest Service, Climate Change Resource Center. https://www.fs.usda.gov/ccrc/topics/management-forest-carbon-stocks.

Leskinen, P., Cardellini, G., González-García, S., Hurmekoski, E., Sathre, R., Seppälä, J., Smyth, C., Stern, T., and Verkerk, P.J. 2018. *Substitution Effects of Wood-Based Products in Climate Change Mitigation*. From Science to Policy 7. Joensuu, Finland: European Forest Institute.

Markewitz, D. 2006. "Fossil Fuel Carbon Emissions from Silviculture: Impacts on Net Carbon Sequestration in Forests." *Forest Ecology and Management* 236 (2-3): 153–161. https://doi.org/10.1016/j.foreco.2006.08.343.

National Council for Air and Stream Improvement, Inc. (NCASI). 2007. *The Greenhouse Gas and Carbon Profile of the Global Forest Products Industry*. Special Report No. 07-02, 46. Research Triangle Park: National Council for Air and Stream Improvement, Inc.

Oswalt, S.N., W.B.Smith, P.D.Miles, and S.A. Pugh, coordinators. 2019. *Forest Resources of the United States, 2017: A Technical Document Supporting the Forest Service 2020 RPA Assessment*. USDA Forest Service General Technical Report WO-97, 223. Washington, DC: US Department of Agriculture, Forest Service, Washington Office. https://doi.org/10.2737/WO-GTR-97.

Pugh, S.A., J.A. Turner, E.A. Burrill, and W. David. 2018. "The Forest Inventory and Analysis Database: Population Estimation User Guide". USDA Forest Service, 166. Available online at http://www.fia.fs.fed.us/library/database-documentation/. Last accessed June 23, 2020.

R Core Team. 2020. "R: A Language and Environment for Statistical Computing." Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Sahoo, K., R. Bergman, S. Alanya-Rosenbaum, H. Gu, and S. Liang. 2019. "Life Cycle Assessment of Forest-Based Products: A Review." *Sustainability* 11 (17): 4722. https://doi.org/10.3390/su11174722.

Sathre, R., and J. O'Connor. 2010. "Meta-analysis of Greenhouse Gas Displacement Factors of Wood Product Substitution." *Environmental Science & Policy* 13 (2): 104–114. https://doi.org/10.1016/j.envsci.2009.12.005.

Saud, P., J. Wang, W. Lin, B. Sharma, and D. Hartley. 2013. "A Life Cycle Analysis of Forest Carbon Balance and Carbon Emissions of Timber Harvesting in West Virginia." *Wood and Fiber Science* 45 (3): 250–267.

Stanke, H., A.O. Finley, A.S. Weed, B.F. Walters, and G.M. Domke. 2020. "rFIA: An R Package for Estimation of Forest Attributes with the US Forest Inventory and Analysis Database." *Environmental Modelling & Software* 127 (May 2020): 104664. https://doi.org/10.1016/j.envsoft.2020.104664.

UL Environment. 2019. "Part B: Structural and Architectural Wood Products EPD Requirements." UL 10010-09. First Edition, October 21, 2019. Bensenville: Underwriters Laboratories, Inc.

United Nations Framework Convention on Climate Change [UNFCCC]. 2013. "Afforestation and Reforestation Projects Under the Clean Development Mechanism: A Reference Manual." Box 4.4: 28. Available online at: https://cdm.unfccc.int/public_inputs/2013/arcdm_01/AR_CDM_Manual_Draft_01.pdf.

USDA Forest Service, Forest Inventory and Analysis Program. 2023. *Forest Inventory EVALIDator Web-Application Version 2.0.6*. St. Paul: US Department of Agriculture, Forest Service, Northern

Research Station. Available online at https://apps.fs.usda.gov/fiadb-api/evalidator.

USDA Forest Service. 2019. *Assessment of the Influence of Disturbance, Management Activities, and Environmental Factors on Carbon Stocks of U.S. National Forests*. USDA Forest Service General Technical Report RMRS-GTR-402. Fort Collins: US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Verra. 2019. "AFOLU Non-permanence Risk Tool. Verified Carbon Standard, A Verra Standard". Available online at https://verra.org/wp-content/uploads/2019/09/AFOLU_Non-Permanence_Risk-Tool_v4.0.pdf.

Westfall, J.A., J.W.Coulston, G.G.Moisen, and H.-E.Andersen. 2022. *Sampling and Estimation Documentation for the Enhanced Forest Inventory and Analysis Program: 2022*. General Technical Report NRS-GTR-207, 129. Madison: US Department of Agriculture, Forest Service, Northern Research Station.

World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). 2022. "Land Sector and Removals Guidance (Draft for Pilot Testing and Review)", 274. Available at: https://ghgprotocol.org/land-sector-and-removals-guidance#-supporting-documents.

World Resources Institute (WRI). 2023. "Greenhouse Gas Protocol: About Us." Available online at https://ghgprotocol.org/about-us. Last accessed July 11, 2023.

Young, R.J., C. Row, J.P. Tonelli, W.A. Côté, and C. Lenocker. 2000. "Carbon Sequestration and Paper: A Carbon Balance Assessment." *Journal of Forestry* 98 (9): 38–43. https://doi.org/10.1093/jof/98.9.38.