Global Warming Mitigating Role of Forests in Washington State, by Land Ownership Type

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Introduction

The Pacific Northwest, especially western Washington and Oregon, is known for its fast-growing forests and vibrant forest industry. With 2.7 billion board feet of annual merchantable log production, Washington is the second largest producer of wood products in the United States. This study sets out to understand the role of Washington's forests in mitigating global warming. Comprehensive analyses of the region-specific private/corporate, WA-DNR, and USFS forestlands are performed, taking into account forest growth rate, harvest practices, the wood product mix produced, the emissions associated with harvesting and manufacturing wood products, and substitution benefits.

Study Objective

This study aims to estimate the global warming mitigating role of forests in Washington State, factoring in natural and harvest-induced biogenic carbon flux in the forests and associated biogenic carbon flux in wood products. The study is divided into two sub-objectives. The first sub-objective is to develop a comprehensive understanding of the impact of the actual biomass flux in Washington's forests after factoring in (i) carbon sequestration due to forest biomass growth, (ii) forest biomass loss due to tree mortality (natural, fire, insect, etc.), (iii) harvest related biomass loss (like, harvest slash burns and decay), (iv) biomass loss during production of wood products, (vi) wood products mix and storage of biomass in wood products, factoring in the longevity of the wood products, (vii) landfill storage and emissions, and (vi) reuse of reclaimed wood. The second sub-objective of this study is to develop a comprehensive understanding of the impact harvest and post harvest biomass flux after factoring in (vii) the fossil carbon emissions associated with harvest and manufacturing, (viii) estimates of landfill and forest residue decay emissions, and (ix) all the fossil emissions, biogenic carbon emissions, and biogenic carbon storage (in the forest and the economy) converted into comparable global warming units.

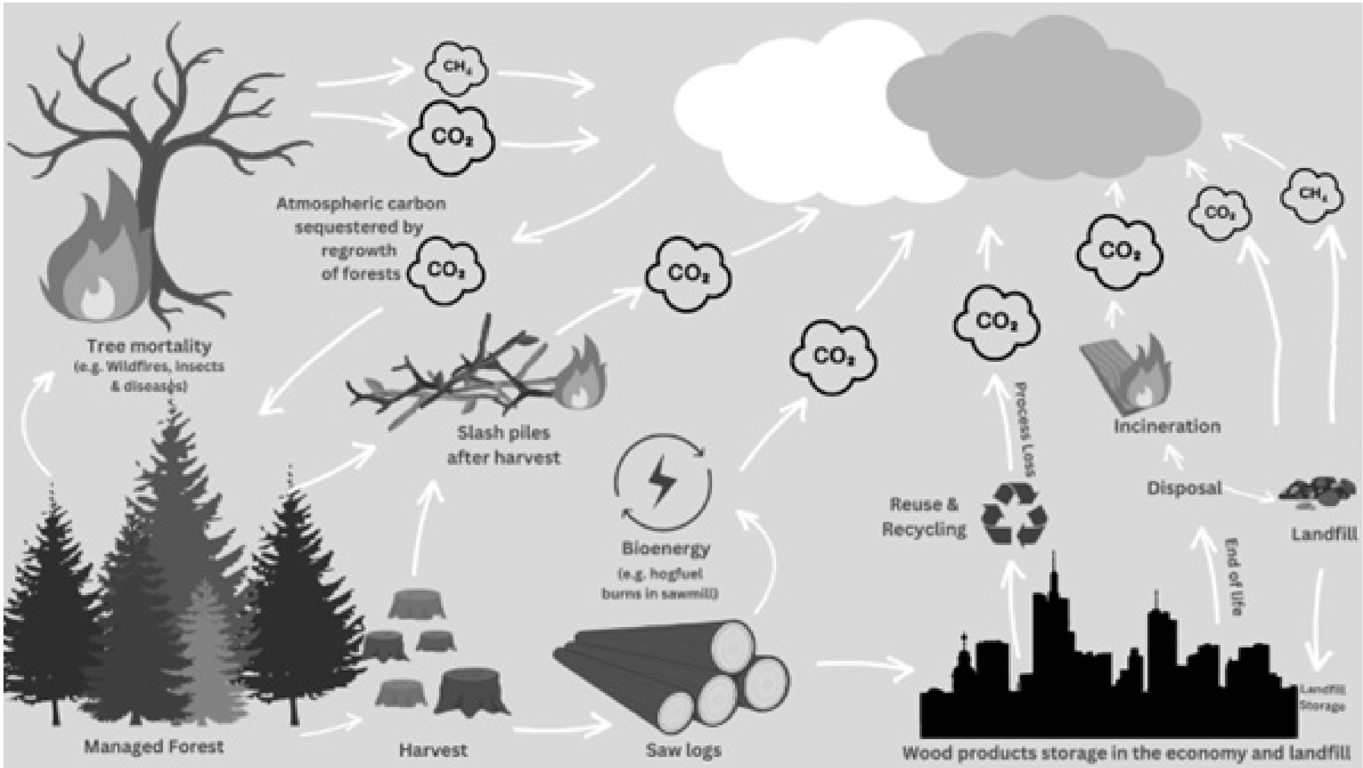
Scope of the Project and Data

When considering carbon in the context of managed forests, it is necessary to consider the overall management objectives associated with a piece of land, the carbon stocks in different pools (including live trees, roots, deadwood, wood products, etc.), and the flows of carbon between these pools (a.k.a., carbon flux). A general pictorial overview of the overall forest carbon flux and biomass flows between pools, analyzed in this paper, is presented in Figure 1.

In fforests, carbon is stored in live trees, standing dead trees, downed wood, the forest understory, and soils, and can be transferred among these different pools and to the atmosphere (Janowiak 2017, U.S. Forest Service 2022). This study used the Washington forest biomass inventory compiled and published by the U.S. Forest Service, Pacific Northwest Research Station, and Washington Department of Natural Resources (Christensen et al., 2020). This USFS-DNR report provides Washington state's first comprehensive assessment of forest ecosystem carbon stocks and flux over 15 years (2002 to 2017).

The bbiogenic carbon accrual in wood products occurs during the functional life of the products in the economy, and the consequent transfer of the carbon in wood products to landfills. Hence, on the industrial side of the forest carbon cycle, this study develops a mass-balanced flow of harvested biomass to various wood products. This study also captures the loss of carbon in the trees and intermediate wood products, during the transfer of this biogenic carbon from the trees to various forms and wood products, and consequent disposal in the landfill. This biomass loss documentation also includes the loss of biogenic carbon through bioenergy conversions (e.g., hogfuel burns in sawmills), and burn disposals without energy capture (harvest slash burns and end-of-life disposal). Landfill emissions and other forms of residual biomass decay emissions are also captured in the study. Finally, the fossil emissions associated with the harvest, transportation, and

Figure 1: Biogenic Carbon Cycle for Managed Forests



Source: U.S. Forest Service, 2022

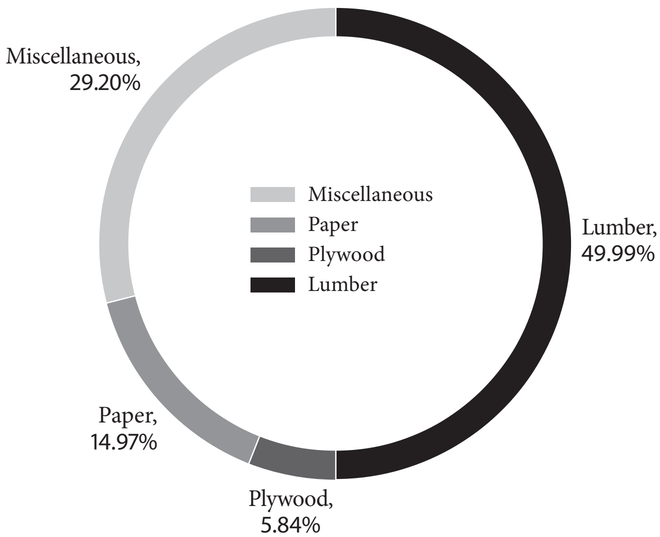
production of emissions in wood products and substitute for fossil fuel-intensive products (like, plastics, steel, and concrete) are also factored in.

Methods

The global warming mitigating potential of Washington's working forests is estimated using the following multi-step approach:

1. Evaluation of the net carbon sequestration of forests: The total aboveground and harvest biomass (merchantable and residues components) is calculated using the previously mentioned Washington forest biomass inventory data, which provides Washington state's first comprehensive assessment of forest ecosystem carbon stocks, flux, and trends, over 15 years (Christensen et al., 2020). This FIA survey-based data is used to calculate carbon sequestration by assuming a carbon content in the biomass of 50%.
2. Creation of a wood products mix scenario: Various wood products manufacturing data is used to create a wood products mix scenario, including different uses of the merchantable harvests from private forests in Washington State in 2015 (Figure 2). All biomass burns, with or without energy capture, are documented and factored in the analyses. However, they are not shown in the wood products mix, as they are not long-lasting wood products.
3. Evaluation of the global warming mitigating potential of wood products: Fconverting all the fossil emissions, biogenic carbon emissions, and biogenic carbon storage (in the forest, in the economy, or the landfill) into comparable global warming units by converting them into temporal radiative forcing units. Radiative forcing represents the net atmospheric warming impact of emitting green-house-gases (GHGs) into the atmosphere.
4. Use of Life Cycle Assessment (LCA) Principles: This study uses information obtained from LCA studies that covered stages from raw material extraction to product manufacturing (cradle-to-gate), guided by a framework and guidelines from ISO 14040 and ISO 14044 (international standards for calculating life cycle inventory and impacts). The overall carbon footprint for the processes

Figure 2: Average Wood Products in Washington's Wood Products Industry



and systems is developed using ISO 14064 protocol, an international standard for quantifying and reporting greenhouse gas emissions (Wintergreen and Delaney, accessed 2022). This study also included end-of-life and disposal-related emissions (gate to grave) using EPA's WARM model (EPA 2020).

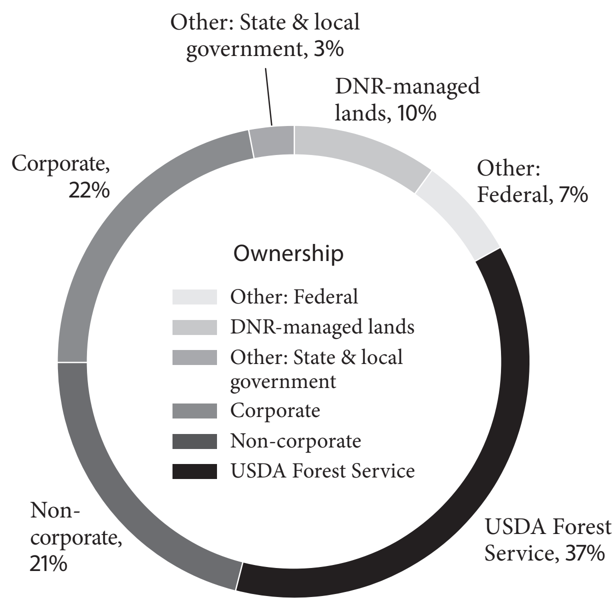
Results and Discussions

Washington State's 22 million acres of forestland can be broadly divided into six ownership types, the dominant being USDA forest service forests (aka, the USFS forests), comprising 37% of Washington's overall forestlands. Of this 37%, approximately 7% consists of the reserved forests and is home to most of the State's old-growth forests, and most of the remaining USFS forests are plantations, previously managed for timber. Private forestlands are divided into 'corporate forests', comprising 22% of the State's forests, and non-corporate forests comprising 21% of the forestland. Approximately 10% of the State's forestland is owned by the Department of Natural Resources (WA-DNR). The remaining forests are owned by other federal agencies, like the fish and wildlife service, the department of defense, and county and municipal corporations, to name a few. Approximately 62% of Washington's wood production comes from the 22% intensively managed corporate forests, and the remaining from the WA-DNR and non-corporate-private forestlands.

Forest Carbon Cycle for Washington State's Forests, by Forest Ownership Types

Forests play an essential role in the global carbon cycle by facilitating the movement of carbon between the atmosphere and the forests—forest carbon flux. Fast-growing forests play a vital role in the global carbon cycle, as they can sequester (i.e., transfer carbon from the atmosphere to the trees) and store large amounts of carbon in the forests over relatively short time periods (e.g., decades). Forests also emit carbon back into the atmosphere due to forest fires, harvest-related disturbances, and natural tree mortality and eventual biomass decay. On average, Washington State's forests have been an effective carbon sink, sequestering more carbon during the 15-year reporting period (2002 – 2017) than the previous, even after deducting all the natural mortality and harvest removals. Given Washington's sizeable wood products industry, factoring in the proportion of harvest carbon stored in wood products further improves the net global warming mitigation potential of Washington's forestry sector.

Figure 3: Distribution of Ownership Types over Total Region, Based on FIA Data



Source: Christensen et al, 2020

The Sankey diagrams in Figure 4 represent the average annual flux (i.e., annual carbon sequestration, mortality, and harvests) of Washington's forests, in tons of CO_2 per acre, by forest ownership types. They present average annual data across 15 years, from 2002 to 2017. The Sankey diagrams in Figure 4 represent the average annual flux, in tons of CO_2, in Washington's forests, divided by ownership types. The first diagram represents data from the corporate forests (Panel 1), the second diagram reflects the annual flux in the Washington DNR forests (Panel 2), and the last diagram reflects the yearly average flux in the U.S. forest service forests (Panel 3). The flow of these Sankey graphs is from left to right. The value next to the orange bars on the left of all the diagrams represents the annual average growth of forests per acre in tons of CO_2 units. The numbers next to the green bars, on the second level from the left, represent the 'mortality of trees in the forests, including forest fires, insect and disease mortality.' The numbers next to the blue bars on the same level represent harvest, and the red bars represent standing live trees left in the forests. A positive value for these red bars, which is the case for all three ownership categories, indicates that the forest standing stock increased during the reporting period. The carbon in the biomass flows from right to left, with the last bars indicating biomass in wood products, standing trees, or landfills by the end of the year. The numbers next to the purple bars on the right indicate carbon sequestered in wood products. The pink bars above the purple ones indicate biomass accrued in the dead biomass pool, the forests, the forest floor, or a slash pile.

As shown in Figure 4, the corporate forests have the highest annual average biomass growth per acre basis, followed by the DNR forests and the federal forests. The corporate forests also have the highest level of harvests, with the federal forests having negligible harvests. The corporate forests, primarily clustered in western Washington, are generally managed with moderate to high intensity, which is reflected in the high biomass growth, and low fire and insect mortality. It can also be observed that harvest activities contribute to dead biomass in the forests, increasing branches, tops, and foliage, either distributed on the forest floor, or piled up in slash piles. However, of the total biomass growth, only 28% (1.42 of 4.93 tons of CO_2/year/acre) of all the biomass in corporate forests ends up in the dead biomass pool at the end of the year, as compared to that number being more than 70% (2.04 of 2.88 tons of CO_2/year/acre) in case of USFS forests. Similarly, more than 56% of the total annual forest growth in corporate forests ends up either in wood products or live-standing trees, whereas this is approximately 28% for USFS forests. Based on these Sankey diagrams, it is obvious that by the end of the year, managed forests, including corporate and DNR forests, retain a significantly larger proportion of their annual growth either in the form of live-standing trees or wood products. On the contrary, the majority (more than 70%) of the annual growth of USFS forests ends up burning or left decaying on the forest floor as dead biomass.

Global Warming Mitigating Potential of Forests

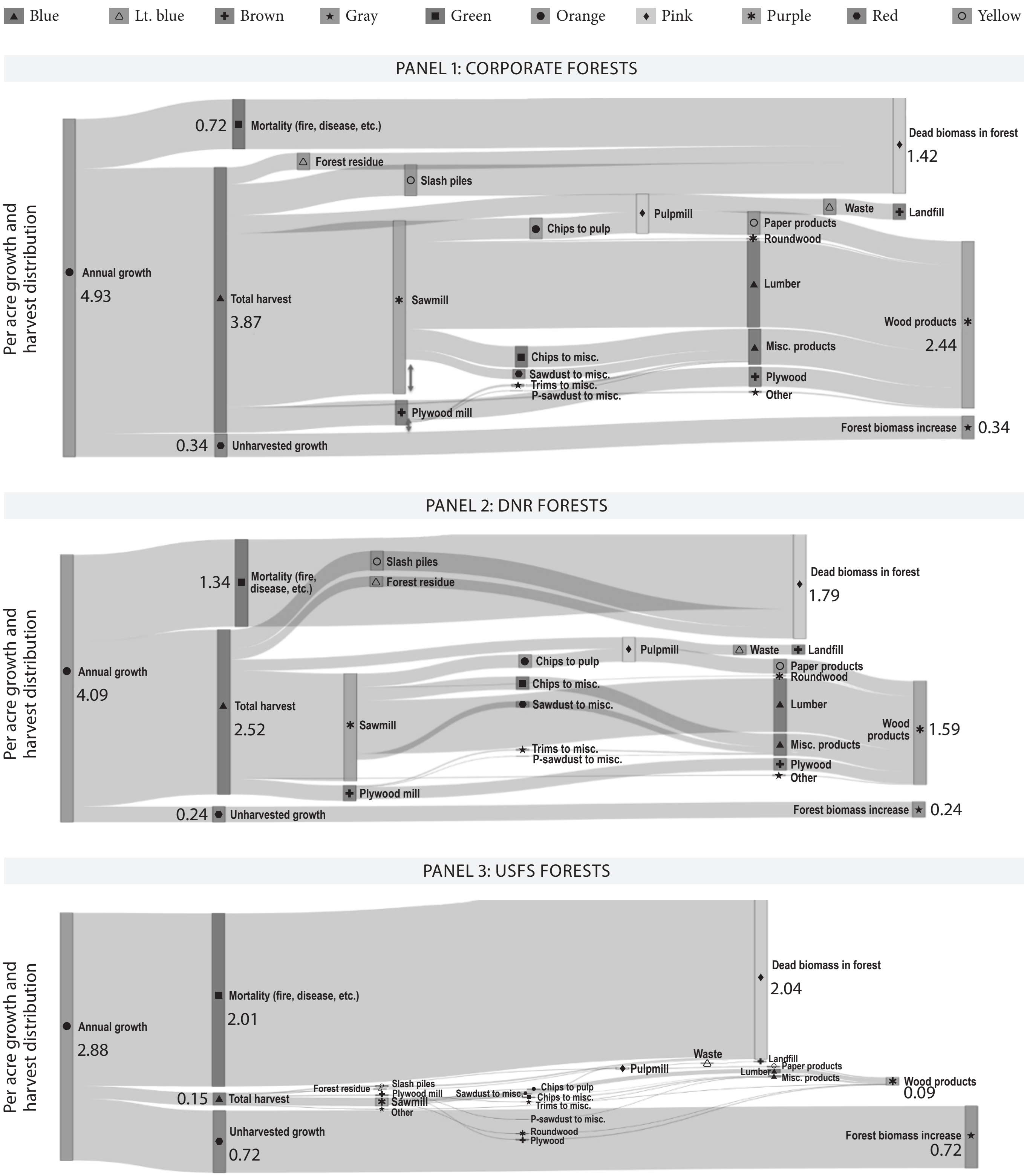
The previous section establishes that, on average, Washington's forests are a net carbon sink. In other words, Washington's forests sequester more carbon from the atmosphere than is lost to the atmosphere or the industry due to mortality, forest fire, and harvest activities. Moreover, the biomass stored in the wood products further enhances the forests' role in removing atmospheric carbon and storing it in the forests and wood products. In this section, we consider a multiyear (15-year) global warming mitigating role of the forests, by removing carbon from the atmosphere and accruing the atmospheric carbon in the forests, wood products, or landfills.

CARBON STORAGE BENEFIT

The rresults of the temporal radiative forcing analysis over a 15-year timeframe, performed without including fossil emissions, are presented in Figure 5. As can be observed from the graph, in the case of corporate and DNR forests, softwood lumber, plywood, and other miscellaneous wood products show significant climate benefits. In the case of non-corporate and USFS forests, the carbon accumulated in live trees presents the primary global warming mitigating potential of forests. In calculating biomass accrual, the functional lives of wood products are factored in using the USFS survey-based functional life analyses of wood products (Stockmann et al., forthcoming). Following the first functional life of wood products, the biomass is either reused/recycled, disposed-of by burning (with or without energy capture), or sent to the landfill. These end-of-life allocations are undertaken using EPA's U.S. survey data and WARM model (EPA 2020). The consequent biomass accruals as a result of these allocations can be seen in reuse/recycle sections or the landfill sections of the stacked bar graphs. Lashoff accounting method (also known as discounting) is applied (Ganguly et al., 2020), starting from the time of harvest, to convert all the biomass accrual data into global warming mitigating potential numbers. When considered without fossil fuel emissions, corporate forests present the greatest environmental benefits per acre, followed by the DNR forests and the non-corporate private forests.

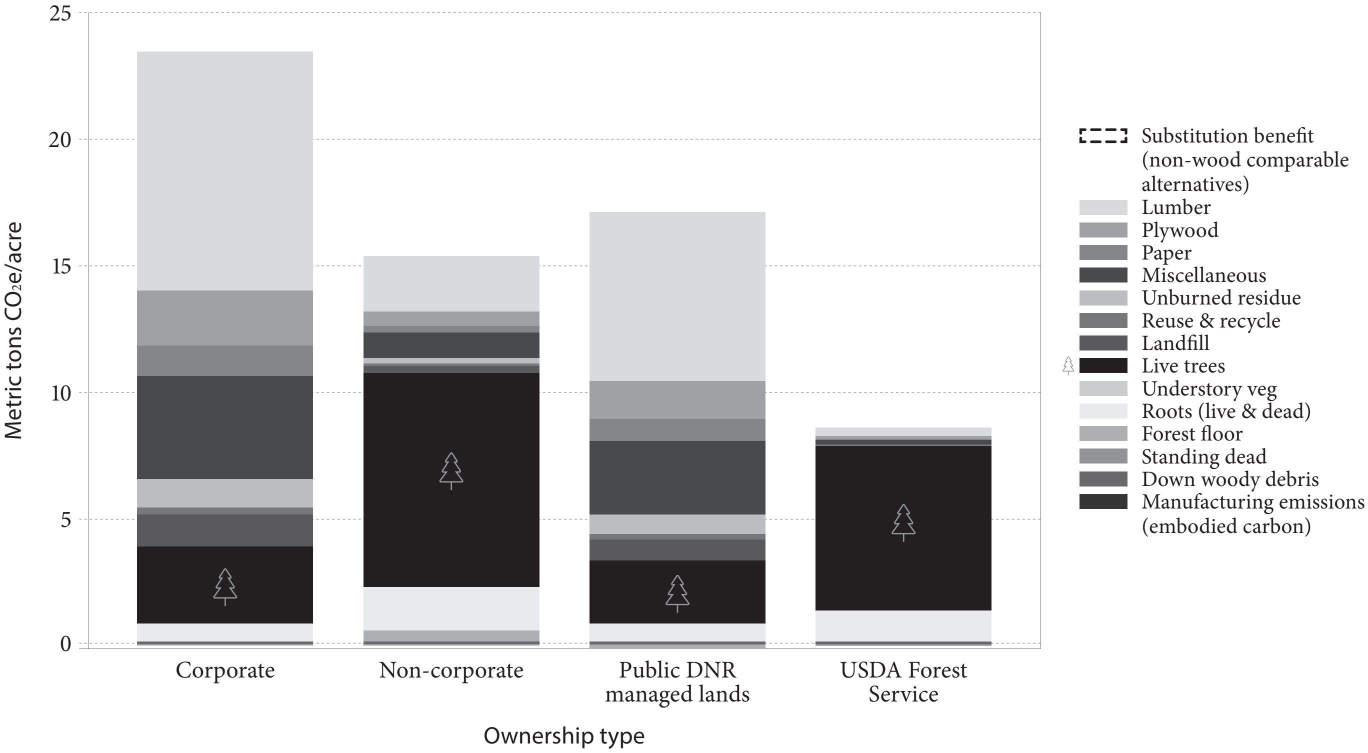
Figure 4: Average Annual Flux in Washington State's Forests, by Ownership Type

The flux includes growth and natural mortality in forests, annual average harvests, and annual storage of biomass in wood products and live standing trees, in tons of CO_2 per acre, per year.



Sources: Forest growth, natural mortality, and harvest data from Cristensen et al, 2020; wood products mix and distribution data from Ganguly et al, 2020

Figure 5: Biomass Accrued over 15 Years and Resultant Global Warming Mitigating Role of Washington State's Forests



DEDUCTING GHG EMISSIONS FROM CARBON STORAGE BENEFITS

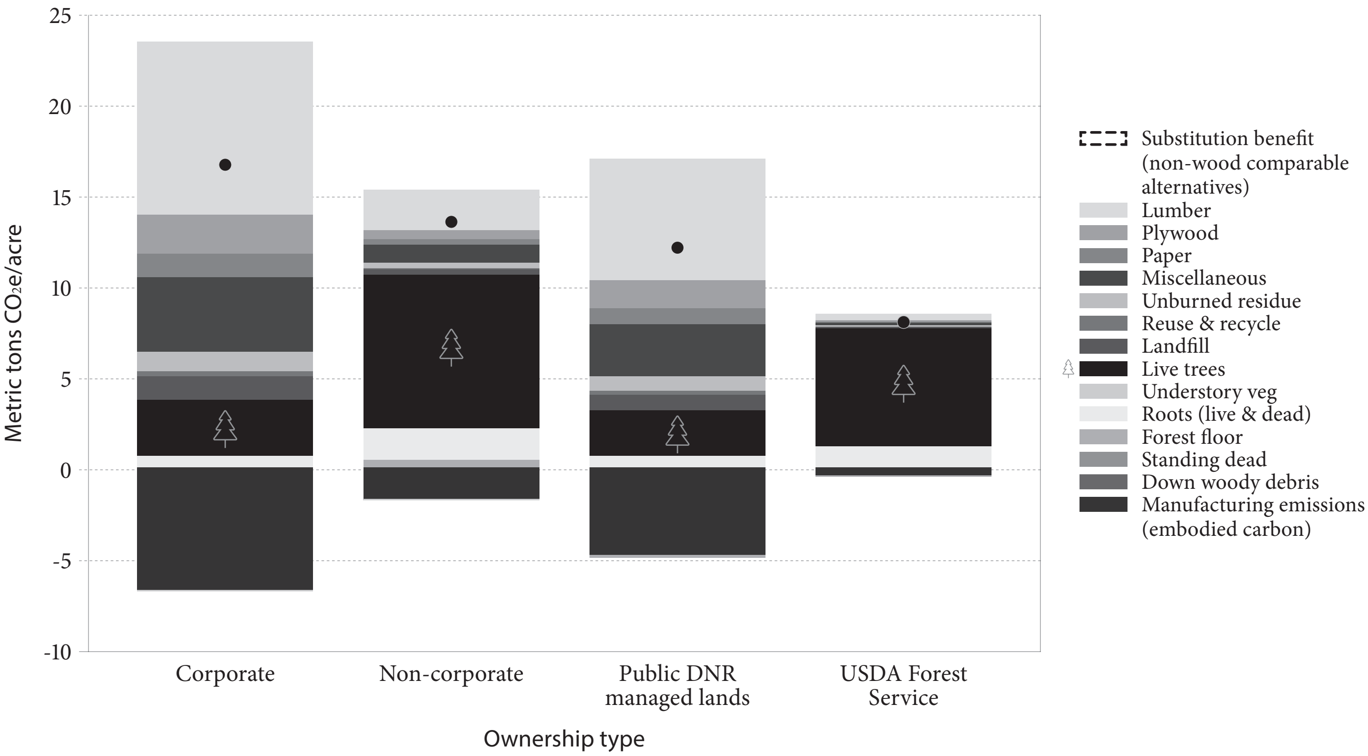
Transferring the carbon from the forests to the economy requires industrial activities that burn fossil fuels and the use of products and services that are fossil intensive. In Figure 6, the biogenic carbon storage benefits are compared against the fossil emissions associated with the harvest and manufacturing of these wood products, which can vary significantly among the wood products (Sathre and O'Connor, 2010; Ganguly et al., 2020).

Moreover, landfill methane emissions are also factored in this study, as biogenic methane (CH4) emissions, if not used for energy capture, are not considered carbon neutral and must be treated as fossil emissions (EPA 2020). The red bars on the negative y-axis in Figure 6 represent the negative global warming impacts associated with emissions of GHGs during harvest, transportation, and production of the wood products, over the same 15-year period. A consistent dynamic temporal analysis was conducted on all the GHG emissions to make the numbers comparable to the sequestration benefit. The black dots represent, in the figure, the net global warming mitigating benefits of each of the forestland by ownership categories, after deducting the negative environmental impact of industrial emission of the wood products industry from their respective sequestration benefits. All the black dots are on the positive axis, indicating all the forest types provide net environmental benefit in terms of global warming mitigation for all ownership types. However, the corporate forests ended up being the best-performing forestland, and the USFS forests continued to be the worst-performing, using the global warming mitigation metric.

INCORPORATING SUBSTITUTION BENEFITS

The analytical approach used up to this point is known as attributional analyses, where relevant fossil emissions, carbon sequestrations, and biogenic carbon storage are documented and used in the analyses. Substitution analyses fall into a different genre of LCA analyses and are termed consequential analyses. In substitution analysis, the life cycle GHG emissions for wood products are compared to emissions from functionally equivalent non-wood products (e.g., concrete and steel). This comparative analysis then calculates the relevant substitution benefits of not using the potentially energy-intensive non-wood product. This is the benefit of choosing an environmentally responsible alternative and associated LCA-based environmental benefits. As a society, we generally accept the concept of

Figure 6: Fossil Emissions and Biomass Accrued over 15 years and Resultant Global Warming Mitigating Role of Washington State's Forests



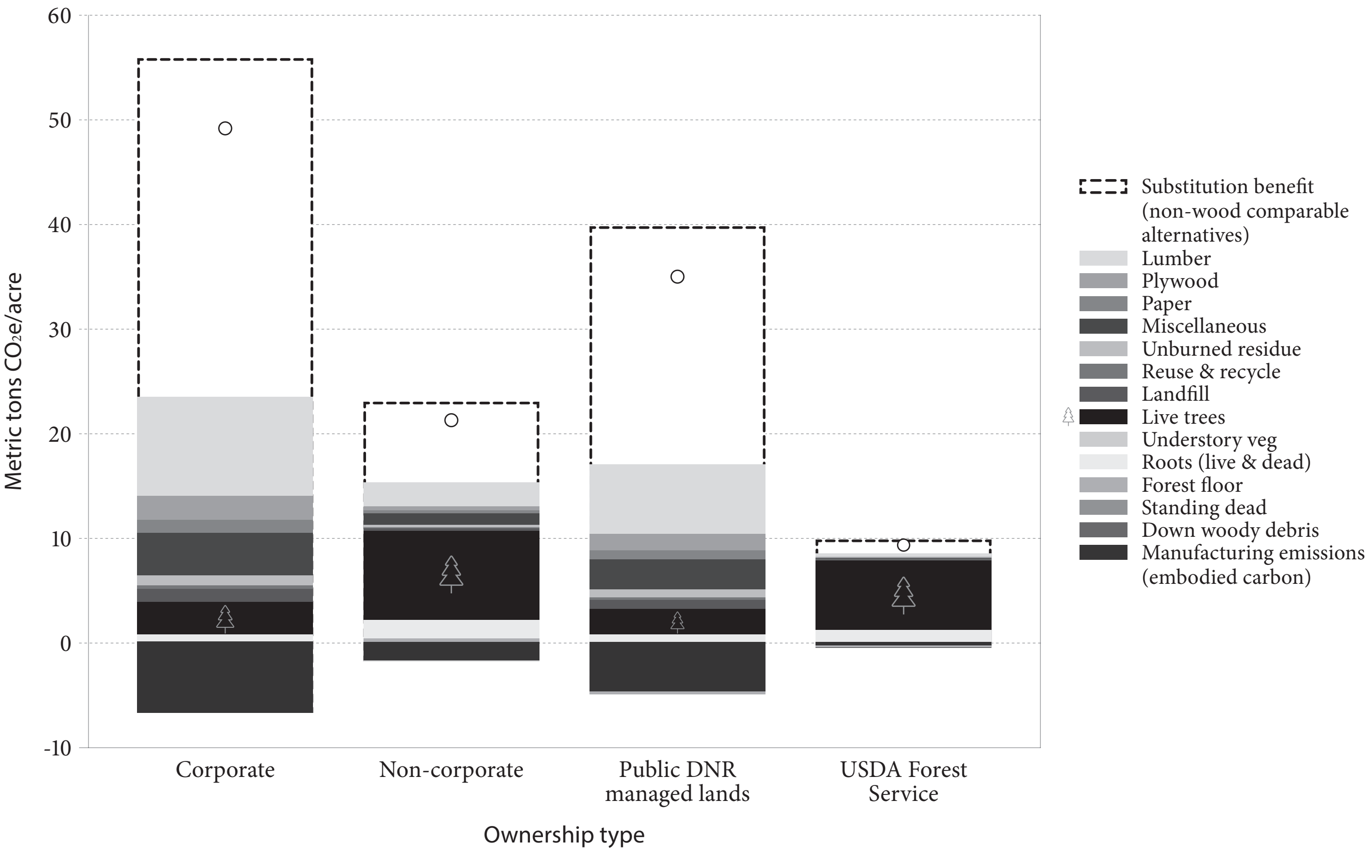
substitution benefit when we choose an electric vehicle over a traditional gasoline vehicle or paper (reusable bags) over plastic at grocery stores. Similar comparisons can be made between renewable energy (bioenergy, hydro-energy, or solar energy) and fossil-based energy (e.g., coal, heating oil, natural gas). However, the evaluation of substitution benefits is based on assumptions associated with the alternate product/s considered for the analyses.

The Washington State's wood products mix is dominated by softwood lumber, which uses minimal fossil energy during its manufacturing and helps displace fossil-intensive materials like steel and concrete for housing construction applications. Similarly, plywood and other wood products also have significant substitution benefits, as they help displace fossil-intensive materials like plastic, aluminum, and steel. For this analysis we used average substitution factors for construction material published in multiple meta-analysis reports (Hurmekoski et al., 2021; Leskinen et al., 2018; Sathre and O'Connor, 2010). Other products or application-specific substitution benefits are drawn for various studies (Xu et al., 2021; Leturcq, 2020; Bergman et al., 2014; Leskinen et al., 2018) and, in some cases, modified/adapted to fit the Washington case study and the PNW situation. The result is depicted with a white bar with dotted boundary lines in Figure 7. While the storage benefits diminish over time, the substitution benefits and the GHG emissions are permanent. Though assumption-based, substitution benefits add significant leverage to the forests managed for wood products. As a result, the net global warming mitigation benefits associated with corporate forests and the DNR forests get a significant bump over the USDA and the non-corporate-private forests.

Discussions and Conclusions

This analysis represents a comparative assessment on a per-acre basis to understand how the forests managed with different objectives contributing to global warming mitigation. Using the flux data of Washington's forests obtained from the USFS and DNR data, this study establishes that

Figure 7: Substitution Benefits, Fossil Emissions, and Biomass Accrued over 15 years and Resultant Global Warming Mitigating Role of Washington State's Forests



Washington's forests are a net sequester-er of atmospheric carbon, even after factoring in the harvest-related loss of biomass and associated industrial fossil emissions. The results of this study also highlight that Washington state's managed forests (corporate and WA-DNR) have significantly higher net global warming mitigating benefits compared to the relatively unmanaged USFS forests.

The Sankey diagrams show that the forest biomass loss, due to natural tree mortality, disease, and fire, in managed forests (e.g., Corporate forests) is significantly lower (14% of total growth) than that in the relatively unmanaged USFS forests (70% of total annual growth). Though a large proportion of the annual growth is removed from the corporate and DNR forests, as commercial harvests, a significant proportion of the harvested biomass (approximately 50%) ends up either in the wood products pool or used up in the manufacturing process for energy recovery. The high proportion of mortality in the USFS forests not only reduces the potential beneficial role of the federal forests but poses increased wildfire risks to the forests and the property around the forests.

This study highlights the importance wood products play in the global carbon flux and help keep atmospheric carbon sequestered in the economy. The study also highlights the towering substitution benefits associated with wood products. The 'true' magnitude of the substitution benefits of wood products can be debated; however, the fact that wood products help displace fossil-intensive materials is evident. We are seeing increasing substitution benefit documentation associated with engineered wood (CLT and Glulam) in building constructions by substituting concrete and steel (Pierobon et al., 2019). The carbon storage and the substitution benefits of the forests can be further improved by converting some of the waste biomass into longer-lasting bio-products like biochar or using them as biofuels, displacing fossil fuels like coal and natural gas.

Finally, the results presented in this paper only present a 15-year outlook, corresponding to the 2002-2007 forest carbon flux data presented in the USFS-DNR report (Christensen 2020). However, if we assume that the general management of these forests would remain constant over a longer period, this analysis could be extended to 30, 50, or 100 years. Choosing a more extended period will increase the uncertainty associated with the results, but can facilitate a longer-term policy and environmental decision.

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