Forest Carbon Modeling Resource Guide

Background: Forest Carbon and Forest Carbon Management

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Greenhouse Effect

To understand the role forests play in mitigating the negative effects of climate change, one must first understand how climate change occurs, via a process referred to as the greenhouse effect. Simply put, the greenhouse effect is warming that results when the atmosphere traps heat radiating from Earth toward space. Figure 1 shows this process in more detail. First, the Earth receives incoming energy at the top of the atmosphere. Around one-third of energy received from the sun is reflected back into space by the atmosphere, clouds, and light-colored surfaces. This reflected energy does not generate heat in the atmosphere. The remaining solar radiation passes to Earth, where it is absorbed and warms the Earth's surface. This surface warming causes some radiation to be emitted back into the atmosphere as infrared radiation, where some of it is lost back into space. However, some of this infrared radiation is absorbed and trapped by greenhouse gases (GHGs) in the atmosphere, causing additional warming of the atmosphere and Earth's surface. The concentration of GHGs present will determine the amount of radiation absorbed and therefore, the magnitude of the warming effect. Under stable conditions, the total amount of energy entering the system from solar radiation will equal the amount radiated into space, allowing the Earth to maintain a constant average temperature over time. However, recent measurements mid-2019 indicate the Earth is presently absorbing ~1.12 watts per square meter more than it emits into space, reflecting a dramatic increase of ~0.5 additional watts per square meter than was observed in mid-2005 (Loeb et al. 2021). This increase is attributed to increases in well-mixed GHGs and water vapor, alongside decreased levels of reflected energy back into space by clouds and sea-ice.

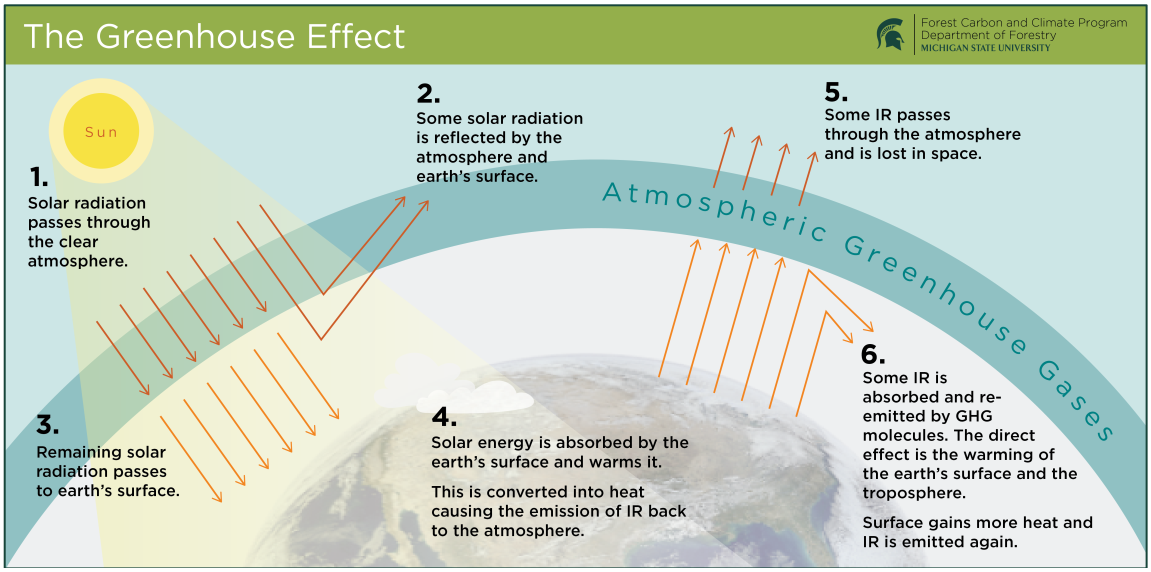

Figure 1. The greenhouse effect. Source: FCCP 2022

Trends in CO_2 and Global Temperature

Given that there are many different greenhouse gases in Earth's atmosphere, one might ask: "Why does carbon dioxide get most of the attention when there are so many other heat-trapping gases?" Carbon dioxide (CO_2) is of key interest to scientists and policy makers due to its significant prevalence in our atmosphere and the relationship between CO_2 concentrations and modifiable human activities. As of 2010, carbon dioxide accounted for 76% of total global GHG emissions, with 65% of total emissions coming from fossil fuel and industrial processes and an additional 11% coming from forestry and other land use (Figure 2).

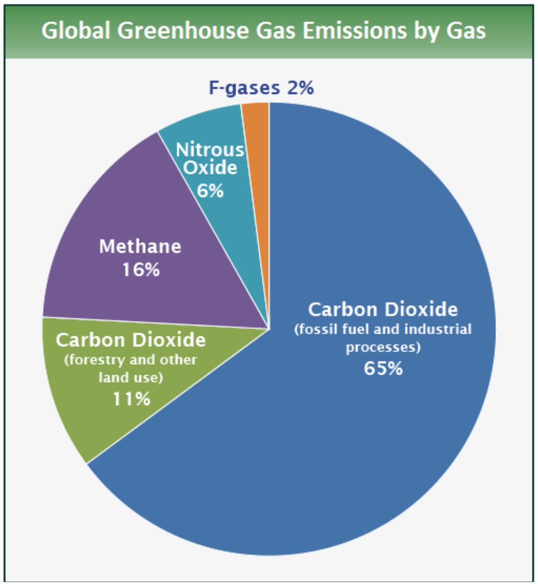

Figure 2. Global greenhouse gas emissions by gas. Source: United States Environmental Protection Agency, 2022 (IPCC 2014 data based on global emissions from 2010)

Figure 3 displays the correlation between atmospheric CO_2 concentrations and annual global average temperatures. There is a long-term trend of increasing temperatures that clearly tracks the increase in atmospheric carbon dioxide concentration.

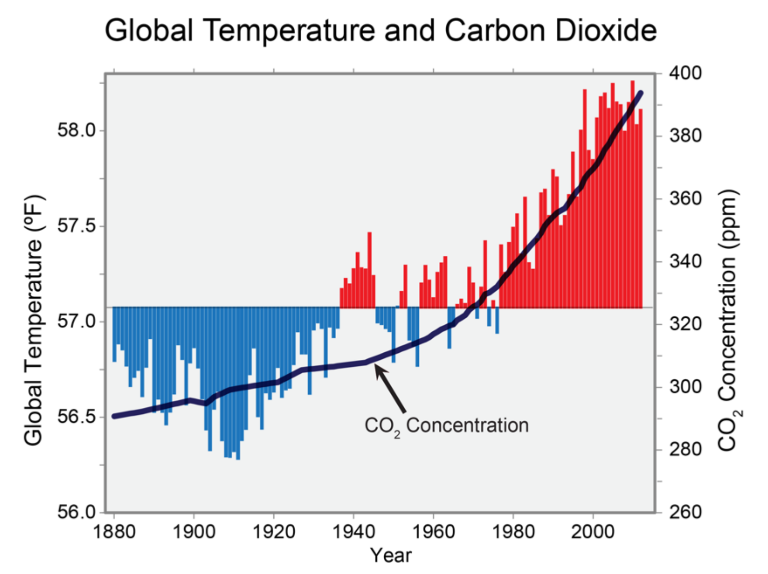

Figure 3. Global annual average temperature (as measured over both land and oceans) has increased by more than 1.5°F (0.8°C) since 1880 (through 2012). Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows atmospheric carbon dioxide (CO2) concentration in parts per million (ppm). While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and volcanic eruptions. (Figure source: GlobalChange.gov, Kenneth E. Kunkel, Cooperative Institute for Climate and Satellites – NC, updated from Karl et al. 2009).

Overview of Global Carbon Cycle

Carbon stocks, or **carbon pools**, refer to the amount of carbon (C) contained in some defined entity such as the atmosphere, oceans, tree stems, soil, and many others **(Figure 4).** Units of C stocks are always a simple measure of mass (Pg, Tg, Mg, etc.). A **carbon flux** is the amount of C moving from one stock to another over a specified period of time (e.g., Pg yr^{-1}, Mg ha^{-1} yr^{-1}, g m^{-2} sec^{-1}). **Figure 4** is a simple diagram of the global carbon cycle, where pools are denoted by boxes and fluxes between pools are denoted by arrows. One important pool is the atmosphere, which holds approximately 830 petagrams (Pg) of carbon. Carbon enters the atmosphere via decomposition, respiration, and wildfire on the land, as well as via exchanges of gases by the ocean, land-use change, and fossil fuel use. Excess emissions from the burning of fossil fuels and land-use change result in a permanent net increase of GHGs in the atmosphere.

The atmospheric carbon pool, which is almost entirely composed of carbon dioxide, is a critical driver of climate change. Carbon is stored on land in living vegetation, dead vegetation (or litter), and soil. These three terrestrial pools store more total carbon than is stored in the atmosphere. The ocean also stores vast amounts of carbon in dissolved organic and inorganic forms. In total, there is an estimated 40,000 Pg of carbon dissolved in ocean waters, nearly 50 times the amount contained in the atmosphere. Fossil fuel reserves of coal, oil, and gas are estimated to contain up to 10,000 Pg of carbon in total – more than 12 times the amount of atmospheric carbon. Natural fluxes of carbon to and from the atmosphere are fairly balanced (i.e., additions of CO_2 to the atmosphere from plant respiration and decomposition, are balanced by removal of CO_2 from the atmosphere by photosynthesis and CO_2 release from the ocean surface is balanced by CO_2 uptake by the ocean). In contrast, counterbalancing processes that return CO_2 to fossil fuel pools take millennia and are significantly outpaced by emissions.

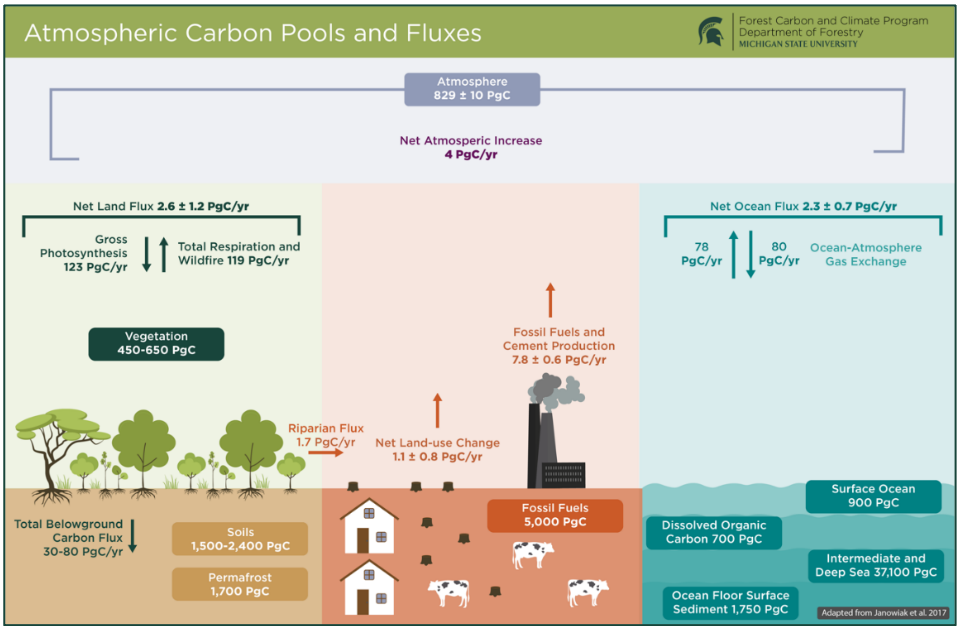

Figure 4. Atmospheric carbon pools and fluxes. Source: FCCP 2022 (adapted from Janowiak et al. 2017)

Sources & Sinks

A **carbon source** refers to a carbon stock or pool that emits carbon whereas **carbon sinks** are pools that *absorb* and *store* the carbon released from another source. For the purposes of climate change science and mitigation efforts, terrestrial and oceanic carbon sources and sinks are often defined with respect to the atmosphere, with sources represented as positive fluxes to the atmosphere (increasing atmospheric CO_2) and sinks represented as negative fluxes (reducing atmospheric CO_2), as is shown in **Figure 5.**

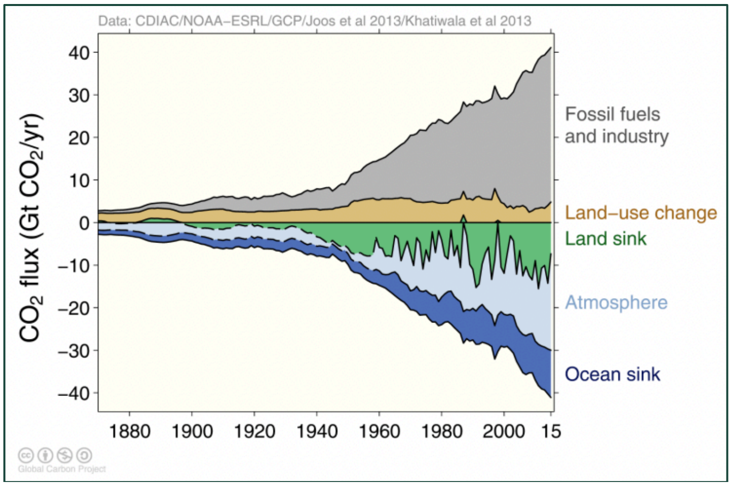

Figure 5. The carbon sources from fossil fuels, industry, and land use change emissions are balanced by the atmosphere and carbon sinks on land and in the ocean. Source: CDIAC 2018

There are two main sources of CO_2 emissions associated with human activities: fossil fuel combustion and land use change. Fossil fuel combustion includes petroleum, natural gas, and coal, which are produced through the burning of these materials for transportation, heating, cooling, electricity generation, industrial activities, and cement production. Land-use change contributes to CO_2 emissions primarily through the clearing of native ecosystems and their conversion to agriculture or other land uses. Forests and native grasslands store vast quantities of carbon; when these systems are disrupted, much of that carbon is released into the atmosphere. Tropical deforestation is a major ongoing example of this type of carbon release.

Anthropogenic (human-caused) CO_2 emissions and natural sinks have changed since the beginning of the industrial revolution in the late 19^{th} century. Emissions during this time and earlier periods were primarily from land-use change. Before 1930, most land-use change emissions were from temperate regions with a major contribution from forest clearing and agricultural expansion in North America. After 1930, land use change emissions in temperate regions declined as forests grew back, but emissions caused by deforestation in the tropics increased markedly.

Over the last century, fossil fuel emissions have increased far more rapidly than land-use change emissions, and now dominate total emissions. The excess atmospheric carbon dioxide is either absorbed by oceans, by vegetation, or remains in the atmosphere. As is shown in Figure 5, carbon emissions over time are mirrored across the zero line, showing that increased CO_2 emissions have also resulted in increased CO_2 storage levels.

For an idea of the carbon sources and sinks that currently affect the overall CO_2 balance, Figure 6 highlights major fluxes from 2006-2015. During this period, fossil fuel combustion and land-use change are the two dominant carbon sources, each of which is associated with human activities. Carbon sinks, such as the atmosphere, terrestrial ecosystems, and oceans, store increased CO_2 emissions caused by these anthropogenic carbon sources in addition to natural fluxes of carbon through these systems. Forests play a dual role in the overall carbon balance as they can represent both a carbon source (through deforestation and forest degradation) as well as a carbon sink (through sequestering and storing CO_2 from the atmosphere). In this way, trees and forests have potential to serve as a long-term carbon storage solution.

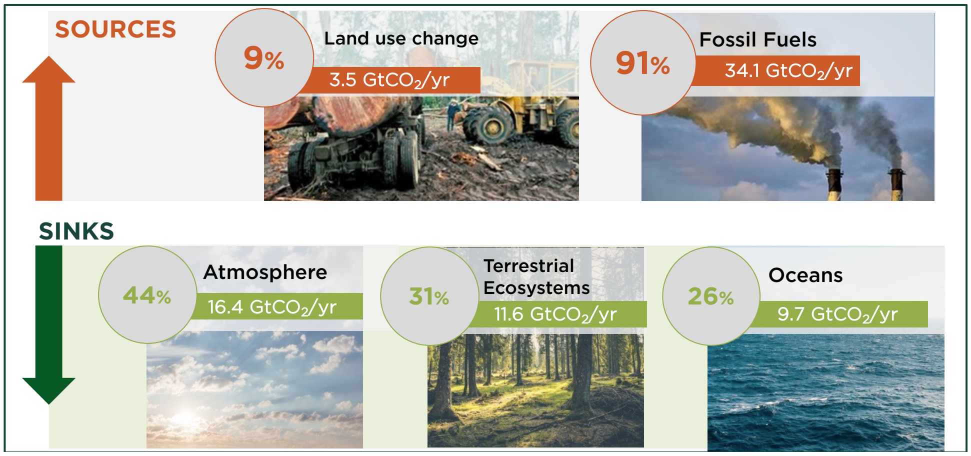

Figure 6. Changes in carbon sources and sinks from 2006-2015. Source: FCCP 2022, adapted from CDIAC 2018

Forest Carbon Pools & Processes

In addition to their role in the global cycle, forests absorb, store, and release carbon through cyclical processes that occur at the ecosystem level (Figure 7). Trees absorb and store carbon from the atmosphere through a process called photosynthesis, in which they use sunlight to power the conversion of CO_2 and water into many types of sugars (called carbohydrates) releasing oxygen in the process. These carbon-based sugars are the building blocks for a variety of tissues necessary for tree growth. As trees grow, they accumulate carbon in leaves, roots, and wood, making up roughly half of their dry weight. These sugars are also used to sustain metabolic processes, such as transporting water from roots to leaves. When trees break down sugars for energy, they release some carbon dioxide back into the atmosphere, via a process called respiration. Growing trees accumulate carbon over time because carbon uptake and storage via photosynthesis outpaces carbon losses from respiration.

When tree tissues die, the dead biomass is broken down by soil microbes. These microbes also break down carbon from root exudates, or carbon-based sugars that move from tree roots into the soil. During this process, some carbon dioxide is released back into the atmosphere via respiration. Over time, soil can accumulate large amounts of carbon as trees provide a constant flow of carbon into the soil. Soils generally store about half of the total carbon in forest ecosystems.

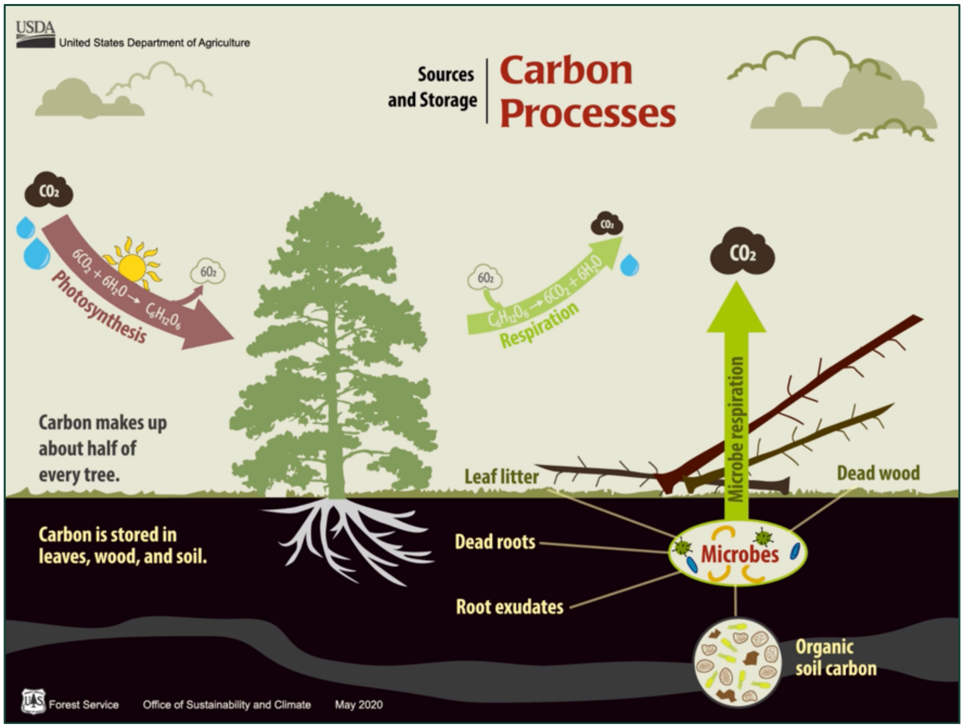

Figure 7. Forest carbon pools and processes. Source: USFS OSC

Natural Climate Solutions (NCS)

Natural Climate Solutions (NCS) refer to conservation, restoration, and improved land management actions in landscapes and wetlands that increase carbon storage or avoid greenhouse gas emissions (Griscom et al. 2017); or in the case of forests, actions that strengthen forests' ability to serve as carbon sinks while minimizing their role as carbon sources. A study by Griscom et al. (2017) found that when combined with clean energy and other efforts to decarbonize economies, NCS offer some of the most promising and cost-effective pathways to achieving CO_2 mitigation targets. The study estimated that NCS alone can provide roughly 37% of CO_2 mitigation needed by 2030 to increase the likelihood of holding warming below 2°C by 66% (Figure 8).

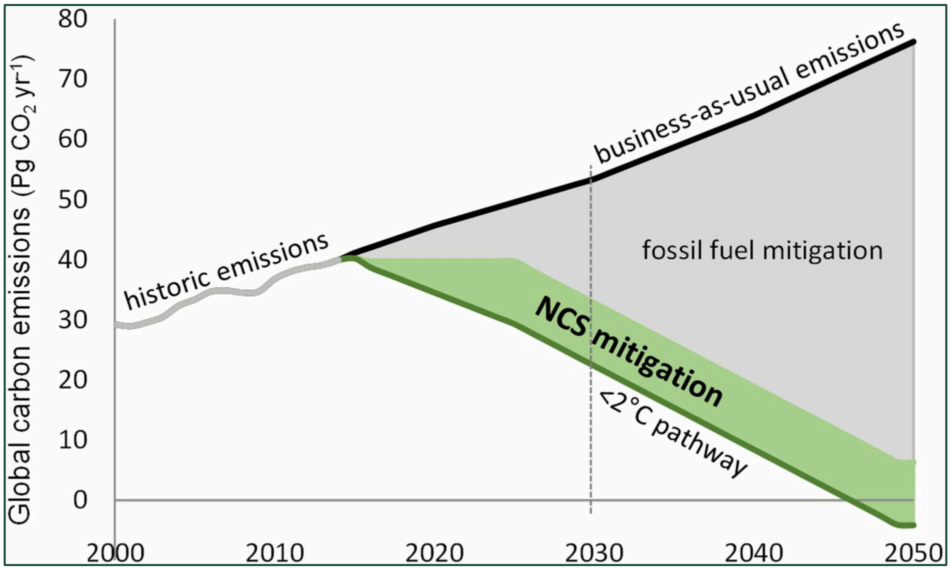

Figure 8. *Contribution of NCS to stabilizing warming to below 2 °C. Historical anthropogenic CO_2 emissions before 2016 (gray line) prelude either business-as-usual (representative concentration pathway, scenario 8.5, black line) or a net emissions trajectory needed for >66% likelihood of holding global warming to below 2 °C (green line). The green area shows cost-effective NCS (aggregate of 20 pathways), offering 37% of needed mitigation through 2030, 29% at year 2030, 20% through 2050, and 9% through 2100. This scenario assumes that NCS are ramped up linearly over the next decade to <2 °C levels and held at that level (=10.4 $PgCO_2\ y^{-1}$, not including other greenhouse gases). It is assumed that fossil fuel emissions are held level over the next decade then decline linearly to reach 7% of current levels by 2050. Source: Griscom et al. 2017*

When comparing the climate mitigation potential of NCS on various landscapes, actions on forested lands are estimated to have high potential for increased atmospheric carbon removals (Figure 9). Results of a 2018 study show that the specific practice of reforestation may have the largest maximum mitigation potential (307 Tg CO_2e $year^{-1}$), with most of this potential occurring in the northeast (35%) and south-central (31%) regions of the US (Fargione et al. 2018), though there is considerable uncertainty around reforestation's potential impact in the US (note the large confidence interval associated with this practice). Reforestation is also linked with all four assessed ecosystem service co-benefits: air quality improvement, habitat provisioning and biodiversity, soil enrichment, and water filtration and flood control.

Natural forest management of privately held forests, which includes activities such as extending harvest cycles, reduced impact logging, and improving silvicultural practices that release suppressed stems, too has a large (and potentially the largest) mitigation potential, estimated at 267 Tg CO_2e $year^{-1}$ (Figure 9). Natural forest management is a unique NCS in that the practices can often be implemented at low or no net cost to the landowner. Other promising forest NCS include avoided forest conversion (avoiding the clearing and conversion of forests to other land uses), urban reforestation (increasing urban tree cover nationwide), fire management (which entails restoring frequent, low-intensity, understory fires in fire-prone systems to reduce the risk of high-severity wildfires), and improved plantations (extending rotation lengths in even-aged, intensively managed wood production forests; Fargione et al. 2018). Importantly, each of these maximum mitigation estimates assume a CO_2e market valuation of 100 USD per metric ton, significantly higher than current values for forest-based carbon.

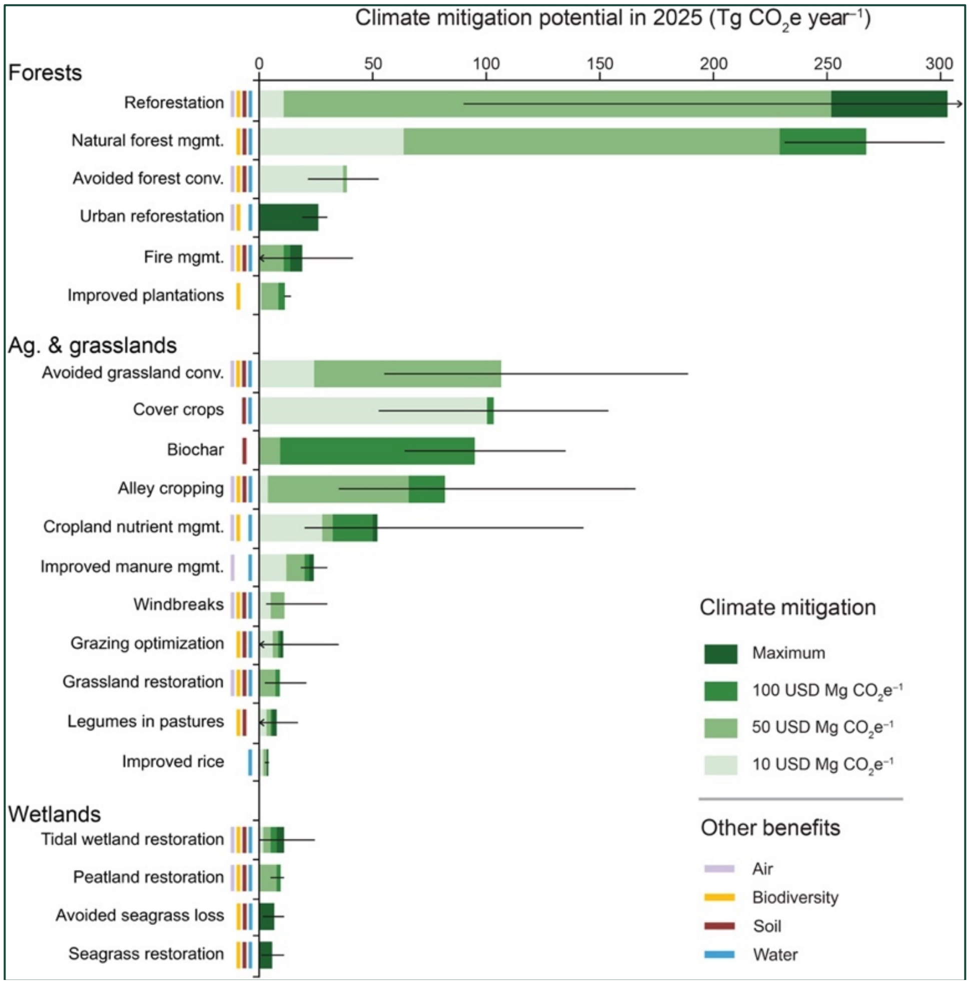

Figure 9. Climate mitigation potential of 21 NCS in the United States. Source: Fargione et al. 2018

Forest Carbon Management

Mitigation includes actions to minimize climate change impacts by reducing sources of GHG emissions and enhancing carbon sequestration. Because actions on forestlands represent some of the most promising pathways to sequester carbon, active forest carbon management is an important climate change mitigation strategy. There are three major categories of mitigation activities associated with the forest sector: 1) increase or maintain forestland, 2) maintain or increase carbon stocks, and 3) increase wood use (Figure 10).

Figure 10. Mitigation strategies and actions in the forest sector. Source: FCCP 2022

Increase or Maintain Forestland

The primary management actions that are undertaken to increase or maintain forestland include avoided conversion, reforestation, and afforestation. **Avoided conversion** involves activities to prevent deforestation (conversion of forestland to another land-use, such as agriculture or development). Forest loss from land-use conversion is a major historical contributor to climate change and has resulted in greater emissions than most other anthropogenic activities, second only to energy production. Forests can be protected from deforestation pressures through regulations restricting use and policy incentives (e.g., property taxes favorable to forest ownership) to maintain carbon stocks on the landscape. However, for regulations to be effective, it must be possible to monitor illegal activities, particularly in remote locations; this typically depends on governance structure, levels of corruption, available monitoring and communications technology, community participation, and geography.

Reforestation consists of restocking understocked forest or the direct conversion of recently cleared land back to forested land through planting, seeding, or the human-induced promotion of natural seed sources. Reforestation measures can be used to help forests recover following a natural or human-caused disturbance – such as a wildfire or clear-cut harvest. Activities can occur on recently harvested land, degraded or marginal land, or grazing lands that had recently been forested. A major economic constraint to reforestation is the high initial investment to establish new stands and, in cases of working forests, the several-decade delay until reforested areas generate revenue. However, policy incentives can also help mitigate the cost burden on landowners. Further, the non-carbon co-benefits of reforestation, such as reduced soil erosion and increased provision of clean water, may help to offset reforestation costs, depending on how such co-benefits are valued.

Afforestation is similar to reforestation but is distinguished by how long the non-forest condition has prevailed. Afforestation generally refers to planting trees on land that has not had forest vegetation for a very long time or is not known to have been previously forested. Costs to undertake afforestation vary by site, and are dependent on the site preparation needed, current land use, and labor costs. Afforestation can be more costly than reforestation due to preparation activities such as biomass clearing (removal of grasses, shrubs, and other plants from the site to clear topsoil for tree planting) and creating road access. As in the case of reforestation, afforestation actions can be constrained by high initial investments and a lag in revenue generation. Another approach to afforestation (and in some cases, reforestation) is to increase trees on working agricultural lands by employing tactics such as agroforestry (when trees or shrubs are planted alongside food crops) and silvopasture (the practice of planting trees in a livestock grazing area or allowing livestock to graze in a forest). Such practices increase the landscape biodiversity and can provide a wide range of benefits, including increased water filtration and reduced soil erosion.

Maintain or Increase Carbon Stocks

The goal of this strategy is to increase or maintain overall carbon density and storage on the landscape and, in some cases, harvested wood product pools. This is accomplished by undertaking management activities to sequester additional carbon (when compared to normal management) or maintain current carbon stocks by reducing the risk of carbon losses (i.e., reducing the risk of tree mortality to stressors and disturbances). Some key management actions undertaken to maintain or increase carbon stocks include restoration, improved forest management, agroforestry, urban forestry, avoiding degradation, and climate change adaptation (i.e., planting future-adapted species, increasing species and structural diversity, thinning stands to reduce risk of losses to wildfire or drought). Some examples of specific activities include increasing stocking of understocked stands, implementing harvest systems that maintain partial forest cover, protecting soil carbon by reducing soil erosion and minimizing soil disturbance, avoiding slash burning and other high-emission activities, planting new trees and thinning congested areas, and reducing competition to enhance growth of retained trees.

There are diverse and cost-effective opportunities in this category, particularly as many of these actions can be implemented rapidly by working with current landowners. These activities are relatively economical as in many cases, they don't require a radical change in land management or management goals. Further, some activities can be implemented without impacting wood volume yields on a given stand (e.g., reduced impact logging), while other activities may reduce yields in the near-term on a given forest stand (such as extended harvest cycles).

Increase Wood Use

The forest sector carbon cycle includes the natural carbon cycle as well as additional activities related to forest management and forest product use. Forest carbon can be stored through purposeful human activities, including the storage of carbon in **harvested wood products (HWPs).** HWPs are wood-based materials harvested from forests, which are used for products such as furniture, plywood, paper and paper-like products, or for energy (UNECE). As noted above, roughly half of a tree's dry weight is made up of carbon; harvested wood continues to store that carbon for as long as that material stays intact. Carbon will flux from harvested wood back into the atmosphere when it is either burned or when it decomposes (Figure 11).

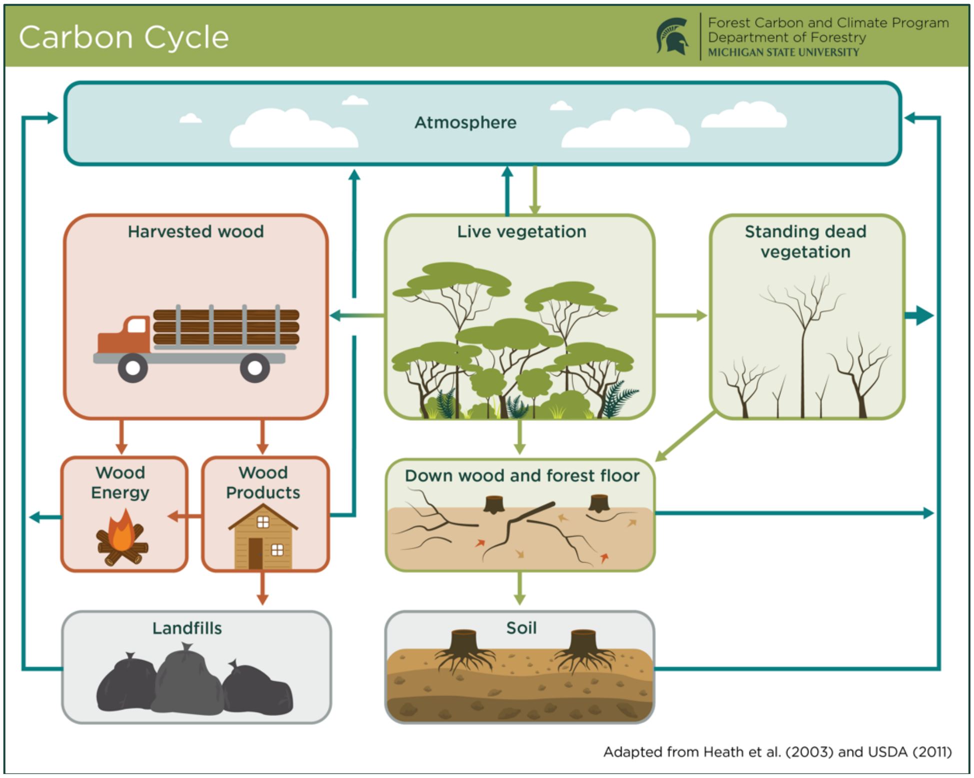

Figure 11. Forest sector carbon cycle. Source: FCCP 2022

Whether and the extent to which HWPs represent a carbon benefit depends on counterfactual materials and energy demand as well as the carbon emissions associated with those counterfactual materials and energy sources (that is, the degree to which wood products substitute for more carbon-intensive products). **Material substitution** refers to the use of wood *instead of* more emissions-intensive materials, such as steel, cement, or plastics. Through this kind of substitution, net GHG emissions can be avoided. HWPs may be "credited" with, or assumed to have, negative emissions. Substitution of HWPs for more carbon-intensive products stands to have the greatest impact in the building and construction sector, where the extraction and manufacturing of building materials alone represents 11% of global emissions (IEA 2019). Life-cycle inventory analyses consistently reveal that the lumber, wood panels, and other forest products used in construction store more carbon, emit fewer GHGs, and use less fossil energy than steel, concrete, brick, or vinyl (CORRIM). Wood has the highest potential for a carbon benefit when it is used in long-lived products (e.g., in substitution for construction materials) and when the lifetime of products is maximized (e.g., with wood reuse).

Energy substitution represents another pathway for mitigation through increased wood use. Where woody biomass is substituted for fossil fuels (such as coal, natural gas, gasoline, diesel oil, and fuel oil), bioenergy is credited with avoiding those additional emissions. Similar to material substitution, bioenergy may be credited with negative *emissions if the energy sources for which it was a substitute would have led to greater energy emissions*. It is easy to see here why counterfactuals are so important: bioenergy may be credited with negative emissions when it substitutes for fossil fuel emissions, but not should it substitute for lower-emissions energy sources (e.g., solar or wind). Woody biomass for energy provides clearest GHG benefits when derived from by-products, wood wastes, and the end-of-lifecycle use of long-lived wood products.

The supply and demand dynamics of HWPs (both alone and relative other products) respond to both government policies and market pressures. Considerations of leakage (e.g., when reduced harvest in one area leads to increased harvest in another), limitations to product substitutability (e.g., the reality that there are structural and other limitations to the likelihood that wood will serve as a suitable substitute for other products, and vice versa), as well as price and population dynamics impacting construction and energy demand (e.g., the possibility that increased harvest will lead to increased absolute construction, rather than a decrease in concrete use, among other possibilities) are important considerations that impact substitution benefit calculations.

In the consideration of HWPs, the importance of sustainable forest management cannot be ignored; wood production stemming from or encouraging permanent forest conversion or forest degradation is associated with greater net emissions rather than increased net carbon storage. These concerns are paramount in (though certainly not exclusive to) tropical forests, especially in countries with a low capacity to regulate and incentivize sustainable forest management. Due to international trade in HWPs and low product traceability, illegal and unsustainable wood resulting in permanent land use change continues to land in US markets. With improved product tracking and labeling, both government policy and private demand can minimize the extent to which US HWP demand fuels unsustainable forest management internationally (and even promote more sustainable forest management abroad).

References Cited

CDAIC. (2018). Global Carbon Project - Full Global Carbon Budget. Carbon Dioxide Information Analysis Center.

- *Data, webpages, and reports compiled and produced by the Global Carbon Budget, a collaborative effort of the global carbon cycle science community coordinated by the Global Carbon Project*

CORRIM. Library of LCA's on Wood Products. https://corrim.org/lcas-on-wood-products-library/. Accessed on 9 August 2022.

- *Resource hub of reports, journal articles, and other materials featuring Life Cycle Analysis (LCA) results for various regions within the US and North America*

Fargione, J. E., Bassett, S., Boucher, T., Bridgham, S. D., Conant, R. T., Cook-Patton, S. C., … & Griscom, B. W. (2018). Natural climate solutions for the United States. Science Advances, 4(11), eaat1869.

- *Quantification of 21 conservation, restoration, and improved land management interventions on natural and agricultural lands to increase storage and avoid greenhouse gas emissions in the United States*

FCCP. (2022). Open Resource Library (ORL). Michigan State University Forest Carbon and Climate Program.

- *An online space dedicated to sharing educational outputs from MSU FCCP's for-credit and non-credit course offerings to a wide audience of practitioners, educators, and members of the public*

GlobalChange.gov. (2013, November 6). Figure nca3 2.2 - GCIS. US Global Change Research Program.

- *Figure showing global temperature and carbon dioxide (1880-2012) from the Third National Climate Assessment*

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., … & Fargione, J. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44), 11645-11650.

- *High-level analysis of the concept of natural climate solutions, their benefits, and potential*

Janowiak, M.; Connelly, W.J.;Dante-Wood, K.; Domke, G.M.; Giardina, C.; Kayler, Z.; Marcinkowski, K.; Ontl, T.; Rodriguez-Franco, C.; Swanston, C.; Woodall, C.W.; Buford, M. 2017. Considering Forest and Grassland Carbon in Land Management. Gen. Tech. Rep. WO-95. Washington, D.C.: United States Department of Agriculture, Forest Service. 68 p.

- *Report describes the role of forest and grassland ecosystems in the carbon cycle and provides information for considering carbon as one of many objectives for land management activities*

Loeb, N. G., Johnson, G. C., Thorsen, T. J., Lyman, J. M., Rose, F. G., & Kato, S. (2021). Satellite and ocean data reveal marked increase in Earth's heating rate. Geophysical Research Letters, 48(13), e2021GL093047.

- *Study comparing satellite observations of the net radiant energy absorbed by Earth with a global array of measurements used to determine heating within the ocean, land and atmosphere, and melting of snow and ice, showing that independent satellite and in situ observations each yield statistically indistinguishable decadal increases in EEI from mid-2005 to mid-2019 of 0.50 ± 0.47 W m−2 decade−1 (5%–95% confidence interval)*

UNECE. Carbon Storage in Harvested Wood Products (HWP) | UNECE. United Nations Economic Commission for Europe. Accessed 5 August 2022.
- *UNECE webpage overviewing carbon storage in harvested wood products*

United States Environmental Protection Agency. (2022, February 25). Global Greenhouse Gas Emissions Data. US Environmental Protection Agency.
- *EPA webpage overviewing global greenhouse gas emissions data including global emissions by gas, global emissions by economic sector, trends in global emissions, and emissions by country*

USFS OSC. Carbon. US Forest Service Office of Sustainability and Climate. https://www.fs.usda.gov/managing-land/sc/carbon. Accessed 5 August 2022.
- *US Forest Service Office of Sustainability and Climate webpage on carbon, includes assessments, reports, tools, graphics, and other related resources*

Additional Resources

Webinars/videos

Cooper, L., Swanston, C., Macdonald, C. (2021, January 6). Latte & Learn: Forest Carbon 101 [Webinar]. FCWG Science Series for Policymakers, Michigan State University Forest Carbon and Climate Program.
- *Webinar recording, presentation slides, and summary document featuring key takeaways and talking points from the Forest Climate Working Group's (FCWG) Science Series presentation on key concepts related to forests' role in climate change mitigation*

Fargione, J. (2020, January 8). Opportunity Assessments for Natural Climate Solutions [Webinar]. FCWG 2019-20 Learning Exchange Series, Michigan State University Forest Carbon and Climate Program.
- *Webinar recording, presentation slides, and supplementary Q+A responses from Joe Fargione's presentation exploring the magnitude of different natural climate solutions at the state level*

Kosiba, A. (2022, May 4). The Science of Forest Carbon [Webinar]. Forest Carbon Webinars in May 2022, North East State Foresters Association Northeast Forest Carbon Program.

- *Webinar recording and presentation slides on the role of forests in mitigating climate change, key terms and concepts, and the carbon status of Northeast forests (direct link to webinar recording; direct link to presentation slides)*

Kosiba, A. (2022, May 11). The Science of Forest Carbon Management [Webinar]. Forest Carbon Webinars in May 2022, North East State Foresters Association Northeast Forest Carbon Program.

- *Webinar recording and presentation slides on key concepts of forest carbon management, including strategies, resources, field methods and tools, cost benefits, trade offs, and considerations (direct link to webinar recording; direct link to presentation slides)*

Kreye, M. (2022, March 25). Forest Carbon Markets: Who are They For? The challenges, Opportunities and Ethics of Financializing Ecological Services [Conference presentation]. 2022 Forest Carbon Decision Support, FIA National Users Group Focus Session, Virtual Event.

- *Presentation addresses market failure in family forest carbon and introduces the Forest Owner Carbon and Climate Education Program (FOCCE) which was designed to empower landowners through a diverse network of strategies (starts at 17:50 in the video)*

North, M., Sprague, E., Germann, S. (2021, March 16). Latte & Learn: Reforestation for Ecosystem Resilience [Webinar]. FCWG Science Series for Policymakers, Michigan State University Forest Carbon and Climate Program.

- *Webinar recording, presentation slides, and summary document featuring key takeaways and talking points from the Forest Climate Working Group's (FCWG) Science Series presentation on exploring ecosystem-scale science, logistics, and opportunities for reforestation in response to disturbance as well as a changing climate*

Peer reviewed resources

Domke, Grant M.; Oswalt, Sonja N.; Walters, Brian F.; Morin, Randall S. 2020. Tree planting has the potential to increase carbon sequestration capacity of forests in the United States. Proceedings of the National Academy of Sciences. 117(40): 24649-24651. https://doi.org/10.1073/pnas.2010840117

- *Study uses data from more than 130,000 national forest inventory plots to describe the contribution of nearly 1.4 trillion trees on forestland in the conterminous United States to mitigate CO2 emissions and the potential to enhance carbon sequestration capacity on productive forestland*

Janowiak, Maria K.; Brandt, Leslie A.; Wolf, Kathleen L.; Brady, Mattison; Darling, Lindsay; Lewis, Abigail Derby; Fahey, Robert T.; Giesting, Kristen; Hall, Eboni; Henry, Molly; Hughes, Maise; Miesbauer, Jason W.; Marcinkowski, Kailey; Ontl, Todd; Rutledge, Annamarie; Scott, Lydia; Swanston, Christopher W. 2021. Climate adaptation actions for urban forests and human health. Gen. Tech. Rep. NRS-203. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 115 p. https://doi.org/10.2737/NRS-GTR-203

- **urban focus* Report synthesizing adaptation actions to address climate change in urban forest management and promote human health and well-being through nature-based solutions*

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