



Educator Guidebook

Carbon Incentives for Forest Owners

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Pre-press Copy (April 1, 2023)

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Purpose of This Guidebook

This guidebook is intended for professionals in forestry, education, and advocacy who want to help family forest owners learn about forest carbon incentives. The materials presented here were developed through a collaboration of forestry experts, and the Forest Owner Carbon and Climate Education (FOCCE) program, and are intended to serve as a starting point for self-directed exploration of climate-smart forestry.

Users of this book do not need to have experience in forest management; however, a forestry professional should always be involved when making recommendations to forest owners.

Teaching tips and links to more resources are provided at the end of each section. The glossary defines key words and phrases presented in the guidebook. If you plan to share the content in this book, please use the citation at the bottom of this page.

If you are using this guidebook in combination with the live webinar series and panel discussions, please register at the Penn State Extension website to receive continuing education credits. Be sure to check out the second part of this training program.

This guidebook document is a pre-press version. Names, dates, and dollar values may differ from future versions of the guidebook.

Suggested Citation: Kreye M., C. Norman, and K. Brooks (Eds.) (2023). Forest Owner Carbon and Climate Education. Educator Guidebook. Part 1: Carbon Incentives for Forest Owners (Pre-press version). The Forest Owner Carbon and Climate Education Program, Department of Ecosystem Science and Management, Penn State, University Park, PA. <https://sites.psu.edu/focce/resources/resources-for-educators/>

A Philosophy for Educators about Carbon Markets

Melissa Kreye, director, Forest Owner Carbon and Climate Education, Penn State Extension

In education and extension, we often pay attention to delivering “just the facts” or the science behind the topics our clients are interested in. This is also true when it comes to climate change and carbon incentives. Unfortunately, polarizing news around these topics can make it difficult to not share our personal opinion or remain unbiased in selecting what we teach.

Today more than ever, what we teach and how we deliver our programs has implications for the environment and ecosystems. We at FOCCE believe the most important goal of extension education is to engage all types of landowners and communities in climate-smart forestry issues. How they choose to interact in that space, as economic actors, voluntary actors, educators, or advocates, is up to them because they are the people who will help create the new future for forests.

The carbon market programs we see today are only the “tip of spear” for establishing new ecosystem service marketplaces. These incentives are very much needed to help make private land ownership financially feasible and to support the continued provision of public goods, such as clean air, water, and wildlife. We also need to recognize the importance of supporting stewardship values and help landowners cultivate a land ethic around climate-smart forestry.

The following is a list of our values that help guide our practice of extension education. We hope this list will be of value to you as you look to bring climate-smart forestry information to your clients.

FOCCE Values for Extension Programming

1. Distribute content that is grounded in interdisciplinary science.
2. Be unbiased in the materials and information we present.
3. Prepare landowners and stakeholders to engage in forest management and the carbon economy.
4. Promote systems thinking so clients can independently navigate our changing forests and the carbon economy.
5. Address the values, needs, and conditions of the forest owner community and those who rely on this community.
6. Recognize and respect diversity in landowner capacity and motivation.
7. Recognize and respect diversity within the carbon economy and the government agencies that work with private landowners.
8. Be inclusive and acknowledge interconnections between social and ecological justice.
9. Foster agency within stakeholders to advance community-level action.
10. Build and sustain a community of practice around climate resilience and private forestlands.

Part 1: The Big Picture for Forests and People

Chapter 1: Systems and Climate Change

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Public concerns about climate change have led more people to become interested in understanding how natural systems help regulate global temperatures. A recent survey conducted by Yale University found that 72% of people in the United States think that climate change is happening, and 52% believe that climate change is mostly caused by human activities.

Learning Outcomes for This Section

- Landscape factors that affect how people experience climate
- Natural and human systems that influence climate

What Is Climate Change?

When people hear about climatic change, they often think about weather changes. Climate and weather are interrelated concepts, but there are some important differences. Weather is a description of the current state of the atmosphere, ranging from a few minutes to weeks. Climate, however, is the average weather condition recorded over a long period of time (e.g., 30 years). Measuring the weather includes assessing changes in air temperature, atmospheric (barometric) pressure, humidity, precipitation, solar radiation, and wind. Climate information includes statistical descriptions of normal weather and weather extremes (e.g., drought and floods). Climate change is when long-term shifts in average temperatures and weather patterns occur. Global warming refers to an increase in average global temperatures, which often leads to more extreme weather conditions.

Landscape Factors That Influence Our Experience of Climate

The climate on planet Earth is regulated using a delicate system of checks and balances that help control atmospheric conditions. Understanding how this system works can help us determine when climate changes are normal, and which are new or extreme. Four major landscape factors influence how we experience the climate and its changes (Figure 1).

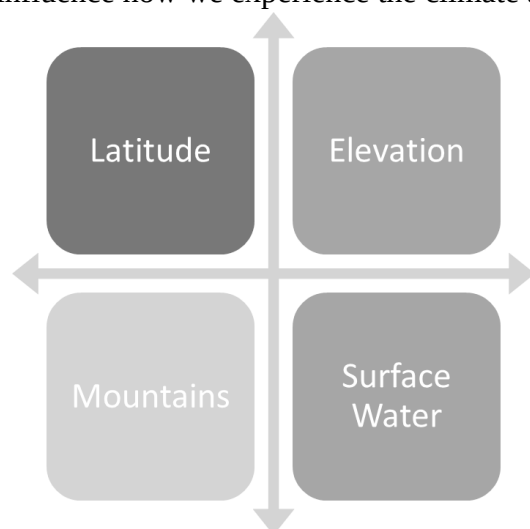


Figure 1. Landscape factors that influence our experience of climate.

The angle at which sunlight strikes the planet is determined by latitude. Latitude causes temperatures to be warmer at the equator and cooler at the poles. As the earth revolves around the sun the angle of the sunlight is altered, which we experience as changes in seasons.

Places where seasons are more extreme are typically the places where people first start to notice climate change. For example, widespread thawing of the discontinuous permafrost in Alaska has caused unexpected damage to costly infrastructure such as homes, buildings, and roads in remote communities.

Elevation has an important influence on local temperatures. Moving up or down 1,000 feet in elevation can decrease or increase temperatures by 1°C (1.8°F). The air temperature has an important influence on weather patterns, which supports local vegetation. Vegetation types have started to respond to climate change by moving in both elevation and latitude. This gives rise to isolated islands of habitat at high or low points on the landscape, which is often described as habitat fragmentation. Migrating birds, such as the common loon (*Gavia immer*), are projected to decline because of changes in elevation-dependent habitats. Migrating loons depend on black spruce wetlands in the northeast, but under climate change, spruce trees are expected to move northwards and wetlands diminish under increased droughty conditions.

Mountains influence how the air moves across the landscape. Water in moist winds that hit the side of a mountain starts to condense around dust particles, and turns into rain as it moves over the mountain. Much of the precipitation is gone by the time the wind reaches the other side of the mountain. This effect is known as a rain shadow and can lead to desert like conditions on the leeward side of mountain ranges. For instance, the Death Valley rain shadow desert is located on the eastern slopes of the Sierra Nevada in California and Nevada. It receives only 2 inches of precipitation annually on average and is also the hottest spot on earth (maximum 134°F). Rain shadows are also common around the Rocky Mountains, Appalachian Mountains, Andes Mountains of South America, and Himalayas of Asia.

Large water bodies, such as oceans and lakes, act as a buffer on local temperatures when seasons change. In the summertime, the air over the sea is generally cooler than the air over land. This can lead to cooler summers in coastal areas. In winter the reverse happens: the air over the sea remains warmer than the air over the land, helping retain heat and leading to warmer winters around coastal areas. The Great Lakes in east-central North America have land breezes and sea breezes that are the result of large temperature differences over the water and land.

Forests and the Carbon Cycle

Living plants, such as grasses and trees, act like a heat sponge absorbing light rays and shading the ground, keeping the soils cool. Cooler air over forests leads to greater condensation and rainfall, which helps maintain water levels in lakes and rivers.

As plants and trees respire, they take carbon dioxide (CO₂) from the air and use it to create carbon-based sugar molecules (e.g., glucose, cellulose, lignin) through the process of photosynthesis. These molecules are used to build the structure of plants, also known as biomass.

When plants die, microbes help plants decompose, which allows the carbon in plants to be released back into the atmosphere. Plants parts that are buried underground, however, are unable to fully decompose and are eventually transformed into oil or coal over many millennia. The carbon in fossilized plants can be stored almost permanently if left undisturbed.

Carbon dioxide in the atmosphere helps absorb infrared radiation from the sun and is often referred to as a greenhouse gas. Greenhouse gases (GHGs) influence global temperatures by acting like a cover or blanket, helping the planet retain heat. Without greenhouse gases, planet Earth would be unable to support life as we know it because the average temperature would be near 0°F. Other primary greenhouse gases in the earth's atmosphere include water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

The exchange of carbon between natural systems and the atmosphere occurs on a cycle that is relatively stable unless there is a shock to the system. Geological activities, such as earthquakes and volcanoes, tend to release large amounts of CO₂ from underground. Likewise, wildfires can result in large numbers of tree deaths and the release of carbon from plants. The more CO₂ in the atmosphere, the greater the warming effect.

Human Factors That Influence Climate

Over the last 40 years, atmospheric carbon has increased by more than 20%, due to human activities. The average global temperature is now 1°C (1.8°F) greater than the average global temperature before the industrial revolution, which started about 200 years ago. In addition to increased CO₂ and other greenhouse gases, widespread changes in land use have altered the distribution of surface vegetation and water bodies. This means that climate changes are sometimes less buffered, leading to greater impacts under warmer conditions.

Population growth is a key driver of land use change. Natural ecosystems, such as forests, are often converted into more intensely managed landscapes (e.g., agriculture) or development (e.g., cities) to support larger numbers of people. The industrial revolution helped accelerate the consumption of natural resources for raw materials. Oil and coal from fossilized animals and plants were extracted at increasing rates to help power the conversion of raw materials into marketable products through industrial activities. Consumers helped drive this production by increasing demand for cheaper goods.

As of now, the United States produces about 15% of global carbon emissions, but the carbon footprint of the average person in the United States exceeds the carbon footprint of most individuals in other countries. The U.S. Environmental Protection Agency (US EPA) recently reported that commercial and residential communities produce about 13% of the country's total emissions primarily from fossil fuels burned for heat, the use of certain products that contain greenhouse gases, and the handling of waste. For the same reasons, U.S. industry is reported to contribute up to 22% of total emissions. Electricity production, through the burning of fossil fuels, is a major producer of emissions (28%), as is transportation (29%).

The agricultural sector has a lesser impact on climate, about 11% of total emissions. Intensive agricultural practices have led to widespread changes in soil health and microbial communities, making it difficult for soil to retain carbon. Irrigation practices and intensive animal production

have also led to increases in other types of greenhouse gases, such as methane, which has a greater warming effect than CO₂.

Forests are generally considered an agricultural land use in the United States. How forests contribute to carbon emissions depends largely on the management of forest carbon stocks. Forests in the United States already offset up to 12% of our carbon emissions due to slowdowns in harvesting. However, changes in land use and deforestation can turn forestlands from a carbon sink into a carbon source.

Closing Thoughts

The natural checks and balances that helped regulate climate before are no longer working in the same way, making it difficult to predict outcomes. A change to one part of the system often leads to other parts changing, sometimes in unexpected ways. For example, the loss of snowpack in the mountains each year may be due to interactions between levels of rainfall and temperature. A rainy year that is warm can result in less snowpack, whereas a cooler year with less rain also results in less snowpack. Either way, less snowpack means less water in local streams and rivers. These droughty conditions can put stress on forests and other natural systems, making them less resilient to a disturbance (e.g., pest outbreak, wildfire).

In another example, widespread deforestation can sometimes lead to desertification because the landscape is no longer able to maintain historic rates of rain or precipitation. Deforestation also leads to higher concentrations of CO₂ in the atmosphere, because fewer trees are taking up CO₂. This feedback effect can accelerate climatic changes. Sometimes the only way to stop the feedback effect is to plant trees using landscaping techniques, such as ditching, that help retain water for longer periods. Small changes to earth's systems and cycles can lead to significant impacts, so changes in a climate no matter how small are always important to consider.

Tips for Teaching

- Use the resources below to create original educational content about climate change that is relevant to your region.

Resources for Teaching

- National
 - Climate Regulation and Change: What Is Causing it? FOCCE article 01-01-2023. <https://extension.psu.edu/climate-regulation-and-change-what-is-causing-it>
 - Yale Climate Opinion Maps 2021. Yale Program on Climate Change Communication. <https://climatecommunication.yale.edu/visualizations-data/ycom-us/>
 - CONUS Climate Console. Climate Projections for the Continental United States <http://www.climateconsole.org/conus>

- Climate Change Tree Atlas and Bird Atlas. USDA Climate Hubs.
<https://www.fs.usda.gov/ccrc/tool/climate-change-bird-atlas>
- ForeCASTS: Forecasts of Climate Associated Shifts in Tree Species. USDA Climate Hubs. <https://www.climatehubs.usda.gov/hubs/southeast/tools/forecasts-forecasts-climate-associated-shifts-tree-species>
- Catalog of all USDA Climate Hub Tools
<https://www.climatehubs.usda.gov/tools/all>
- Climate Literacy and Energy Awareness Network (CLEAN) Educational Resources. USDA Climate Hubs.
<https://www.climatehubs.usda.gov/hubs/tools/climate-literacy-and-energy-awareness-network-clean-educational-resources>
- Southeast—USDA Climate Hubs
 - Southeastern Forests and Climate Change
<https://www.climatehubs.usda.gov/hubs/southeast/tools/southeastern-forests-and-climate-change>
 - Focus on Forestlands in the Southeast
<https://www.climatehubs.usda.gov/hubs/southeast/topic/focus-forestlands-southeast>
 - Salt Water Intrusion and Salinization on Coastal Forests and Farms
<https://www.climatehubs.usda.gov/hubs/southeast/topic/saltwater-intrusion-and-salinization-coastal-forests-and-farms>
 - Pine Forest Landowners Guide—Hurricane Preparation and Recovery in the Southeastern United States
https://www.climatehubs.usda.gov/sites/default/files/Pine%20Forest%20Landowners%20Guide%20SE_0.pdf
 - Emerging Forest Threats—State Fact Sheets (Southeast)
<https://www.climatehubs.usda.gov/hubs/topic/emerging-forest-threats-state-fact-sheets>
- Northeast—USDA Climate Hubs
 - Shifts in Growing Degree Days, Plant Hardiness Zones, and Heat Zones (Northern Forests) <https://www.climatehubs.usda.gov/hubs/northern-forests/topic/shifts-growing-degree-days-plant-hardiness-zones-and-heat-zones>
 - Climate Warming Brings Earlier Spring
<https://www.climatehubs.usda.gov/hubs/northeast/topic/climate-warming-brings-earlier-spring>
 - Insects Change the Story
<https://www.climatehubs.usda.gov/hubs/northeast/topic/insects-change-story>
 - Extreme and Persistent Rains and Flooding in the Midwest—Can It Happen across the Northeast?
<https://www.climatehubs.usda.gov/hubs/northeast/news/extreme-and-persistent-rains-and-flooding>

- 2021–22 Winter Outlook for the Northeast <https://www.climatehubs.usda.gov/hubs/northeast/news/2021-22-winter-outlook-northeast>

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Chapter 2: The Potential of Private Forestlands for Addressing Climate Change

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Up to 70% of forests in the United States are in private ownership. Investors and government agencies are looking for ways to leverage private forests to mitigate climate change. While carbon offsets and markets are a main topic of discussion in this guidebook, it is not our intention to suggest that offsets should be the primary way of dealing with climate change. Forests are a limited resource and provide many other important goods and services. This section provides a broad overview of private forestlands and carbon markets so that readers gain a better sense of how carbon management may become part of private forestry.

Learning Outcomes for This Section

- Timber and carbon stocks in United States
- The “value” of forest carbon
- Implications for the forest economy

Private Forests and Change

Over the last century the total amount of forests in the United States has remained about the same, but the size of forested properties has been shrinking and the number of nonindustrial forest owners has increased. In short, more people own forests than ever before. Timber harvesting on these lands has also slowed down due to cultural shifts in forest management and economy-of-scale issues for smaller properties. Helping make forest ownership financially feasible for nonindustrial forest owners is an important strategy for managing carbon stocks and protecting other forest ecosystem services.

Carbon Values Are a Function of Rate and Risk

How society values the climate regulation services provided by forests depends on the “rate” at which carbon is removed and the “risk” that carbon will be released. The rate at which trees grow and how long they live often depends on local environmental conditions, tree species, and forest management. However, under the same conditions, different tree species sequester or take up carbon at different rates. Pine tree species (e.g., red pine (*Pinus resinosa*), short-leaf pine (*Pinus echinate*), and loblolly pine (*Pinus taeda*)) tend to grow at a faster rate, but have shorter life spans compared to most hardwood tree species (e.g., northern red oak (*Quercus rubra*), water hickory (*Carya aquatica*), and sugar maple (*Acer saccharum*)). Stand density, or change in the amount of live woody biomass per acre over time, is the basis for how most carbon sequestration rates are calculated.

Forests can store large amounts of carbon in the trees and soils for long periods of time. This carbon is unable to become a greenhouse gas unless it is released, either through decomposition or combustion. Risk of carbon release is the likelihood that a forest will stop serving as a carbon sink and become a carbon source. Forestland conversion to other uses (e.g., development) often causes the land to become a permanent carbon source. Forests that are harvested can sometimes operate as a carbon source until new trees are grown to replace the trees that were removed.

Invasive species, disease, and wildfire increase the risk that many trees will die, and the forest operates as a carbon source until it recovers.

The goal of a nature-based carbon offset project is to use forest management to enhance the likelihood of carbon gains over carbon losses over time. Paying forest owners to delay harvest is the strategy most often used today to enhance carbon gains. Reforestation is also a strategy used globally to combat climate change, but the amount of land available for cost-effective reforestation in the United States is limited. It is critical that the United States protect forest health under climate change. Hazards such as drought, disease, extreme storms, and wildfire are expected to increase under climate change, and a greater number of tree deaths can cause forests to become a carbon source.

Most family forests are managed passively, either due to financial constraints or the incorrect belief that the forest can take care of itself. For example, a survey by the National Woodland Owners Association found that only 11% of family forest owners have a forest management plan. Programs that support active forest management and planning can help mitigate the impact of these hazards and protect forest carbon stocks on private lands.

If the carbon does leave the forest in the form of wood products, climate benefits are still provided. Wood products in use (e.g., construction, furnishings, and flooring) hold onto carbon and displace the use of other materials that are more fossil fuel-intensive (e.g., steel, concrete, and glass). Cradle-to-grave carbon accounting methods are often used to track total carbon inputs and outputs associated with wood products over time, but the analysis can get complicated as products have different lifespans and require various amounts of transport and energy to create. Unfortunately, the climate benefits provided by forest products are rarely included in carbon offset projects. Information about the climate benefits provided by wood products is discussed in future chapters.

Carbon and Timber Stocks in the United States

The U.S. Forest Service maintains a census of all forests in the United States. The data collected, using remote sensing and field data collection methods, describe key forest features, such as location, tree species composition, and tree density. These data are available to the public through the Forest Inventory Analysis (FIA) website and are often used by state agencies and other organizations to help inform planning and investment decisions about forests.

On average, private forests in the United States contain about 22 metric tons of carbon per acre in aboveground live biomass (i.e., trees and living ground cover). Forests in the eastern states and some western states contain the most carbon. These forests have carbon stocks up to 33 metric tons per acre and can sequester over 1 ton of carbon per acre per year (Table 1).

Currently, more wood is grown than lost through mortality or harvesting in the United States. A recent census found 90% of U.S. forestland has reached a biologically relevant threshold of stand density, or maximum number of trees per acre. In parts of the southern United States the growth-to-drain ratio for pine tree species is greater than 2, meaning that for every tree that is harvested two more are grown to replace it. Working forests are an important source of sustainable wood products. Up to 80% of U.S. domestic timber supply comes from private lands. Timber

production in the United States accounts for approximately 4% of total gross domestic product (\$200 billion). However, up to 12% of U.S. greenhouse gas emissions have been offset each year due to voluntary or unintentional slowdowns in harvesting on public and private lands. Experts estimate that U.S. forests could help offset another 10% of U.S. emissions.

Table 1. Average values for carbon and emissions reductions on private forestlands per state in the United States.¹

State	(A) Average amount of carbon in above ground living biomass on private lands (metric tons/acre)	(B) Average amount of CO ₂ emissions avoided by preventing forest loss (metric tons/ acre)	(C) Average rate of carbon sequestered in living biomass on private lands (metric tons/acre/ year)	(D) Average rate of CO ₂ emissions offset each year due to forest growth (metric tons/acre/y ear).	(E) Average social value of preventing forest loss (\$/acre) at price \$51/metric ton CO ₂	(F) Average value of delaying harvest (\$/acre/year) using voluntary market prices \$8.00/metric ton CO ₂	(G) Average social value of delaying harvest (\$/acre/ year) at price \$51/metric ton CO ₂
AK	20.34	74.59	0.41	1.49	\$3,804.12	\$11.92	\$75.99
AL	22.87	83.85	0.76	2.79	\$4,276.24	\$22.32	\$142.29
AR	22.18	81.31	0.74	2.71	\$4,146.93	\$21.68	\$138.21
AZ	7.01	25.71	0.14	0.51	\$1,311.35	\$4.08	\$26.01
CA	29.84	109.42	0.6	2.19	\$5,580.67	\$17.52	\$111.69
CO	9.66	35.42	0.19	0.71	\$1,806.19	\$5.68	\$36.21
CT	38.15	139.9	0.76	2.8	\$7,135.01	\$22.40	\$142.80
DE	35.93	131.73	0.72	2.63	\$6,718.20	\$21.04	\$134.13
FL	18.35	67.29	0.61	2.24	\$3,431.59	\$17.92	\$114.24

¹ Methods and data sources for Table 1.

(A) Data describing the average amount of carbon in above ground living biomass on private lands in each state was collected from the USDA Forest Inventory Analysis Database.

(B) The average amount of CO₂ emissions avoided by preventing forest carbon loss on one acre of private lands was calculated by multiplying the values in column A with 3.6667.

(C) The average rate of carbon sequestered per acre per year was calculated by divided the values in Column A with the average stand age of forests within the state. All states were assigned an average stand age of 50 years, except the southeastern region where states were assigned average stand age of 30 years. Data for average stand ages was collected from Pan et al., 2011.

(D) The average rate of CO₂ emissions offset on one acre each year (due to forest growth) was calculated by multiplying the values in column C with 3.6667.

(E) The average social value of preventing forest loss on one acre was calculated by multiplying the values in Column B with the estimated social value or the value of preventing one more ton of CO₂ emissions from entering the atmosphere (\$51/metric ton CO₂). Data describing the social value of carbon emissions abatement collected from Bloomberg Law News (November 2022).

(F) The average value of carbon sequestered by delaying harvest for one year on one acre, was calculated by multiplying values in column D with the current price on the voluntary market (\$8.00/metric ton CO₂).

(G) The average social value of carbon sequestered by delaying harvest for one year on one acre was calculated by multiplying values in column D with the social value of avoiding one more ton of CO₂ emissions (\$51.00/metric ton CO₂).

GA	22.98	84.26	0.77	2.81	\$4,297.39	\$22.48	\$143.31
IA	21.51	78.87	0.43	1.58	\$4,022.28	\$12.64	\$80.58
ID	16.46	60.35	0.33	1.21	\$3,077.77	\$9.68	\$61.71
IL	25.66	94.1	0.51	1.88	\$4,799.02	\$15.04	\$95.88
IN	28.83	105.69	0.58	2.11	\$5,390.38	\$16.88	\$107.61
KS	18.19	66.7	0.36	1.33	\$3,401.54	\$10.64	\$67.83
KY	27.49	100.81	0.92	3.36	\$5,141.41	\$26.88	\$171.36
LA	21.91	80.35	0.73	2.68	\$4,098.03	\$21.44	\$136.68
MA	39.07	143.25	1.3	4.78	\$7,305.89	\$38.24	\$243.78
MD	38.79	142.23	0.78	2.84	\$7,253.87	\$22.72	\$144.84
ME	19.81	72.63	0.4	1.45	\$3,703.94	\$11.60	\$73.95
MI	21.89	80.27	0.44	1.61	\$4,093.64	\$12.88	\$82.11
MN	16.51	60.55	0.33	1.21	\$3,087.90	\$9.68	\$61.71
MO	21.35	78.27	0.43	1.57	\$3,991.57	\$12.56	\$80.07
MS	25.17	92.3	0.84	3.08	\$4,707.24	\$24.64	\$157.08
MT	8.88	32.55	0.18	0.65	\$1,659.81	\$5.20	\$33.15
NC	28.17	103.29	0.94	3.44	\$5,267.97	\$27.52	\$175.44
ND	13.35	48.95	0.27	0.98	\$2,496.53	\$7.84	\$49.98
NE	15.57	57.1	0.31	1.14	\$2,912.12	\$9.12	\$58.14
NH	30.74	112.71	0.61	2.25	\$5,748.28	\$18.00	\$114.75
NJ	31.83	116.71	0.64	2.33	\$5,951.98	\$18.64	\$118.83
NM	5.25	19.27	0.11	0.39	\$982.56	\$3.12	\$19.89
NV	4.74	17.37	0.09	0.35	\$885.85	\$2.80	\$17.85
NY	30.53	111.96	0.61	2.24	\$5,709.89	\$17.92	\$114.24
OH	30.15	110.57	0.6	2.21	\$5,638.83	\$17.68	\$112.71
OK	11.56	42.37	0.23	0.85	\$2,161.05	\$6.80	\$43.35
OR	24.67	90.44	0.49	1.81	\$4,612.45	\$14.48	\$92.31
PA	32.22	118.12	0.64	2.36	\$6,024.33	\$18.88	\$120.36
RI	35.12	128.77	0.7	2.58	\$6,567.07	\$20.64	\$131.58
SC	23.97	87.88	0.8	2.93	\$4,481.85	\$23.44	\$149.43
SD	11.19	41.04	0.22	0.82	\$2,093.22	\$6.56	\$41.82
TN	28.74	105.38	0.96	3.51	\$5,374.30	\$28.08	\$179.01
TX	6.59	24.17	0.13	0.48	\$1,232.75	\$3.84	\$24.48
UT	7.82	28.66	0.16	0.57	\$1,461.42	\$4.56	\$29.07
VA	31.56	115.71	1.05	3.86	\$5,901.12	\$30.88	\$196.86
VT	31.82	116.66	0.64	2.33	\$5,949.55	\$18.64	\$118.83
WA	27.93	102.41	0.56	2.05	\$5,222.81	\$16.40	\$104.55
WI	20.36	74.64	0.41	1.49	\$3,806.74	\$11.92	\$75.99
WV	34.47	126.37	1.15	4.21	\$6,445.05	\$33.68	\$214.71
WY	8.13	29.83	0.16	0.6	\$1,521.09	\$4.80	\$30.60
Average	22.56	82.71	0.55	2.00	\$4,218.18	\$16.00	\$102.00

The Market Price of Forest Carbon

Corporations and individuals interested in reducing their carbon footprint tend to prefer nature-based carbon offset projects. This has created opportunities for family forest owners to become involved in the carbon economy. More specifically, instead of changing their behavior to reduce carbon emissions, buyers are looking to pay someone else (i.e., landowners) to change their behavior, from a business-as-usual forest management plan to a climate-smart plan (Figure 2). The emission reduction benefits that come from the landowner changing plans are then credited to the buyer.

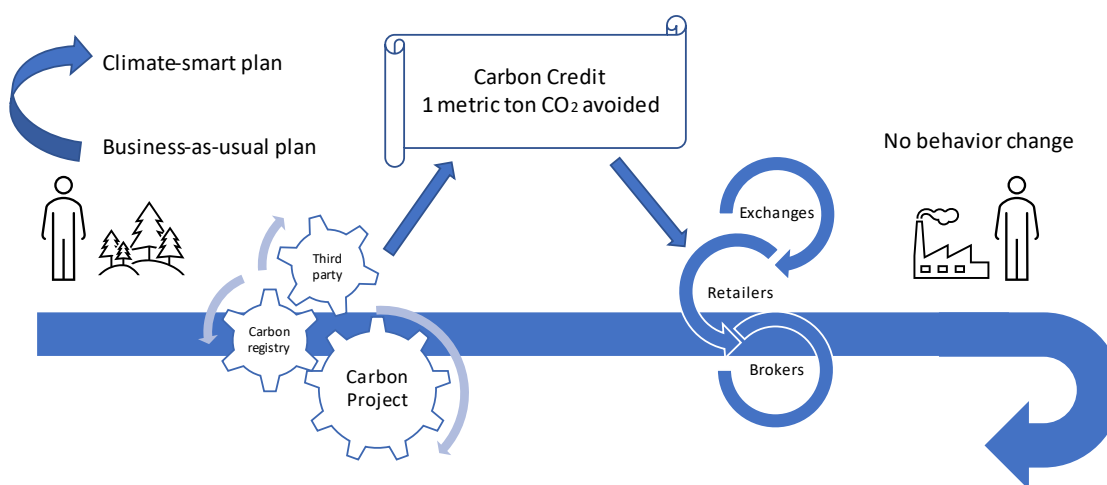


Figure 2. Life cycle of a carbon offset project.

To help make this trade possible a growing number of carbon project developers have emerged with a variety of business plans for quantifying and trading carbon credits. The standards that must be met for developing a legitimate carbon credit include the idea of additionality (i.e., emissions reductions should come from a real change in behavior), permanence (i.e., a guarantee that carbon emissions reduction benefits are long-term) and nonleakage (i.e., carbon offset projects do not have unforeseen impacts on carbon emissions and forests outside the project area). Standards for carbon projects will be discussed more in future chapters.

Standard-setting bodies and carbon registries provide the rules for managing and measuring forest carbon and verifying carbon emission reductions. The registries also track the generation and sale of carbon credits from projects that use their protocols. Once carbon reductions are verified and the landowner is paid, a carbon credit is generated by the project developer and distributed to buyers through a series of brokers and exchanges. Carbon markets use the nomenclature CO₂e to describe the market value associated with a metric ton of carbon dioxide and/or equivalent greenhouse gases, since some emissions contain multiple types of greenhouse gases. One carbon credit represents 1 metric ton of CO₂e emissions avoided or reduced for at least 100 years. Feeding the demand for carbon offsets is an increasing number of corporations looking to buy carbon credits in order to raise their environmental, social, and corporate

governance (ESG) ratings. Learn more about the economic actors and carbon markets in the key words list at the end of this chapter.

The voluntary carbon offset market is where most forestland offsets are currently sold. In 2022, sales for nature-based carbon offset projects ranged from \$3 to \$7 per metric ton of CO₂e. The California-Quebec Carbon Market is a compliance market in the US that trades nature-based offsets. This market had CO₂e sales approaching \$28 per metric ton in November 2021, but the projects sold on this market don't typically involve family forest owners. The wide range in market prices, as seen on news sources, are due to variation in the types of assurances associated with the project and the procedures used to manage and verify carbon gains.

How much compensation is directed to forest owners is largely a function of how much CO₂ emissions are offset by their forest. Forest carbon exists as a sugar molecule (e.g., cellulose, lignin) until disturbed by decomposition or combustion. When oxygen is added, the carbon transforms into CO₂, which is a common greenhouse gas. Using chemical calculations, 1 unit of forest carbon stored helps avoid 3.6667 units of CO₂ being emitted into the atmosphere.

Using this ratio, preventing forest loss on 1 acre of private land in the United States helps avoid the release of 83 metric tons of CO₂ emissions, on average (Table 1). In the eastern United States, up to 150 metric tons of CO₂ emissions can be avoided by preventing the loss of 1 acre of forestland. Delaying harvest for 1 year on 1 acre of forestland helps avoid the release of almost 2 metric tons of CO₂ emissions, on average. Forests in the southeastern United States are especially efficient. Up to 4.78 metric tons of CO₂ emissions can be avoided by delaying harvest on 1 acre of forestland for 1 year.

Using current carbon market prices and FIA data, one can estimate an average market value for emissions reduction services provided by private forest land per acre per state (Table 1). On the voluntary market, the average value of delaying harvest on private forest land for 1 year is \$16.00 per acre, but it can be as high as \$30 per acre in some southeastern states. The dollar values reported in Table 1 does not necessarily reflect what the landowner may be paid, because (1) project developers tend to target properties with higher rates of carbon storage, and (2) the project developer, registries, and other collaborators collect a commission for arranging transactions with buyers. Compensation for forest owners is also based on the type of commitment made by the forest owners. Longer contracts (e.g., 100+ years) tend to provide better assurances of permanent carbon storage, so payments to forest owners may be higher. However, many family forest owners prefer short contracts because over half of people in the United States own their forests for less than 24 years.

Today, carbon revenues per acre (about \$8–\$10 per acre per year). are generally less than the per-acre revenues that come from alternative forestland uses, such as agriculture, development, and timber harvesting. However, depending on the type of carbon management and how the cost-benefit analysis is set up, owners can benefit from receiving carbon incentives. For example, owners looking to secure some income from their forests may want to stack income streams from compatible management objectives. Other owners may see climate-smart forestry as part of being a good climate steward and are less concerned about maximizing income (e.g., willing to

accept a cost-share). Finally, some owners may prefer the idea of receiving a regular carbon payment, compared to the complicated task of arranging a one-time harvest. Either way, it is important that owners have a financial analysis performed before acting, to help avoid unforeseen risks or costs.

The Social Value of Forest Carbon

Public investment in climate-smart land uses has increased dramatically, as part of a broader agenda by state and federal agencies. In 2021, over \$3 billion in federal funds was allocated to the U.S. Department of Agriculture (USDA) to help jump-start the production of climate-smart commodities in agriculture. Other recent federal actions (i.e., Inflation Reduction Act of 2022) are directing millions of dollars to state programs that support climate-smart forestry practices on private lands.

The economic justification for allocating public dollars to climate change mitigation programs is based on the expected “social cost” of not mitigating climate change. This value represents the expected impacts to the economy and human health and well-being from extreme changes in environmental conditions due to climate change. In 2022, the Biden administration set the social cost of allowing one more ton of CO₂ and similar greenhouse gases to enter the atmosphere at \$51. However, scholars at Resources for the Future estimate that the social cost of carbon could be set as high as \$185 per metric ton of CO₂.

Using FIA data and the price of \$51 per metric ton of CO₂, the average social value of preventing forest loss on 1 acre of private land in the United States is \$4,158 per acre (max \$7,305; min \$885). The average social value of delaying harvest on private lands for 1 year is about \$100 per acre (Table 1). Currently, the market price of forest carbon is far less than the estimated social value of avoiding carbon emissions.

Closing Thoughts

Harvesting on private lands will likely slow down further if the market value of carbon credits from delay-in-harvest projects approaches the estimated social value of carbon. Related research has found potentially 2.5 million acres of merchantable pine forests could be set aside if the price of CO₂ reaches \$55 per metric ton. This has important implications for the U.S. timber economy and other nations that may use their forests to help meet U.S. demand for wood. If not managed properly, delayed harvests may have unexpected impacts on forest health by pushing biological limits for stand density and increasing risk of wildfire and disease.

To put the limited scale of our forest resources in perspective, consider this. The average person in the United States needs about 8–10 acres of forest to offset their personal emissions each year (i.e., 16–20 metric tons CO₂ per year). However, if an equal portion of US forests (818 million acres total) was allocated to everyone in the population (331.9 million), the average amount of forests per person is only 2.46 acres. Even if harvesting was prohibited on all forest land, there are still not enough forests in the United States to offset the carbon emissions of U.S. residents.

The pathway forward for people and forests is to (1) continue looking for ways to lower our carbon footprint through behavior change, and (2) expand strategies for carbon offset projects that help support the broader forest economy. New types of wood products (e.g., biochar,

bioenergy, and cross-laminated timber), carbon offset protocols, and forest landowner assistance programs will be key for managing carbon on private forest land. Designing regional solutions based on forest conditions and landowner needs will also be important for sustaining climate change solutions into the future. To learn more about climate-smart forestry check out the links and references below.

Tips for Teaching

- Learners need to understand that the carbon economy is still evolving, so what may be true today could change tomorrow. Encourage learners to do their own investigation and talk to their peers about what they find.

Resources for Teaching

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Chapter 3: Forest Carbon Project Development and Credit Generation

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Learning Outcomes for This Section

- Defining credits and offsets
- Forest carbon project methodologies and activities
- Project development

Forest Carbon and Offset Projects

A carbon offset project is the process by which carbon credits are generated and that process is defined by the people, place, and protocols involved. To generate credits from a forest-based project, additional carbon is sequestered and stored on forestland and measured using set protocols. Forest carbon projects should use carbon measurement protocols or methodologies that are approved by standard-setting bodies, also referred to as carbon offset registries. Project developers are required to seek methodological certification from one of these organizations. In the United States, the bodies with the greatest market share (i.e., the most carbon offset projects) are the Verified Carbon Standard (VCS), the Gold Standard, Climate Action Reserve, and the American Carbon Registry (ACR). Standard-setting bodies seek to ensure transparency, quality, and integrity of carbon credits.

There are four types of forest carbon projects that meet established standards: afforestation, reforestation, avoided conversion, and improved forest management. Harvested wood products are typically not associated with forest-based offset projects, except in rare cases. Table 1. provides descriptions of the major types of forest offset activities used today.

Table 1. Forest offset activities in the United States before 2023.

Activity	Description	Percentage of total in U.S. (%)
Afforestation and reforestation	Establishing forest on land not previously forested (or not forested within the previous 50 years), and restoring tree cover on lands that are not at optimal stocking levels (e.g., postharvest or following other forest disturbances).	8
Avoided conversion	Preventing the conversion of forestland to nonforested land	4

	(must have demonstrably high likelihood of forest stand and carbon loss).	
	IFM describes activities that maintain or increase forest resilience and carbon stocks (e.g., management of pests or invasive species, stand irrigation or fertilization, and extending harvest rotations or forgoing intensive harvesting). Due to variations in baseline forest management as well as key threats to forest health by geographic area and landowner type, different regions and project developers focus on different aspects of approved IFM activities.	
improved forest management (IFM)		88

Additionality and Credit Generation

Key to carbon offset credit generation is the concept of **additionality**. In forest carbon projects, additionality is typically a measure of additional carbon sequestered and stored on forested land. Additionality has to be quantified relative to a baseline condition in order to understand that the carbon storage was **additional** to what would have otherwise occurred under a business-as-usual scenario. The difference in carbon stored over time between a **baseline** scenario and a scenario where project activities increase stored carbon is referred to as the **carbon benefit**. Carbon benefit can come from increasing forest carbon sequestration and storage or by avoiding GHG emissions. For instance, a project developer can measure how newly planted trees in a reforestation project will generate a carbon benefit over time by subtracting the GHG emissions from the planting activities from the carbon sequestered due to new tree growth over time. This benefit is considered additional because it can be measured against a baseline scenario in which no new trees were planted. In carbon trading schemes, additionality created by carbon project activities provides the potential to generate marketable forest carbon credits.

What Does a Carbon Credit Represent?

Credits are measured and sold in metric tons of CO₂. Each credit represents one metric ton of CO₂, or its equivalent in other greenhouse gases (written as "tCO₂e"), that has been removed from the atmosphere or avoided (for at least 100 years) due to a change in behavior. Other GHGs include methane, nitrous oxide, and fluorinated gases. Because 1 tCO₂e stored or avoided is equivalent to 1 carbon credit, which can be used to offset 1 tCO₂e in emissions, the terms "credit" and "offset" are often used interchangeably.

One tCO₂e represents the global warming potential (GWP), or atmospheric impact, of GHGs in terms of the amount of CO₂ that would lead to an equivalent degree of global warming over a

certain period. For instance, over a period of 100 years, methane would have a GWP that is 25 times more impactful than an equivalent amount of CO₂, while nitrous oxide would have a GWP that is 298 times more powerful. Therefore, a metric ton of methane removed from the atmosphere would be equivalent to 25 tCO₂e, and a tonne of nitrous oxide removed would be equivalent to 298 tCO₂e. In terms of carbon dioxide, 1 tCO₂e simply equals 1 tonne of CO₂. See the Greenhouse Gas Protocol for [global warming potential values](#) for the tCO₂e equivalencies of other GHGs. This standardization facilitates comparison as well as assessment of collective GHG impacts. Although CO₂ has the lowest global warming potential (GWP) of all GHGs, it represents the dominant GHG emitted—79% of total emissions in the U.S. are attributed to CO₂.

Project Development

Project development follows a multistep process. The first step revolves around assessing project feasibility. To satisfy feasibility, a landowner must be deemed **eligible** based on legal constraints and decision-making power. If landowners have already involved their property in a conservation easement or cost-sharing program, they may not be eligible to participate in additional projects.

Second, an initial inventory of carbon stocks will also be conducted. Project developers must follow all required guidance to quantify projected net GHG reductions and removals in a "business-as-usual" scenario. This determines the project **baseline**, against which **additionality** is measured. Considerations to ensure **permanence** are required—prior to the project, developers must measure and calculate projected GHG reductions for the first reporting period, assess risk for carbon loss, and create a plan for future project monitoring.

Next, **monitoring and reporting** entities measure the GHG reductions during the reporting period and develop a plan for monitoring emissions reductions in the future. This monitoring and reporting plan will be reviewed and **verified** by a third party. Finally, the registry will complete a review of the verification results and will **issue credits** upon approval. Other entities seeking to offset their emissions can then purchase these credits. Protocols set by standard-setting bodies provide the transparency, guidance, and quality control required for development of verified forest carbon credits.

As part of the credit-generation process, all projects undergo **third-party verification** to determine the appropriate quantity of carbon credits generated. This determination considers additional carbon accrued while also setting aside necessary **carbon buffer pools**, which hold a certain percentage of carbon credits aside as insurance against possible future carbon losses due to unavoidable events (such as wildfire, pest, or disease disturbance) and avoidable events (such as additional harvest). The determined credits are then made available via registries that serve as publicly available platforms for reporting and tracking project documents, credits, ownership, sale, and retirement. Registries provide transparency and so increased trust for all parties involved in carbon trading schemes.

The project development process is a multistep endeavor that must meet standards to ensure forest management actions result in additionality, permanence, proper monitoring, reporting, and

verification. Once project credits are registered, they can be used by a variety of actors within carbon markets.

Summary

Forest carbon projects that reduce the amount of GHG in the atmosphere, either by increasing forest carbon sequestration or by avoiding emissions, may produce carbon credits tradable in carbon offset markets. These credits are measured using a standardized unit of 1 metric ton of CO₂ or its equivalent in other GHG. Activities such as afforestation, reforestation, avoided conversion, and improved forest management are the primary project types with methodologies approved by standard-setting bodies. Project developers are required to adhere to established guidelines and methodologies that ensure that any carbon credits generated represent additional and permanent carbon stored or sequestered—over and above what would occur in a business-as-usual scenario, or baseline. These project guidelines also establish landowner eligibility; ensure that buffer pools are set aside to protect against potential future carbon losses; and require monitoring, reporting, and verification. Because eligibility requirements can present a common obstacle for many landowners, some programs have taken steps to reduce high up-front costs and make forest carbon projects more accessible.

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Chapter 4: Compliance and Voluntary Market Structures

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Learning Outcomes for This Section

- Comparing compliance markets and the voluntary market
- Factors that affect supply and demand for carbon credits

Credits generated from forest carbon projects can be sold to either compliance or voluntary carbon markets, depending on the methodology and standard used for the project. Key aspects of each of these carbon market structures are discussed in this paper, including the motivation for credit transactions, dynamics of supply and demand, and differences across the market schemes in terms of commitments, requirements, development, verification, and market size.

Compliance Markets

Compliance markets are created and regulated by mandatory national, regional, or international carbon reduction programs. Generally referred to as cap-and-trade markets or emission trading systems (ETS), these are markets in which actors, generally businesses within capped sectors, are required to emit no more than their set GHG emissions cap. Any emissions above that cap must be offset by a reduction in emissions elsewhere, with such transactions occurring within the compliance market. Emissions allowances are typically lowered over time such that, in theory, this mechanism will reduce overall emissions from a given sector over a set timeframe. Individual businesses make decisions about when and how to invest in new technology or participate in other advancements to reduce emissions, recognizing that the costs of continuing to emit will increase over time as the cap lowers.



Figure 4 shows a depiction of a compliance, or cap-and-trade, market. In this example, Business A has produced emissions that exceed its emissions cap. In contrast, Business B has emitted fewer GHGs than its set cap and, as such, is in possession of excess allowances. Business A has two choices: either buy the excess allowances from Business B or offset their excess emissions by purchasing credits generated by projects storing or sequestering additional carbon, such as an approved forest carbon project.

Figure 4. Compliance carbon market.

For example, if a power plant is required to keep emissions below 2 million metric tons of CO₂e annually but emits 2.5 million metric tons each year, the plant will need to purchase 0.5 million credits to offset the excess emissions. The terms “credit” and “offset” are often used interchangeably because they refer to the same unit. One metric ton of CO₂e stored or avoided for 100 years is equivalent to 1 carbon credit and can be used to offset 1 metric ton of CO₂e. Note that most compliance markets limit the percentage of allowable emissions that may be offset with carbon projects in addition to having rules limiting the types and locations of allowable projects. As an example, under the California Cap-and-Trade Program, regulated entities are currently permitted to offset only 4% of their emissions in order to meet overall compliance, and 50% of those offset credits must come from projects that directly benefit California.

Voluntary Markets

Like compliance markets, the voluntary carbon market (VCM) aims to facilitate overall emissions reductions. Here, too, actors seek to keep emissions at or below a specific target level, though it is not regulated that they do so. Often these are sustainability targets agreed upon by companies or groups of companies representing specific industries. Because participation is voluntary and unregulated, voluntary markets do not have viable enforcement mechanisms to ensure that actors comply with their expressed targets. An entity that emits more than their target has two choices: it can either offset emissions elsewhere and remain in compliance with their self-enforced target, or it can become noncompliant (Figure 5). In the absence of enforceable penalties, VCMs are driven by a variety of factors such as considerations around corporate social responsibility, ethics, and reputational or supply chain risk.

Supply and Demand of Forest Carbon Credits

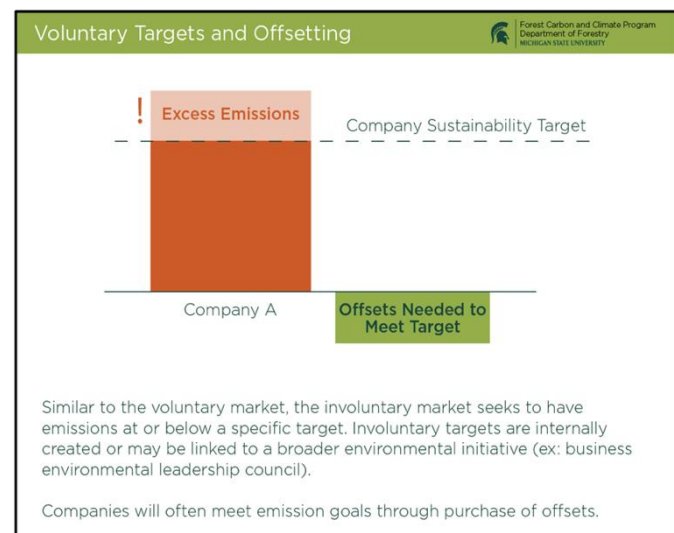


Figure 5. Voluntary carbon market.

Key actors involved in the supply and demand of forest carbon credits in compliance and voluntary carbon markets are shown in Table 3. Forest landowners and managers who voluntarily engage in forest management activities (as part of a forest carbon project) are the primary suppliers of carbon credits in both voluntary and compliance markets, alongside project developers and credit brokers, who are involved in the issuance and transfer of credits.

However, the demand side of the two market types is fueled by different actors and actor motivations. Under a compliance market, demand for carbon credits comes directly from businesses in emissions-capped sectors that have emitted more than their determined allowance. Government action can impact the strength of that demand by adjusting the terms of the compliance regime through actions such as manipulating or mandating carbon credit prices, increasing or decreasing corporate emissions allowances, and determining which industries are required to cap emissions.

In the voluntary market, demand can come from a variety of actor types including businesses, nonprofits, governments, and individuals. Demand may shift in response to market prices and motivational changes such as organizational climate commitments and personal interest.

Table 3. Actors impacting the supply and demand of forest carbon credits in compliance and voluntary markets.

Market	Demand	Supply
Compliance	Direct demand comes from businesses in emissions-capped sectors that have emitted more than their <i>allowed amount</i> . Demand is impacted by government actions affecting carbon credit price, emissions targets (how difficult they are to achieve), and which industries are included in the scheme.	• Forest landowners and managers engaging in voluntary forest management activities • Project developers • Credit brokers and exchanges
Voluntary	Demand comes from businesses, nonprofits, and individuals <i>voluntarily</i> looking to curb net emissions, motivated by ethical, reputational, or supply chain considerations.	• Forest landowners and managers engaging in voluntary forest management activities • Project developers • Credit brokers and exchanges

Although voluntary markets are growing rapidly (nearly quadrupling between 2020 and 2021), the demand from voluntary markets is still dwarfed by that of compliance markets. In 2020, demand from across the 30 compliance markets operating around the world represented US\$851

billion (15,811 mtCO₂e), while demand from voluntary markets in 2021 was US\$1.985 billion (493 mtCO₂e). Notably, the European Union's Emissions Trading System (EU ETS), which does not allow forest carbon offset projects, accounted for 90% of the global value of compliance credits in 2021. In voluntary markets, 46% of credits supplied in 2021 came from forestry and land use projects, with 65% of those credits coming from REDD+ projects. 'REDD' stands for 'Reducing emissions from deforestation and forest degradation in developing countries. The '+' stands for additional forest-related activities that protect the climate, namely sustainable management of forests and the conservation and enhancement of forest carbon stocks.

Comparing Attributes of Compliance and Voluntary Markets

Beyond the supply-demand divide, other differences exist between compliance and voluntary markets. These differences are associated with external standards set by certifying bodies—standards that project developers must comply with to generate credits appropriate to the type of market they are supplying. However, many attributes are shared between compliance and voluntary markets. Table 4 lists a series of market attributes for easy comparison.

Beyond the fundamental difference of mandatory versus voluntary enrollment, the biggest differences between the two markets are found in the project commitment parameters. For credits traded in compliance markets, projects must commit to a 100-year or longer contract with varied acreage requirements, whereas in voluntary markets projects can span a much shorter time period of contracts ranging from 1 to 40 years and project acreage is generally small, under 40 acres.

Many attributes are shared across compliance and voluntary markets, such as project requirements concerning additionality, permanence, and leakage; the basic developmental stages projects must go through (feasibility analysis, carbon inventorying, verification, registration, and monitoring); and the need for third-party verification processes.

Forest landowners with smaller parcel sizes may find voluntary carbon markets more accessible, especially if they are able to enroll in programs that reduce the burden of up-front costs associated with determining feasibility and other developmental stages of a carbon project such as inventorying, verification, registration, and monitoring.

Table 4. Attributes of compliance and voluntary markets.

Attribute	Compliance	Voluntary
Enrollment	Mandatory according to regulations	Voluntary by interested parties

Commitments	Initial ~100+ year contract (generally can renew for shorter period); acreage requirement varies by project developer	1–40+ year contracts; 1–40+ acres, depending on approved project methodology
Requirements	Real, additionality, permanence, nonleakage	Real, additionality, permanence, nonleakage
Development stages	Feasibility analysis, carbon inventorying, verification, registration, monitoring	Feasibility analysis, carbon inventorying, verification, registration, monitoring
Verification process	Third-party audit, periodic ground-truthing	Third-party audit, verification process varies
Market size (2021)	US\$851 billion (15,811 mtCO ₂ e)	US\$1.985 billion (493 mtCO ₂ e)

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Part 2: Managing Forest Carbon

Chapter 5: Climate-Smart Forestry: What Is It?

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Forest management practices influence the rate of carbon losses and gains over time. Practices that help promote carbon gains are considered an important part of climate-smart forestry.

Learning Outcomes for This Section

- Approaches used in climate-smart forestry
- Definitions for additional carbon storage and improved forest management

Carbon sequestration is the process where trees take carbon dioxide from the atmosphere and store it in the form of woody biomass. The carbon stored in woody biomass is only temporarily locked up. Most trees have life spans of less than 100 years, either because the species is short lived or due to forest management. Carbon is gained and lost on a regular cycle, as trees grow, die, decompose and grow back again. Because of this, carbon accounting in a forest is often the quantification of total carbon "gains versus losses" within the project area over time.

Forest management practices influence the rate of carbon losses and gains over time. Practices that help promote carbon gains are considered an important part of climate-smart forestry. Climate smart forestry also involves practices that help forests adapt to climate change, but these practices are not discussed at length in this article. The four strategies described in Figure 6 can all be used to provide additional carbon storage and offset carbon emissions. These include creating new forests, protecting forest health, improved forest management for carbon and production of climate-smart wood products. Most market payments to forest owners (over 80%) are associated with improved forest management practices, but many of the activities in Figure 6 can also be implemented voluntarily.

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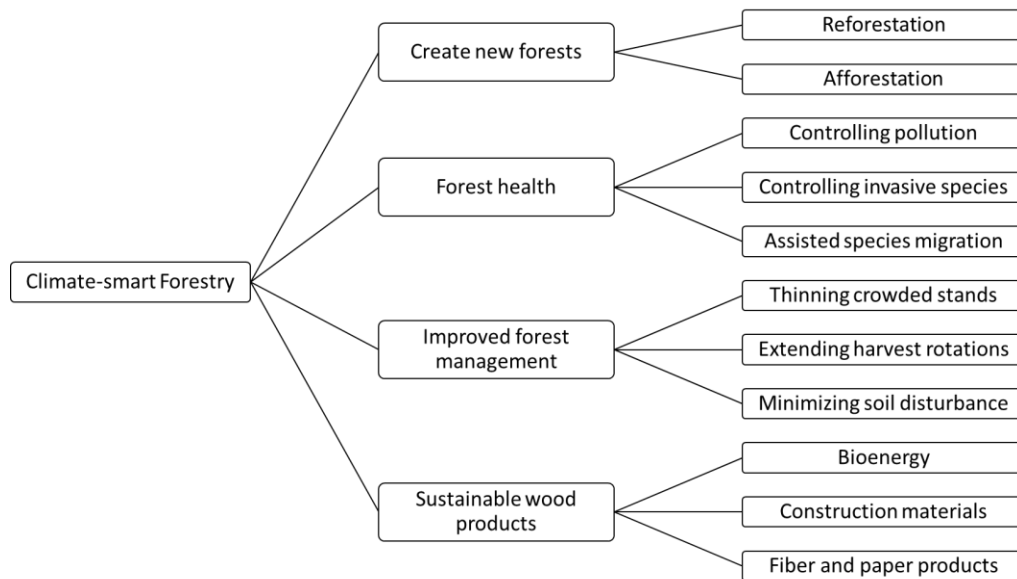


Figure 6. Examples of climate-smart forest management strategies.

Additional Carbon Storage Is Extra Wood

Planting new forests helps create a new carbon sink by increasing the total amount of woody biomass on the landscape. Reforestation occurs when new trees are planted in locations where forests are in decline. Afforestation is the process of planting trees in locations where there were no trees previously. The carbon sequestered after new trees are planted may qualify as being “additional.” Classifying which carbon is “additional” is important for assigning value to the carbon because the extra carbon storage is the outcome that buyers pay for to offset their carbon footprint.

Carbon storage can also be provided by generating sustainable wood products. The process is sustainable when new trees are grown to replace the harvested trees. Wood products in use and wood disposed of in landfills continue to store carbon for many years. It has been estimated that some wood products continue to store 10%–50% of the original carbon after 100 years. Wood products and bioenergy also help displace the use of other products with a larger carbon footprint, such as coal, concrete, and steel.

The key to making wood products qualify as “additional” is to develop carbon offset projects that lead to the production of wood products that would not have been created but for that project. For example, biochar is a wood product with many potential uses (e.g., filters, soil enhancement), but the production and distribution of biochar is limited due to a lack of investment in businesses and facilities that can produce biochar. An offset project that supports the establishment of new biochar producers also helps generate more biochar than what would have been otherwise. Because the production of biochar was dependent on the project being created, managers can claim that the carbon stored in the biochar is additional.

The number of investors in projects that help plant new forests and expand forest products is growing. Many of these projects are collaborations between nongovernmental conservation organizations (e.g., Arbor Day Foundation²) and market investors. The United States Department of Agriculture (USDA) recently invested almost \$4 billion to help jump-start the production of climate-smart commodities in agriculture and reach underserved communities.

Additional Carbon Storage Is a Function of Risk

The future of forests and climate is interlinked. Forests help regulate the climate by controlling the amount of CO₂ in the atmosphere. A stable climate helps forests grow and live longer by reducing likelihood of drought, extreme temperatures, and intense storms. To help avoid a negative feedback loop between forests and climate, management activities can help protect forest health.

- Controlling pests and disease in forests is one important way of reducing tree mortality and the risk that forest carbon will be released earlier than expected.
- Managing extreme wildfire and the distribution of invasive plants also helps promote conditions that allow native forests and soil to remain healthy and store carbon for as long as possible.
- Assisted species migration is the practice of moving seed sources or populations to new locations within the historical species range, in response to environmental changes caused by climate change. This practice may help forests adapt to changing climates by introducing genes from trees better adapted to the new climate. For instance, sugar maple from Virginia could be brought north to Pennsylvania, to help Pennsylvanian sugar maple stands become better adapted to a warmer climate.

The risk of forest degradation can be understood by looking at current trends and making predictions about future conditions if nothing changes. For example, the risk of a beetle infestation such as southern pine beetle (*Dendroctonus frontalis*) can be predicted by looking at the species of trees in the stand, the number of trees in the stand (i.e., density), the stand's location, and movement of woodborers in the region. The risk of wildfire can be understood by looking at the amount of woody fuel on the forest floor and the type of land uses surrounding the forest. Practices that help reduce the risk of carbon losses can be considered additional because future outcomes are changed from the business-as-usual outcome (i.e., not managing forest health) (Figure 7).

² The authors do not endorse the organizations mentioned.

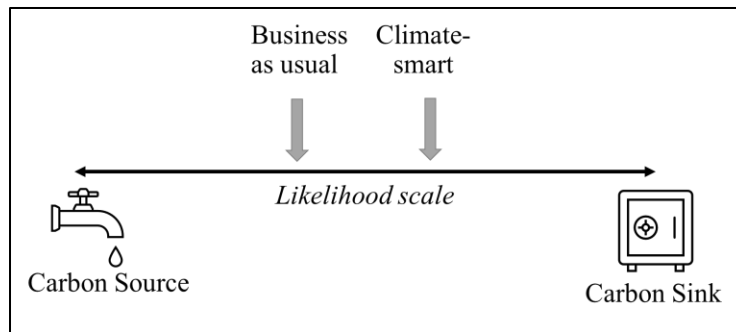


Figure 7. Likelihood of carbon gains and losses under business-as-usual and climate-smart forestry scenarios.

Protocols for quantifying reductions in risk for use in a carbon offset project are only just starting to be developed. For example, the Verra registry recently approved a method (vm0045) that uses matched baselines to determine differences in carbon storage between enrolled and unenrolled forests with the same risks.

Additional Carbon Storage Is a Planned Trade-Off

In climate-smart forestry, improved forest management (IFM) practices are intended to help increase carbon stocks within forests and/or reduce greenhouse gas emissions from forestry activities.

Making forest carbon a priority can come with some costs, to the owner, the ecosystem, or society. For example, delaying harvest is one of the most common IFM practices, but it also means revenues to the owner are delayed. Extending harvest rotations can also reduce the amount of early successional habitat on the landscape, which is important for a wide variety of wildlife. Maintaining trails to prevent erosion and carbon losses can be expensive or lead to the closure of some trails. In short, managing for improved carbon outcomes can lead to trade-offs in other management objectives, depending on the context in which it occurs. When changes in forest management practices are incentivized, the extra carbon stored is considered additional and can be traded on a carbon market.

In a delayed harvest scenario, additional carbon storage is determined by comparing the business-as-usual outcome with a delayed harvest outcome (Figure 8). In year 1 of a business-as-usual outcome there are significant carbon losses due to harvesting activities, but as years pass some of that carbon will be recovered due to new forest growth. In a delayed harvest outcome, there are no carbon losses in year 1 and over the next few years the forest sequesters even more carbon. Additional carbon is the difference in total carbon sequestered between these two scenarios.

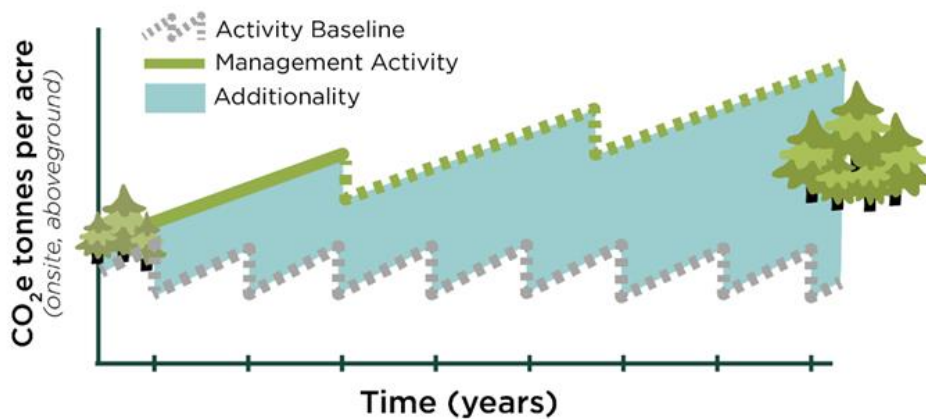


Figure 8. Additional carbon storage as the difference between the baseline activity (i.e., business-as-usual) and the new management activity (i.e., delay in harvest).

A key assumption in this approach is that timber harvesting is the most common business-as-usual situation for a forest. The likelihood of harvest is generally based on the percent of commercially valuable trees on the property and the forest owner's intentions about harvesting. Forest owner intentions are often a function of their management objectives, timber market conditions (e.g., price), and distance to mills. Trees that are unlikely to be harvested are not included in a delay harvest scheme. For example, natural forests with low grade wood, or forests that have been high-graded (i.e., most of the commercially valuable trees have been removed) often don't have enough economic incentive to risk being harvested in the first place.

From a carbon offset project perspective, incentivizing widespread delays in harvesting is an efficient way of enhancing carbon gains at the landscape level. Project managers can estimate increases in total woody biomass and carbon storage in a region over time by tracking multiple properties of land enrolled in a harvest deferral scheme (Figure 9).

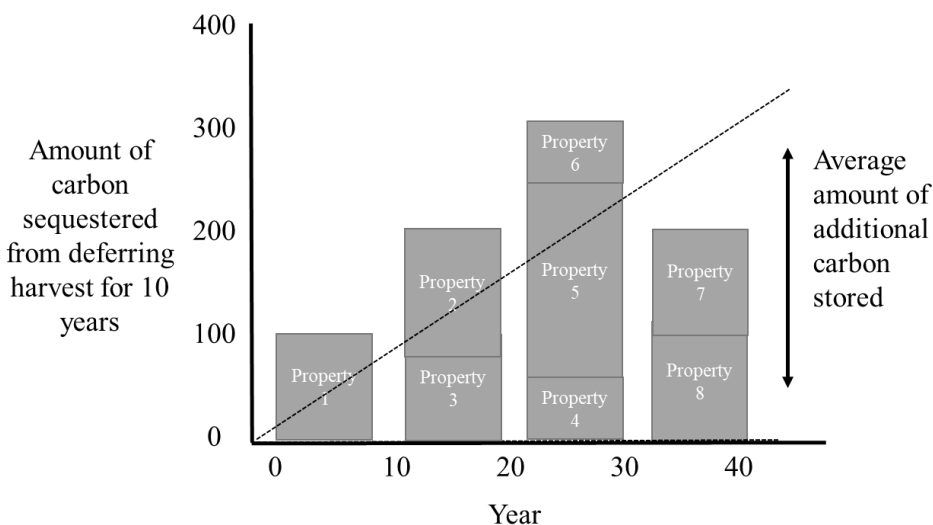


Figure 9. Distribution of carbon storage across multiple properties of land (gray boxes) and over time using a 10-year harvest deferral contract.

Most carbon market programs today use delay in harvest strategies; however, there is opportunity to support innovation in a wide variety of climate-smart forest management approaches. Recent federal actions (i.e., Inflation Reduction Act of 2022) are directing millions of dollars to state programs that support climate-smart forestry practices on private lands. You can be part of climate-smart solutions in your community by working with your state representatives, state foresters, and landowner associations.

Closing Thoughts

Regardless of what owners have or want for their forest, the criteria used to determine the value of forest carbon will include concepts such as additionality, risk, and rate of carbon sequestration. In addition to these requirements, carbon offset managers must provide assurances to buyers that the project protocols they follow offer permanent benefits (100+ years) and will not increase the likelihood of carbon releases (e.g., harvest) in other regions. Learn more by checking out the links below. Before enrolling in a program, it's important that landowners seek advice from a forestry professional to understand whether required management actions are a good fit for their broader management objectives and a good fit for their forest.

Tips for Teaching

- Start conversations with learners by pointing out how their current management activities are part of climate-smart forestry.
- Encourage learners to communicate to state agencies and project developers about which kinds of carbon incentive programs may work best for them.

Resources for Teaching

- How to Manage Forests for Carbon: An Introduction for Family Forest Owners. FOCCE article 12-01-2022 <https://extension.psu.edu/how-to-manage-forests-for-carbon-an-introduction-for-family-forest-owners>
- Climate-Smart Buildings Ahead. USDA Climate Hubs. <https://www.climatehubs.usda.gov/hubs/northeast/topic/climate-smart-buildings-ahead>
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- How Can Agroforestry Support Climate Change Mitigation in the Northeast? USDA Climate Hubs. <https://www.climatehubs.usda.gov/hubs/northeast/topic/how-can-agroforestry-support-climate-change-mitigation-northeast>

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- Verra Registry. Protocol VM0045, Methodology for improved forest management using dynamic matched baselines from national forest inventories, v1.0. <https://verra.org/methodologies/methodology-for-improved-forest-management/>

Chapter 6: Forest Carbon: Where Is It?

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Forests contain the largest store of land-based carbon. Forest management changes the structure and function of forests, which can influence where and how carbon is stored.

Learning Outcomes for This Section

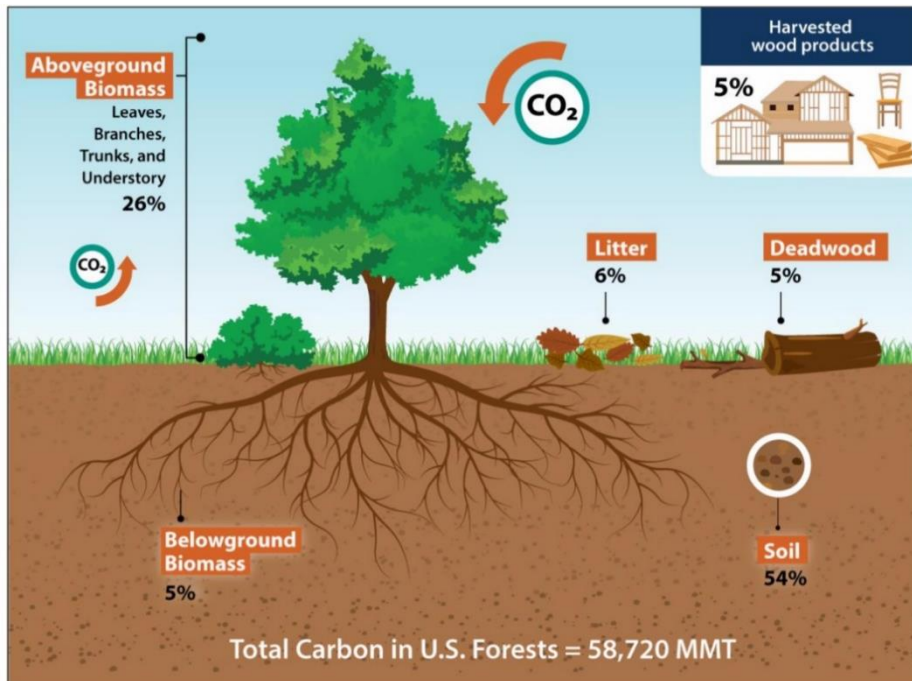
- Location of forest carbon pools
- How carbon is transformed through natural processes and forest management
- Regional variation in carbon pools

Carbon Pools in the Forest Ecosystem

The simplest definition of forest carbon is that it is a carbon-based sugar molecule (e.g., glucose and cellulose). Carbon sequestration is the creation of glucose in a plant through the process of photosynthesis. Carbon storage is the building of plant structures by converting glucose into cellulose and lignin. Forests are largely made of carbon, but only one-quarter of carbon is in the living aboveground biomass. The carbon remains in a somewhat stable form until disturbed through decomposition or combustion. When decomposed or combusted, oxygen is added and carbon turns into CO₂, which acts as a greenhouse gas.

Forest carbon tends to accumulate into different pools (Figure 10). Five major categories of forest pools are:

1. *Aboveground biomass*: This major pool includes living plants such as trees, shrubs, forbs, grasses, and sedges. Carbon occurs in all parts of the plant, including the leaves, stems, branches and limbs, and fruits. Carbon pools in woody plants are sometimes separated into additional components depending on the type of wood and bark.
2. *Belowground biomass*: This pool includes the roots of living vegetation, as well as rhizomes, stolons, and other underground fruiting bodies.
3. *Dead wood*: Standing dead trees or snags and downed dead wood lying on the ground are another important carbon pool. Dead woody vegetation is often referred to as coarse woody debris or fine woody debris. Dead roots underground can also be considered part of the dead wood pool.
4. *Forest floor litter*: Leaves, needles, and twigs on the ground are considered a separate carbon pool, because of how quickly carbon cycling occurs due to rapid decomposition.
5. *Soils*: Mineral soils (sand, silt, and clay particles) and organic soils both contain large amounts of carbon, however, in organic soils the carbon primarily comes from decomposing plant matter.



Source: CRS, using data for 2019 from EPA, Table 6-12 in Chapter 6, "Land Use, Land-Use Change, and Forestry," in *U.S. National Greenhouse Gas Inventory*, EPA 430-R-20-002, April 13, 2020.

Figure 10. Forest carbon pools.

Carbon pools can also be arranged into more general categories, which can be helpful for informing management decisions. For example, the five pools above can be reshuffled into an aboveground category (both living and dead) versus belowground category (both living and dead), or the living versus nonliving (dead) carbon pools.

Carbon Transport across Pools

Natural systems are dynamic. Continuous carbon transport can make it difficult to draw strict lines between the pools. For example, how much of the carbon in Figure 10 belongs to the decomposing log and how much to the forest litter or soils? Given this challenge, it is sometimes difficult to quantify how much carbon is in any pool at a specific point in time.



Figure 11. A decomposing log in the forest (Photo credit: Calvin Norman).

One of the biological processes that move forest carbon between the atmosphere and forest pools is *respiration*. Respiration involves using the sugars produced during photosynthesis plus oxygen to produce energy for plant growth. *Decomposition* is another critical process in which microbes help break down organic matter back into the original elements (Figure 11).

These biological processes often occur at different time scales across pools. For example, a living tree can take up CO_2 from the atmosphere on a continuous basis through the process of photosynthesis. However, the leaf litter on the forest floor decomposes in just a few months, releasing the carbon back into the atmosphere. When the tree eventually dies it becomes part of the dead wood carbon pool. Over the next several decades fungi and microbes break down the wood, which allows some of the carbon to be slowly released back into the atmosphere. Some of this carbon will also enter the soil and, if undisturbed, it can remain there for up to a millennia. When new trees replace the ones that were lost, they sequester more carbon from the atmosphere, offsetting the carbon released from older trees that are now decomposing. This cycle helps forests be carbon-neutral over time.

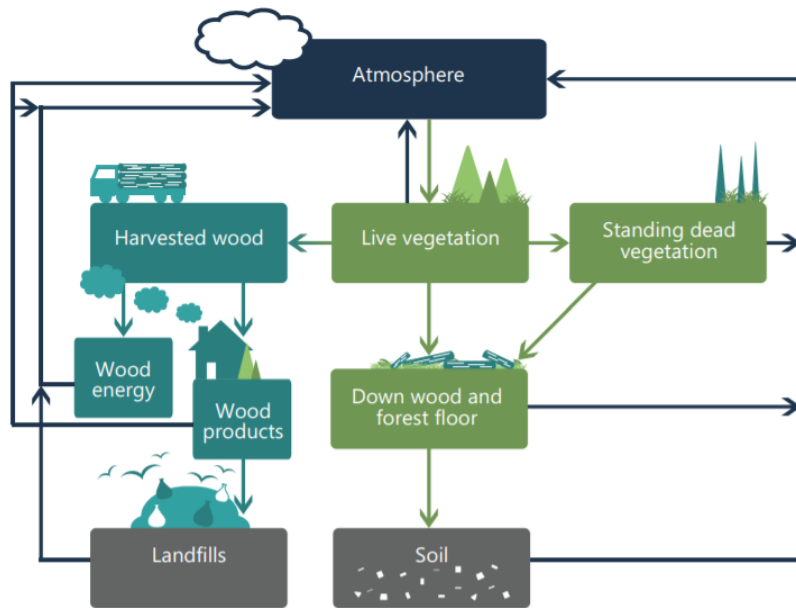


Figure 12. The forest sector carbon cycle includes forest carbon stocks and carbon transfer between stocks. Adapted from Heath et al. (2003) and USDA (2011). Published in Janowiak et al., 2018.

Managing live vegetation alters respiration and decomposition processes and can push forests toward being either a carbon source or carbon sink. The arrows in Figure 12 show the direction of carbon movement between carbon pools and in and out of the atmosphere. Carbon releases into the atmosphere can be delayed by using management practices, such as site preparation and fertilization treatments, which help trees grow larger and live longer. Herbicide treatments help reduce competition and water stress on trees, which also allows trees to grow larger and healthier. Methods that help control pests such as the southern pine beetle (*Dendroctonus frontalis*), emerald ash borer (*Agrilus planipennis*), or Asian longhorned beetle (*Anoplophora glabripennis*) are important for preventing large numbers of tree deaths. Prescribed fire can also help reduce the risk of large wildfires, since extreme wildfires can destroy large numbers of trees, burn soil, and prevent future forest growth.

Timber harvests are another common management activity that impacts how much carbon is in a forest at any given time. Single tree or group selection harvests can reduce the amount of carbon in a stand for a little while until new growth occurs. Another way carbon is released to the atmosphere is through increased soil erosion due to large equipment disturbing the topsoil during harvesting or the loss of surface vegetation in areas prone to rain or landslides. This is why some practitioners prefer to conduct harvests either in the wintertime, when cold temperatures help stabilize the soils, or in the summertime, when soils are drier to avoid rutting. Trees removed during a commercial harvest help relocate forest carbon to a new pool—the wood product pool.

Carbon Pools in Harvested Wood Products

The carbon stored in wood products is often referred to as the harvested wood products (HWPs) carbon pool. Some wood products, such as high-quality wood furniture and wood-framed buildings, can hold onto carbon longer than if the tree had been left in the forest. In other words, some wood products help bank existing forest carbon while giving space for new trees to grow.

The carbon footprint of a harvested wood product can be calculated by subtracting the amount of carbon in the wood from the amount of carbon released due to related activities such as harvesting, transporting, and processing the wood into a product. A “cradle-to-grave” analysis is a comprehensive footprint analysis that does carbon accounting throughout the wood product’s existence, as well as the footprint of substitute products (e.g., metal, concrete) that are offset by the wood product.

When harvested wood products are eventually disposed of, they enter landfills or the solid waste disposal site (SWDS) carbon pool. At this point the carbon in harvested wood products returns to the atmosphere due to the decomposition of the wood product. Thus, there are seven pools of forest carbon: five in the forest ecosystem and two in the wood product pool (HWPs and SWDS).

Quantifying Carbon Pools

Understanding how much carbon is in the different forest pools is important for developing management plans that help maximize carbon storage or prevent the unnecessary release of carbon. A report by the US EPA in 2019 described the total amount of forest carbon and percent of carbon in major pools across the United States (Table 5). Just over half of carbon in forests is stored in the soil, followed by aboveground biomass (live trees and plants). Less than 5% of forest carbon is stored in harvested wood products.

Table 5. Percentage of total carbon (in million metric tons—MMT) within forestry-related carbon pools as estimated for 2019.

		Total Carbon MMT	Total Carbon Pools
<i>Number</i>	<i>Forest Ecosystem Pool</i>	<i>56,051</i>	<i>95.5%</i>
1	Aboveground biomass	14,989	25.5%
2	Belowground biomass	3,081	5.2%
3	Dead wood	2,777	4.7%
4	Forest floor litter	3,641	6.2%
5	Soil	31,564	53.8%
<i>Number</i>	<i>Wood Products Pool</i>	<i>2,669</i>	<i>4.5%</i>
6	Products in Use	1,521	2.6%
7	Solid Waste Disposal	1,148	2.0%
Total		58,720	100%

The numbers in Table 5 are an average estimate across multiple types of forests in different regions. The U.S. Forest Service recently published a report containing “carbon lookup tables” drawing from Forest Inventory Analysis (FIA) data to provide estimates of forest carbon attributes based on region, forest type, and stand age. While regional estimates are not as accurate as site-specific data, they provide a reasonable estimate of expected carbon stocks when site-specific data are not available. For example, in the Southeast, loblolly pine trees at 30 years old contain an average of 55.5 metric tons of carbon per hectare (22.4 metric tons per acre). In the Northeast, oak and hickory trees at 100 years old have an average of 108 metric tons of carbon per hectare (43.7 metric tons per acre). The dead wood, leaf litter, and organic soils in oak-hickory stands contain an average of 83.4 metric tons of carbon per hectare (33.7 metric tons per acre).

To understand carbon stocks at the stand level, practitioners often use field inventory data, such as tree diameter and height, in conjunction with the allometric equations developed using destructively sampled trees (see Chapter 7 for more information). Generally, the amount of carbon in a tree is 50% of the dry weight of the tree, but this ratio can be higher for hardwood species, which have less water. U.S. Forest Service researchers recently found wood carbon ranged from 18.4% to 75.1% across 3,600 observations and the mean wood carbon fraction was 47.4%.

The development of remote sensing and satellite technologies has allowed users to measure changes in living biomass, determine forest stocks, and make vegetation maps without being physically in the forest. These maps can be combined with carbon density values collected using ground data to quantify carbon stocks across large areas. This type of quantification tends to focus on living aboveground carbon and is not well suited for quantifying carbon in soils, dead biomass, and leaf litter. Quantifying carbon in soils can also be complicated because of the

variation in carbon concentrations across space and at different soil depths. Continued research helps provide more precise estimates of carbon within major pools to better inform local management decisions.

Tips for Teaching

- Field tours are a great place to introduce the topic of forest carbon pools.
- Allow participants to build their own molecular models of forest carbon (carbon-based sugar molecules) using craft materials.

Resources for Teaching

- Forest Carbon Pools: Where Are They? FOCCE # #09-01-2023
<https://extension.psu.edu/forest-carbon-pools-where-are-they>
- Forests: A Carbon Cycle Checking Account. USDA Climate Hubs.
<https://www.climatehubs.usda.gov/hubs/northeast/topic/forests-carbon-cycle-checking-account>
- Carbon lookup tables in Standard Estimates of Forest Ecosystem Carbon for Forest Types of the United States. U.S. Forest Service.
https://www.fs.usda.gov/nrs/pubs/gtr/gtr_nrs202.pdf
- How Much Carbon Is in Tree Biomass? U.S. Forest Service.
<https://www.fs.usda.gov/nrs/highlights/2256>
- Housing Starts and the Associated Wood Products Carbon Storage by County by Shared Socioeconomic Pathway in the United States. U.S. Forest Service.
<https://www.fs.usda.gov/research/treearch/64622>

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- 2022 Northern Research Station Highlights, How Much Carbon is in Tree Biomass?
<https://www.fs.usda.gov/nrs/highlights/2256#>
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Chapter 7: Methods for Estimating Carbon within Forests

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It is unlikely that a private forest owner will be responsible for measuring the carbon in their forest if they want to manage it or sell the carbon to an offset project developer. This section provides examples of equations used by professional foresters to quantify carbon in living forests.

Learning Outcomes for This Section

- How data and equations are used to estimate carbon stocks in forests
- Innovation in remote sensing to measure forest stand characteristics

Estimating Carbon Is a Prediction

The carbon in forest biomass is not an obvious feature, so it is difficult to measure carbon directly. Instead, carbon amounts are predicted for a tree or stand (a collection of trees managed together as a unit) using simplified mathematical relationships.

Allometric equations are a standard practice in forestry and can be used to estimate the amount of carbon in a tree or stand. They work by determining how the tree variables that are easy to measure (e.g., diameter of a tree) are proportionally related to another tree variable that may be more difficult to measure (e.g., metric tons of carbon).

Estimating changes in the amount of carbon sequestered in a stand over time is done by repeated stand inventories. This procedure helps verify how much carbon was likely stored in the same stand between two time periods. “Additional” carbon is produced when there is a change in management activities that leads to more living biomass on the landscape than there would have been otherwise.

Estimating Carbon in a Tree

Estimating carbon in a tree involves two basic steps: (1) determine the dry weight of the wood, and (2) determine how much of that wood is carbon. The following is a simple allometric equation form for predicting the dry weight of a loblolly pine tree growing in the southeastern United States. More specifically, it estimates the dry weight of wood in the aboveground part of the tree (i.e., stem) and requires only that you know the tree’s diameter (in centimeters) at 4.5 feet above the ground (i.e., diameter at breast height, or *dbh*). This equation is shown here:

$$dbh^{2.77} \times 0.021 = \text{Stem biomass for loblolly pine (dry weight in kilograms)} \quad [1]$$

Example calculation for a loblolly pine tree:

Step 1: Let’s say that you have a loblolly pine tree that is 12 centimeters in *dbh*. Using equation [1], the dry weight of the aboveground wood would be,

$$12^{2.77} \times 0.021 = 20.49 \text{ kilograms of dry wood}$$

Step 2: Once you have estimated the dry weight of the wood, it is typically assumed that the amount of carbon in a tree is approximately half the dry weight. In this example the amount of carbon would be:

$$20.49 \text{ kilograms of dry wood} \div 2 = 10.25 \text{ kilograms of carbon}$$

Most allometric equations are developed for tree species that have a market value. Species-specific equations are generally preferred for their accuracy, but in many cases a generalized composite equation may be used because it is assumed to be representative of many tree species.

Estimating Carbon in a Stand

In forestry, data describing many individual trees are collected to describe the whole stand. You can use allometric equations, such as the one above, along with other metrics (e.g., number of trees per unit area), to estimate the amount of carbon within a stand.

Initially, an inventory must be conducted of the trees that you want to manage. The inventory can include all the trees, or alternatively, only the trees within designated plots, which are then used to make predictions about the whole stand. Steps 1 and 2 described in the section above can be used to predict the dry weights and amount of carbon in each of the measured trees. The amount of carbon in each of the trees would then be summed to estimate the total amount of carbon in a plot. The plot-level data are then “expanded” or “blown-up” to a per unit area basis—say an acre or hectare. At this point you would have the information needed to estimate the total amount of carbon in a forest of a known size, or the average amount of carbon per acre.

Estimating Carbon in a Forest

Within forests, carbon sequestration is not just limited to the merchantable living stems of trees. Carbon is also sequestered in the different parts of the tree (e.g., crown, branches, roots), dead trees and leaves lying on the forest floor, understory vegetation, and forest soils. Managing for these parts of the forest can also provide climate regulation benefits, especially if you plan to harvest some trees from time to time.

In 1987, Baldwin presented an allometric equation that has a slightly different form than equation [1]. This equation can be used to estimate the dry weight of the foliage in the crown of a loblolly tree as a function of *dbh* (inches) and total tree height (feet).

$$16.38 dbh^{2.91} \times \text{Height}^{-1.47} = \text{Dry weight of crown foliage in pounds} \quad [2]$$

Sometimes managers need equations so they can better understand the biological trade-offs between understory and overstory vegetation and the impact to carbon pools. In this case, non-allometric equations may be used, in part because non-tree-related variables, such as rate of fertilization and precipitation, must be accounted for. We can also see how forest management actions such as thinning impacts number of trees and site resources to the understory vegetation. The following example is more technical but is a good illustration of how well-designed equations can help make predictions about forest carbon in all types of contexts.

Equation to estimate total understory vegetation dry weight in loblolly pine plantations by VanderSchaaf et al. (2010):

$$\ln\text{Total} = -20.0312 + 0.000177\text{Fert} \times \text{Precip} + 6.656713\ln\text{Precip} - 0.02987\ln\text{Precip} \times \text{SDI}^{1/2} - 0.00015(\text{SDI}^{1/2} \times \text{Fert} \times \ln\text{Precip}) \quad [3]$$

Explanation of equation 3. (from VanderSchaaf et al. 2010) Natural logarithmic transformations, represented by the “ln” term in the equation, are often required when estimating various carbon pools. Total refers to what vegetative forms or types are actually being estimated and here it refers to the dry weight biomass of grasses and grass-like, forbs, woody vines, and shrubs in mid- to late August, measured in kilograms on a per hectare basis. As you can see, it is assumed that understory biomass is a function of precipitation amounts and fertilization rates. The positive sign in front of the fertilization and precipitation term (Fert x Precip) represents the synergistic effect of fertilization with greater amounts of precipitation, thus nutrients and precipitation are more available to the understory. Additionally, understory vegetation production is greater as precipitation increases, as shown by the positive sign in front of the precipitation (lnPrecip) term. SDI refers to Reineke’s stand density index, a metric that represents the amount of site resources being utilized by the overstory tree component. Generally, a larger SDI results from more trees. Site resources such as light, moisture, and nutrients at some point become limited to the understory vegetation. The negative sign in front of the terms that contain SDI (SDI^{1/2} x Fert x lnPrecip and lnPrecip x SDI^{1/2}) represents the negative relationship between overstory trees and understory vegetation, the competition for limited resources. Further, the negative sign in front of the SDI terms implies that fertilization and precipitation not only benefit the understory vegetation, but also the overstory vegetation. Fertilization along with greater precipitation actually deters understory vegetation production at an accelerated rate because of the greater amount of overstory tree production.

Remote Sensing Technology and Forest Measurements

Drones equipped with special cameras, such as LiDAR (light detection and ranging) sensors, have revolutionized the way we monitor forest cover. These drones capture high-resolution images of forests from above, creating detailed 3-D maps of the trees and other vegetation. By analyzing these images, scientists can derive morphological and structural parameters such as the size, shape, density, and spatial arrangement of trees, which are then used to estimate important forest characteristics such as biomass and carbon storage. Compared to traditional inventory methods, drones are a cost-effective alternative that can cover large areas with greater precision, allowing for more accurate estimates of forest carbon stocks. Furthermore, drones can access remote and rugged terrain that may be difficult or impossible to access through traditional field methods, enabling better monitoring of forest cover and carbon storage.

The use of auto-regressive integrated moving average (ARIMA) and deep learning models in forest monitoring represents an innovative and cutting-edge approach to tackling the challenges of carbon estimation. These models can process vast amounts of data and detect complex patterns that may be difficult for humans to identify. Scientists use different models to understand and protect forests. These models have been used to analyze data from satellites, drones, and other remote data sources to identify different types of forests, predict forest fires, and detect diseases, insects, timber quality, and carbon storage.

Overall, the use of drones in forest monitoring has significant implications for both conservation and climate change mitigation. By providing accurate estimates of forest carbon storage, this technology can inform policy decisions and help us better understand the role of forests in the global carbon cycle.

Closing Thoughts
The forest carbon sold on an offset market is not the carbon already in the stand, but the promise that additional carbon will be stored in the future, due to changes in forest management. To measure the carbon potential in a stand, it is best for owners to work with a professional forester to identify which management practices can help enhance carbon storage based on the condition of the forest.

Resources for Teaching

- Methods for Estimating Carbon Within Forests. FOCCE #06-01-2022
<https://extension.psu.edu/methods-for-estimating-carbon-within-forests>
- i-Tree tools and resources. <https://www.itreetools.org/>

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Chapter 8: Carbon Accounting in Forest Management

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The rate of carbon sequestration changes in a forest over time, and this impacts how baselines and harvesting are included in carbon accounting.

Learning Outcomes for This Section

- Setting baselines for measuring changes in carbon storage and challenges
- Forest carbon and definitions of permanent storage
- Impact of harvesting on forest carbon over time
- Calculating average rates of carbon gains across forest types

Measuring Carbon over Time

How much carbon is in living woody biomass varies over space and time, depending on tree species, stand density (e.g., number of trees per acre), silvicultural management (e.g., fertilization), and tree age. The USDA Forest Service has an open access database called the Forest Inventory Analysis (FIA). This database can be used to estimate the average amount of carbon stored in a typical acre in the United States, based on tree species and location. The “carbon lookup tables” offered by the U.S. Forest Service were created using FIA data and describe forest carbon values based on region, forest type, and stand age.

A planted pine stand provides a good illustration of how carbon storage changes over time. FIA data were used to develop Figure 13, which shows the amount of carbon sequestered over time for a planted slash pine stand in Mississippi. The concepts presented here can also be applied to an uneven-aged or mixed hardwood forest as well.

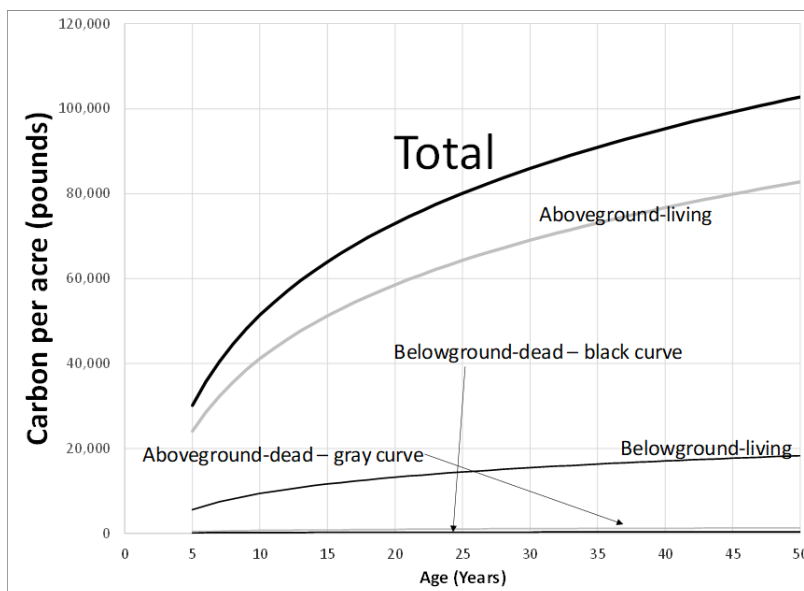


Figure 13. Carbon per acre estimates for planted slash pine stands in Mississippi using data from the USDA Forest Service Forest Inventory and Analysis (FIA) program.

In this figure, the gray line for “aboveground living” biomass increases over time compared to the black line for “belowground living” biomass, which remains relatively flat. This means each year the amount of carbon stored per acre tends to increase meaningfully aboveground, but not much belowground.

After the trees are first established, the rate of carbon sequestration increases, but then it eventually starts to level off as the trees mature. You can see this between years 5 and 15 the gray line is slightly steeper in slope compared to years 25 to 45. These changes are often referred to as the rate of carbon sequestration or change in carbon (pounds or tons) over time (years). Rates can change depending on the age of the stand.

In most cases, only the aboveground living biomass is considered in a carbon offset scheme, because living biomass can be easily managed to provide additional carbon storage. Managing carbon in the soils and belowground living biomass, however, is also an important part of climate-smart forestry when possible.

Setting the Baseline

Setting a baseline is critical for determining when carbon storage is “business-as-usual” and when it is “additional” and can be sold in a market. Reforestation, or planting trees, is a common strategy for removing additional carbon sequestration. The baseline amount of carbon in a reforestation project is zero, because there were no trees to begin with. It is assumed that the forest was unlikely to occur unless planted and after planting the land would remain forested into the future. If slash pine trees were planted, the total amount of carbon would approach 100,000 pounds per acre at year 45 (Figure 13). The carbon stored in a planted forest is typically not accounted for during the first 5 years, due to higher rates of tree mortality and measurement error.

Delaying harvest is another common strategy and is often referred to as an improved forest management (IFM) practice. Growth and yield models are often used to establish the baseline in a delay harvest scheme, or the average amount of live woody biomass per acre just before harvest. If the starting point in Figure 13 was set at 25 years (when southern pine stands are financially mature for harvest), then the baseline amount of carbon would be 80,000 pounds of total carbon in live woody biomass. Delaying harvest another 5 years is predicted to provide an additional 8,000 pounds of carbon stored beyond the baseline amount. Keep in mind that when a stand has been cut (business-as-usual management), another forest may start to grow after harvest. Any carbon sequestered during the business-as-usual activity would also have to be accounted for when estimating how much additional carbon was stored by changing management activities.

There are several key challenges to determining an appropriate baseline for offset projects that include multiple owners and properties of land:

- If the average amount of living woody biomass across all properties is used as the baseline, then some properties may already exceed or be below average at the time of enrollment. This can be problematic when trying to determine which properties will provide more benefits and what is fair compensation for different owners.
- There will always be some proportion of properties that do not fit the business-as-usual assumptions about harvesting. In other words, some owners’ original intentions about

harvesting can change due to circumstance. Carbon accounting procedures tend to be more accurate when baselines are more representative of changing conditions.

- In cases where the period of contract is shorter than the window of optimal harvest, payments for delaying harvest may not cover the whole period of “harvest risk.” Longer contracts can offer more assurances that a harvest was truly delayed.

Since working with multiple properties can be complicated, how much error is acceptable when measuring the baseline is of continuous debate.

Permanence

During respiration up to half of the carbon taken in by a forest is stored to create new woody biomass. Wood that is buried underground, where there is little oxygen, can hold onto carbon for centuries. Increased use of fossil fuels has allowed the carbon from ancient forests to reenter the atmosphere, enhancing the greenhouse effect. A true carbon offset should provide the same benefits as never extracting fossil fuels from the ground in the first place. This is why the concept of permanent storage or “permanence” is fundamental to the role of a carbon offset.

Permanence in a forest carbon offset project has been defined by the California Air Resources Board as impacts from carbon emissions avoided for at least 100 years. However, climate models show that even when CO₂ molecules have been removed from the atmosphere, a portion of the effects on temperature can still linger for thousands of years. This means that the impacts of fossil fuels emissions can never be fully erased, only mitigated.

The challenge with using living forests as a carbon offset is that the carbon is temporarily locked up. Most trees have life spans of less than 100 years, because the species is short-lived, individual trees are harvested as part of forest management, or trees are lost to forest pests/pathogens. Carbon is gained and lost on a regular cycle, as trees grow, die, decompose, and grow back again. Because of this, the carbon accounting in living biomass is really the quantification of total carbon “gains versus losses” within the project area over time. Forest management activities help carbon gains persist into the future, by maintaining a certain amount of woody biomass above a prescribed baseline. Unfortunately, forests are also vulnerable to unplanned disturbance (e.g., wildfire), which can reverse the carbon storage benefits. This is why forests are sometimes considered a leaky reservoir for carbon. Moving forest carbon into certain kinds of wood products can help slow down the leak by extending the carbon storage time.

Harvesting and Carbon Accounting

Working forests are an important source of sustainable wood products, which means that they are occasionally harvested. Currently, there is more wood grown than harvested in the United States (i.e., tons of living woody biomass). Between 1990 and 2016, up to 15% of U.S. greenhouse gas emissions were offset due to voluntary and unintentional slowdowns in harvesting on public and private lands. When harvesting does occur, the impact on forest carbon often depends on the type of harvesting conducted.

Clear cutting a forest resets carbon storage in the living aboveground biomass to almost zero. Vegetation and woody debris may still have carbon, but this is typically not included in some carbon offset projects. Clear cutting is an uncommon management practice on family forestlands in the United States except when the forest is a planted stand, the species being managed (e.g., white pine) benefits from clear-cut treatments, or the owners want to clear the land for other

uses. Forestlands that are cleared and converted to other uses typically become a permanent carbon source. Where a forest is cleared, but new trees grow back, this is considered a temporary carbon source. That land eventually becomes a carbon sink again when the new forest exceeds the age of the original forest.

A study published by Ter-Mikaelian et al. (2015) in the *Journal of Forestry* showed that wood products, such as biofuels, can help working forests restore important climate benefits at a faster rate after harvesting. In this example, the climate benefits provided by biofuels are included in the carbon accounting. Figure 14 shows an increase in forest carbon stocks over time (A), but carbon stocks decrease temporarily when the stand is harvested (B). If the wood from the harvest is used to make biofuel or wood pellets, a portion of greenhouse gas (i.e., GHG) emissions can be offset by displacing the use of fossil fuels (C). The benefits of displacing use of fossil fuels allows the carbon debt from the harvest to be repaid sooner (D).

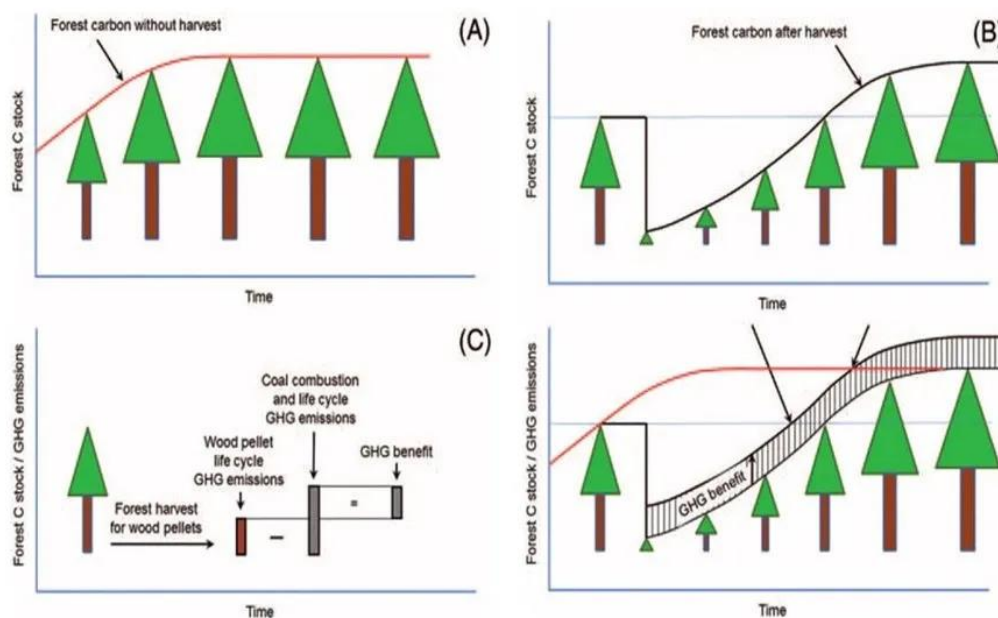


Figure 14. Carbon accounting in a forest when wood pellets (i.e., bioenergy) are included in the carbon life cycle analysis.

Selection harvesting methods, or partial cuttings, are generally more common in natural forests on family forestlands. This occurs when only certain trees are harvested. Sometimes the trees are selected for their commercial value, and sometimes to help improve stand health and wildlife habitat. The harvested trees are eventually replaced through planting or natural tree regeneration. If done correctly, species composition and tree age classes remain relatively the same, and the volume of carbon remains relatively stable over time. Reducing or delaying a selection harvest allows the average age of the forest to increase, thereby increasing the total amount of live woody biomass and carbon stored.

Average Annual Rates and Carbon Accounting

In a carbon offset project, total carbon gains and losses within a designated area are quantified to generate an offset. However, calculating an average rate of carbon gains for different types of forests can be useful for planning and making predictions about the value of a project.

The average annual rate of carbon sequestration for a slash pine forest (Figure 14) can be calculated by dividing the total amount of carbon stored by total number of years of tree age. This is illustrated in the following equation:

$$100,000 \text{ pounds carbon per acre} \div 45 \text{ years} = 2,222 \text{ pounds of carbon per acre per year}$$

In other words, a carbon project that includes slash pine forests will sequester an average of 2,222 pounds of carbon per acre per year.

The economic value of additional carbon storage is based on how much greenhouse gas emissions are avoided, delayed, or captured from the atmosphere. When forest carbon is released through decomposition, it binds with oxygen molecules to form CO₂, a common greenhouse gas. Carbon dioxide has about 3.6667 times the atomic weight of carbon alone. So, when converting forest carbon into atmospheric CO₂, use the following equation:

$$2,222 \text{ pounds of forest carbon per acre per year} \times 3.6667 = 8,147 \text{ pounds of CO}_2 \text{ emissions avoided}$$

A carbon credit sold in a market is typically traded using metric tons. Converting pounds of emissions avoided to metric tons can be done using the following equation:

$$8,147 \text{ pounds of CO}_2 \times 0.000453592 = 3.69 \text{ metric tons of CO}_2 \text{ emissions avoided}$$

In this final equation, it is determined that on average 1 acre of slash pine forest offsets about 3.69 metric tons of CO₂ emissions per year. In reality, there can be a lot of variation from site to site due to differences in stand age, site quality, silvicultural management, and planting density. To estimate total carbon gains and losses at the site level, one would first need to determine the total amount of woody biomass per acre, as the baseline, and then track changes in the amount of woody biomass resulting from the business-as-usual outcome and the climate-smart forest management outcome.

Closing Thoughts

The total value of a forest is greater than its carbon storage benefits. For example, trees located near surface waters help protect stream health by controlling water temperatures and streamside erosion. Forests in urban areas help provide recreational benefits and provide corridors for wildlife to pass through. Working forests provide wood products that help displace the use of other more fossil fuel-intensive products (e.g., plastics, concrete). The sustainable management of forests under climate change requires that all the values associated with that particular forest also be taken into consideration.

The slash pine illustration in this chapter is an example of a tree species that is highly efficient at storing carbon because it is a densely planted fast-growing species. In reality, most forests in the United States are not as efficient and offset about 1–2 tons of CO₂ emissions per acre per year. This is because over the landscape forests differ in many ways based on factors such as tree species, age classes, and silvicultural management.

Tips for Teaching

- Landowners who have a forest management plan are better able to define their business-as-usual scenario and propose baselines that are more representative of their property.

Resources for Teaching

- Carbon Accounting in Forest Management. FOCCE #06-04-2023
<https://extension.psu.edu/carbon-accounting-in-forest-management>
- Carbon lookup tables in Standard Estimates of Forest Ecosystem Carbon for Forest Types of the United States. U.S. Forest Service.
https://www.fs.usda.gov/nrs/pubs/gtr/gtr_nrs202.pdf
- LOBplantation Carbon Estimator and User Guide. Mississippi State University Extension. <https://docs.google.com/spreadsheets/d/1EWTjcqnzFVILLAqGsD3qs7ovUg-Vwido/edit#gid=287994003> and <https://drive.google.com/file/d/1Bl3is0rBad8zLAhx-QJy98VkCTL0XKPX/view>
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Part 3: Carbon Payments to Owners: How Much Is Enough?

Chapter 9: What Is a Fair Price for Forest Carbon?

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Since carbon offsets are a relatively new commodity, it can be a challenge for some forest owners to decide what is fair compensation for enrolling in a forest carbon payments program.

Learning Outcomes for This Section

- Economics of forest ecosystem services
- Values-based decision-making
- Tax implications for carbon revenues

Forest Ecosystem Services

About 70% of the forestlands in the United States are under private ownership, but family forest owners can be very different in terms of ownership reasons, ownership size, and management practices. What most owners agree on is that they enjoy owning forestland for its beauty or scenery and to protect wildlife habitat, biodiversity, and nature, as well as for a financial investment.

A recent study by Frey (2021) estimated that in the United States, total payments to forest owners for water quality and watershed protection, wildlife habitat, and carbon sequestration and storage services averaged \$3.3 billion per year, or about \$7.16 per acre. Most payment programs focus on properties located near urban areas or agricultural lands and support the protection of water and wildlife resources. A 2018 survey by the National Woodland Owners Association found very few forest owners were familiar with forest carbon programs, but two-thirds were concerned about climate change.

The value of carbon offset markets has been increasing, suggesting that payments for carbon sequestration programs could become more widespread. About 35% of the carbon credits sold on the voluntary market include forestland as the primary mechanism to store additional carbon. The approach used by many carbon programs is to pay owners to delay harvest. Carbon payments are intended to help compensate for the delay, but what is a “good deal” can be difficult to determine due to differences in forest types and management objectives across owners.

Values-Based Decision-Making

Forest owners often see forest stewardship as a type of balancing act. Many owners prefer to enhance the nonmonetary benefits associated with forest ownership, but they need to make forest ownership financially feasible as well. As a result, some take advantage of any new payment opportunities, and some are willing to consider options if they are a good fit for how they want to use their land. Some owners even look to share in the cost of protecting environmental quality because it supports their views about stewardship and social responsibility. This means that what

owners consider “fair compensation” when arranging a transaction largely depends on how they approach forest ownership.

Research has found that some owners approach forest ownership as an investment in timber production, whereas other owners have multiple objectives and/or are conservation-focused. Owners with financial and multi-objective reasons may be more likely to factor opportunity costs into their decision-making. Opportunity costs represent the value of an alternative outcome that is lost when taking a specific action.

Landowner choices are also a function of the size of the forest they own. Due to differences in financial feasibility, forest landowners with larger acreages (over 500 acres) tend to have timber management objectives, while those with smaller acreages (20 -100 acres) tend to have amenity-related or heritage ownership objectives.

Carbon programs that offer contracts to nonindustrial forest owners are still very new. As a result, there is very little real market data on what landowners are willing to accept as payment. A recent study by Sharma and Kreye (2021) examined forest owners’ choices about hypothetical carbon markets by reviewing survey studies collected over a 20-year period. They found that forest owners throughout the United States were willing to accept anywhere between \$6 and \$280 per acre per year for managing carbon. In other words, up to half of forest owners were willing to accept up to 75% less compared to the other half of forest owners. The most important factors in owners’ choices were the priority they gave to timber production and length of contract. Owners with smaller properties (less than 20 acres) preferred slightly higher payments compared to owners with larger properties.

Another key factor in owners’ choices was associated with opportunity costs, which are sometimes difficult to define for private forestlands because the importance given to an outcome can be different from person to person. For example, an owner may reject a long carbon contract because they are worried about how it will affect their property values in the future. Forest owners may also be concerned that delaying harvest for too long may increase the risk of storm damage or disease in the stand, thereby reducing the market value and aesthetic value of the forest. The perceived risk of losing out on something important can vary and helps explain why some people need to be paid more, or why some choose to wait and see how it goes for others.

What Is the Best Approach?

It is indeed useful to consider what other forest owners consider acceptable compensation when opportunity costs are not well understood. The study by Sharma and Kreye (2021) also investigated which payment levels may be preferred by specific categories of forest owners based on their management priorities and risk perceptions.

The *passive* forest owner enjoys having forest on their property and using the forest, but they only sometimes manage or harvest the forest. One reason for not managing a forest is the belief that a forest is able to take care of itself. Another reason is the owner is still waiting for more preferred investment options to become available. For these reasons, the passive owner may prefer shorter carbon contracts, just in case a better opportunity comes along. Owners who fit this description (and have more than 20 acres) were estimated to accept between \$6 and \$13 per

acre per year for contracts that require a management plan and restrict harvesting for periods of less than 20 years.

The *conservation-oriented* forest owner may see their forest as a legacy that they want to leave to their family or friends. They have already worked with a professional forester to make a management plan that ensures certain management goals are achieved. When financially possible, they invest in making forest improvements, which may or may not involve timber harvesting. They are willing to make long commitments to help ensure their forest is conserved into the future. Owners who fit this description (and have more than 20 acres) were estimated to accept between \$5 and \$15 per acre per year for contracts that restricted harvesting for periods of more than 20 years.

The final category of forest owner described by Sharma and Kreye (2021) is the *timber production-oriented* forest owner. This owner sees their land as an important financial asset, with timber production being a key investment option. They may already have harvest rotations scheduled as part of their long-term plans for sustainable timber production. Delaying harvest increases risks to future harvest value (e.g., timber quantity or quality may be lost due to forest pests, natural disturbances, and wildfire). Owners who fit this description (and have more than 20 acres) were estimated to accept \$33 to \$67 per acre per year for contracts that restricted harvesting for periods less than 20 years.

In reality, most forest owners could identify with all these categories depending on which part of their property is being considered and what they have been able to do with their forest. These values should not be seen as a substitute for a long-term financial plan. Investing in opportunities that help increase the value of the land and the forest in the long-term (i.e., land expectation value) is generally more sustainable. Some options may include:

- Delay harvest schemes are generally a good financial option for owners when the contracts are short enough that the current owner also benefits from the eventual harvest and when the stand has a high percentage of merchantable trees per acre.
- Forests that have been high-graded (i.e., most of the merchantable trees have been removed) would generally benefit from a longer contract (to help grow more merchantable trees) and incentives that help manage tree regeneration and stand health (e.g., thinning, invasive species management).
- Stands with low grade or low value wood could benefit from harvesting and would be better suited for carbon projects that create climate-smart wood products (e.g., bioenergy, biochar).

In short, finding a program with a good fit means taking into consideration the condition of the forest and the long-term financial objectives of the owner.

Tax Implications

Timber income is typically subject to capital gains tax, which is lower than the regular income category. Currently, carbon income is being treated as regular income and not subject to capital gain tax for the forest landowner. Enrollment in a carbon contract could also change the type of

tax benefits associated with forestland. Frequently check-in with the state tax assessor for any changes in tax law or policy.

Closing Thoughts

Most forest owners can identify with aspects of the three categories of landowners discussed above, depending on which part of their property is being considered, what they have been able to do with their forest, and their stage of life. Owners with fewer acres are less able to diversify investments across different land uses, so enrolling all or most of their property into a carbon program may be seen as riskier and require a higher payment.

The preferred payments for the hypothetical carbon programs described in this chapter come from data collected from landowners in the past. The benefits and costs of forest ownership may be different in the future, due to changes in market opportunities and climate change. This means that what owners value and are willing to accept as payment for carbon in the future may also change.

Tips for Teaching

- Encourage learners to think about their values for forest ownership and how a long-term financial plan will be helpful for sustaining their forest into the future.

Resources for Teaching

How Much Should I Be Paid to Manage Forest Carbon? FOCCE article # 13-01-2022
<https://extension.psu.edu/how-much-should-i-be-paid-to-manage-forest-carbon>

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Chapter 10: Conversions for Comparing Carbon and Timber Values

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Learners often get stuck when trying to calculate carbon credits on their own using forest inventory data, because of how units of measure need to be converted.

Learning Outcomes for This Section

- Units of measure typically used to quantify carbon in timber
- How to convert forest carbon into carbon credits

If an owner decides to delay a timber harvest, then they may want to be compensated for forgoing expected timber revenues for a short time. For the choice to be economically efficient, you would need to compare the value of the timber “today” with the value of the carbon and the timber “tomorrow.” The following conversions will help you keep track of the units describing carbon and timber values. Chapter 11 will discuss how to account for the time value of money.

Conversions for Conventional Forestry Measurements

Foresters traditionally used measurements such as cords or thousand board feet (MBF) to describe the volume of harvested wood. Today foresters are more likely to use English units such as cubic feet (a volume measure) and U.S. tons to quantify wood. Tons and cubic feet are also useful for converting to metric units and calculating the amount of carbon in wood.

A typical rule of thumb for converting a cord of softwood logs (e.g., pine, spruce, and fir species) to tons and pounds (lb) is as follows (1 U.S. ton = 2,000 lb):

$$1 \text{ cord} = 2.68 \text{ tons} = 5,360 \text{ lb}$$

A typical rule of thumb for converting a cord of hardwood logs (e.g., oak, hickory, and beech species) to tons and lb. is as follows:

$$1 \text{ cord} = 2.90 \text{ tons} = 5,800 \text{ lb}$$

Why are there more tons in a cord of hardwoods than softwoods? The specific gravity of wood varies by wood type. Specific gravity is the measure of a wood’s density in comparison to water. If wood were the same density as water, the specific gravity would be 1.00. Hardwood is more dense than softwood.

This is an important consideration since tree species with different specific gravity (along with tree size) will have different amounts of carbon for the same volume. Pines and other softwoods store less aboveground carbon per unit of volume compared to hardwoods such as oak, hickory, and beech. Regardless of the species, the amount of carbon stored will always increase as tree size increases.

Greenwood Weight and Carbon

The term “green” is used to describe wood that has been recently cut and therefore has not had an opportunity to dry out. Typically, the weight of wood is reduced by half when it is kiln-dried, the process of removing moisture from the wood in a large oven or kiln. This means that if a slash pine tree that weighs 989 lb (wood and bark) was cut down and dried, it would only weigh 438.5 lb after kiln-drying.

After estimating a dry weight, most foresters use another convention that assumes that 50% of the wood’s dry weight is solid carbon. This means the 438.5 lb of dried out slash pine wood is expected to contain about 219 lb of carbon. While the 50% rule for estimating carbon works very well for softwood species, it can undervalue hardwoods species since the wood is denser.

Converting Carbon to Carbon Dioxide

Forest carbon remains in a somewhat solid form until disturbed by decomposition or combustion. When oxygen is added, the carbon transforms into CO₂, which acts as a greenhouse gas in the atmosphere. If a forest owner wants credit for carbon storage, it is important to know how much CO₂ is being prevented from entering the atmosphere by delaying harvest.

Carbon has an atomic weight of about 12, and the two oxygens each have an atomic weight of about 16. Adding the weights together (12 + 16 + 16) results in a total atomic weight of 44. In other words, CO₂ has about 3.6667 times the atomic weight of carbon alone. So when making this conversion, 1 unit of carbon equals 3.6667 units of CO₂. In the example for a slash pine tree, the storage of 218.9 pounds of carbon equals 802.7 pounds of CO₂ being prevented from entering the atmosphere.

Converting Carbon Dioxide to Carbon Credits

Carbon credits are sold in metric tons of CO₂ emissions averted from entering the atmosphere. If you are working with pounds of CO₂, that number must be converted to metric tons to calculate prices and conduct trading. An English ton is slightly less than a metric ton. One metric ton of CO₂ emissions avoided for 100 years is equal to 1 carbon credit.

Putting It Together

In a delay harvest scenario, carbon calculations would apply only to the woody biomass grown during the delay in harvest, not the total woody biomass of the stand. The only time the total woody biomass of a stand is used is if the forest was planted by the offset project (e.g., reforestation).

A few examples of how to convert a predicted amount of additional woody biomass into CO₂ emissions avoided can be found in Table 6. Keep in mind that all conversions need to consider: (1) the transfer of values from English to metric units and (2) whether the wood is dry. The final carbon value represents avoided emissions of CO₂.

Table 6. Common forestry units and conversions for use in carbon accounting.								
	Cubic feet (ft ³) ¹	Cubic meters (m ³)	Wood wet (lb.)	Wood wet (U.S. ton) ²	Wood dry (U.S. ton) ³	Wood dry (metric ton) ⁴	Carbon (metric ton) ⁵	CO ₂ (metric ton) ⁶

a. 1 cord of green stacked pine logs, with space for air and bark (128 ft ³)	128	3.62	5,360	2.68	1.34	1.20	0.60	2.20
b. 1 cord of green stacked pine logs, with the space for air and bark removed	90	2.54	5,360	2.68	1.34	1.20	0.60	2.20
c. 2,000 lb of green pine wood and bark	29	0.822	2,000	1	0.50	0.45	0.22	0.81
d. 2,000 lb of green mixed hardwood, wood, and bark	28	0.787	2,000	1	0.60	0.54	0.27	0.99

¹ Divide cubic feet by 35.315 to calculate cubic meters.

² 1 cord = 2.68 tons = 5,360 lb

³ Wood dry weight is typically 50% of the wet weight for softwood and 60% for hardwood.

⁴ 1.10231 U.S. ton = 1 metric ton. To convert from U.S. tons to metric tons, multiply by 0.9.

⁵ About half of the dry weight of wood is carbon.

⁶ 1 unit of carbon equals 3.6667 units of CO₂.

In scenarios (a) and (b), the cubic foot volume of wood is slightly different because one scenario includes the space between the logs and the other does not. This doesn't affect the weight; they are both 5,360 lb., but if you intend to calculate weight based on cubic feet, you need to account for the gaps between logs (solid weight).

Since we know the weight of a green pine cord in pounds, we can calculate the number of tons by dividing 5,360 lb by 2,000 lb (the weight of 1 U.S. ton), to arrive at 2.68 tons. Green wood weighs about twice as much as kiln-dried wood, so to calculate the dry weight, the green value is then divided by 2 to arrive at 1.34 tons of dry wood.

The U.S. ton (2,000 lb.) is somewhat less than a metric ton (2,205 lb). To convert from English to metric units, 1.34 tons is multiplied by 0.90 to get 1.20 tons. To estimate carbon, the total weight of the dry wood is divided in half, so that 1.20 tons of dry wood is estimated to have 0.60 tons of carbon. Finally, to determine how much the carbon stored represents as avoided CO₂ emissions, the carbon value is multiplied by 3.6667 (because CO₂ has about 3.6667 times the atomic weight of carbon alone) to get 2.20 metric tons of CO₂ avoided.

Moving on to scenarios (c) and (d), we understand the weight in 1 U.S. green ton is always 2,000 lb. The cubic foot volume of wood in these scenarios is slightly different, however, because one contains pine species and the other contains mixed hardwood species.

The dry weight of the pine is expected to be about 50% of the wet weight. However, the dry weight of hardwoods is a little more, with the wood sometimes representing 60% of the wet weight and water representing 40% of the wet weight.

To convert from English to metric units, the ton value is multiplied by 0.90 to get 0.45 and 0.54 tons, respectively. The amount of carbon in dry wood is assumed to be half the weight of dry wood, or 0.22 and 0.27 tons, respectively, in this example. These values are then multiplied by 3.6667 because CO₂ has about 3.6667 times the atomic weight of carbon alone to get 0.81 and 0.99 tons of CO₂, respectively. Notice that 1 ton of green hardwood can sometimes equal almost 1 ton of CO₂ emissions sequestered.

Closing Thoughts

The CO₂ emissions sequestered represents only part of the value of a carbon credit sold in a carbon market. The price of a carbon credit also depends on guarantees that the offset will be permanent (100+ years) and will not result in leakage (i.e., cause harvests in other regions to increase). Forest owners may find that carbon payments tend to be higher for projects with longer contracts.

Any financial comparisons need to consider changes in value at future points in time and subtract any current or future costs to be incurred—for example, tree planting and management costs. This will be discussed in the next chapter.

Tips for Teaching

- The conversions shown in Table 6 may help learners be able to assess their property before contacting a carbon program, but learners should be aware that they may not always arrive at the same numbers as the project developer.

Resources for Teaching

Conversions Commonly Used When Comparing Timber and Carbon Values. FOCCE Article # 09-03-2022 <https://extension.psu.edu/conversions-commonly-used-when-comparing-timber-and-carbon-values>

Pine Timber Volume-to-Weight Conversions. Mississippi State University Extension. <http://extension.msstate.edu/publications/pine-timber-volume-weight-conversions>

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Chapter 11: Long-Term Financial Planning for Timber and Carbon

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Owners who depend on their forest for some income should consider financial planning as part of their stewardship activities.

Learning Outcomes for This Section

- Identifying important costs and benefits
- The value of time
- Barriers to investment

A financial plan is just like the creamy center of an Oreo cookie (Figure 15). It helps bring together the owner's management activities and long-term goals. One way to approach a financial analysis is to determine at what point carbon payments to the owner can add value to the stand (i.e., land expectation value), but also exceed opportunity costs. The costs and benefits associated with forests can vary significantly depending on the owner's values, management objectives, and forest conditions.



This chapter introduces how to make financial estimates for both timber and carbon in two scenarios, reforestation and a delay in harvest.

Identify Harvest Rotations

A key consideration in financial planning is deciding on the harvest rotation interval or time of final harvest. A clear-cut harvest is used in even-aged management strategies, and the rotation interval represents the lifetime of the stand before it is clear-cut. Uneven-aged management strategies are more often used in natural forests and the rotation refers to the frequency with which individual trees are selected and harvested over time (i.e., cutting cycle). The example used in this chapter is an even-aged pine stand, but the lessons are still useful for understanding the long-term financial implications for either approach.

Establishing a rotation interval or cutting cycle is also useful for helping owners get better prepared for upcoming harvests (e.g., operations planning, hiring forestry and tax consultants). For example, hiring a forestry professional to make a harvesting plan can help ensure that the owner's intentions are carried out while also practicing sustainable forestry. Forestry professionals can help owners avoid violating any local or state regulations related to zoning, transportation, or environmental quality. Being aware of tax provisions before your income taxes are due can also help maximize financial returns.

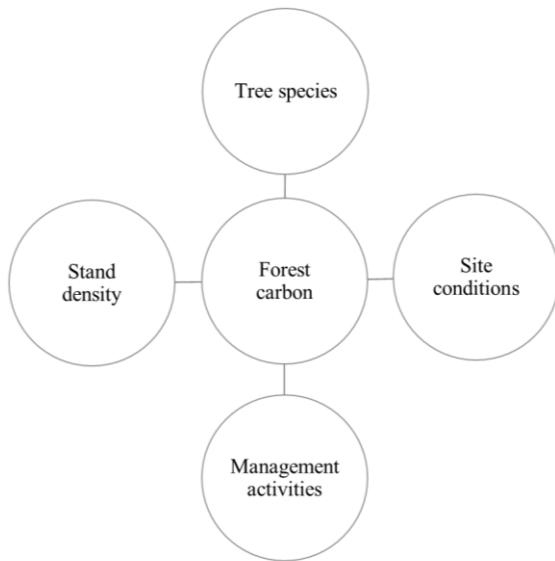


Figure 16. Factors that influence the rate of forest growth and carbon sequestration.

Consider Management Costs

Forests that grow quickly can be harvested at shorter intervals than forests that are slower growing. Faster growing forests also have higher rates of carbon sequestration. How quickly a forest grows depends on factors such as type of tree species (e.g., evergreen conifer versus hardwood species), site conditions (e.g., soil quality, erosion, annual rainfall), and number of trees per unit area, which influences competition among trees (e.g., for water, light, nutrients) (Figure 16).

Management activities also influence how quickly trees grow and can include site preparation activities. There is also site prep for naturally regenerated stands.

Examples of common labor costs and management costs include the application herbicides to control competition between crop trees and undesirable plants, pesticides to help reduce disease and infestation, and fertilizers to help improve sites where nutrients are limiting. Accounting for differences in tree species, stand quality, and associated management costs is part of smart financial planning.

The Value of Time

Owning forests is a long-term investment, which requires a special kind of accounting. For example, payments for timber occur only after the harvesting occurs at some point in the future. Since money is more valuable today than in the future, it is necessary to use discounting to “bring back” those potential revenues from the future and compare them with other options today using the same baseline (discounting effect). These calculations are shown below. Keep in mind that as trees age they also grow bigger and generally become more valuable, but that value declines when the payout is further in the future (Figure 17).

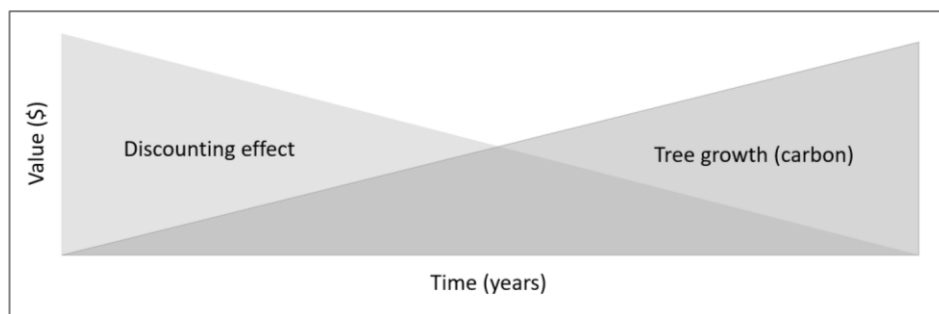


Figure 17. Inverse relationship between value and tree growth.

Scenario A: Financial Plans for Timber Production

This section describes the value of investing in tree planting for the purpose of timber production. Maximizing timber production, or often the maximization of financial returns, is often considered the “business-as-usual” scenario in carbon incentive programs. The best way to account for the value of time in timber production is to estimate the “present value” of future harvests based on rotation lengths. Using current timber market prices, 1 acre of slash pine at age 25 is estimated to produce timber benefits of up to \$8,314 per acre (Table 7).

Table 7. Forest product yield estimates, timber prices, and total timber benefits at 25 years.

Product	Cubic feet per acre	\$ per cubic feet	Total revenues \$ per acre
Sawtimber	7,421	0.76	7,421 * 0.76 = 5,640
Chip and saw	3,018	0.55	3,018 * 0.55 = 1,660
Pulpwood	3,495	0.29	3,495 * 0.29 = 1,014
Total			\$8,314
Yields of sawtimber, chip and saw, and pulpwood are from Pienaar et al. (1996). Timber prices were obtained from Norris Foundation (2022).			

The problem is that the slash pine stand is only 1 year old today, so the timber benefits can be captured only 24 years in the future. To make useful comparisons with other management alternatives, all estimates need to be converted to the present value.

To determine the present value (PV) of the timber benefits, we use the following formula:

$$PV \text{ timber benefits} = \frac{\text{Future value of timber benefits}}{(1+r)^t} \quad (4)$$

In this equation, t represents time until harvest, and r represents the discount rate (i.e., the opportunity cost of the capital invested in the forestry investment). In many forestry models, the discount rate is set at 3%.

$$PV \text{ timber benefits} = \frac{\$8,314}{(1+0.03)^{25}} = \$3,970 \text{ per acre}$$

Here we find that \$8,314 per acre obtained at age 25 years in the future is the same as \$3,970 per acre today.

Forests grow more quickly when they have more space to grow. Thinnings and select harvests at designated times can help make more space in the forest and help generate small amounts of income in the near future. In this example a thinning occurs at year 15 and provides an income of \$350 per acre. The present value of all the timber benefits throughout the entire 25-year rotation is:

$$\begin{aligned}
&PV \text{ timber benefits} \\
&= \text{present value of thinnings} + \text{present value of final harvest} \quad (5)
\end{aligned}$$

$$PV \text{ timber benefits} = \frac{\$350}{(1 + 0.03)^{15}} + \frac{\$8,314}{(1 + 0.03)^{25}} = \$4,195 \text{ per acre}$$

Likewise, we need to determine the present value of management costs that occur over time. All costs in this example were obtained from Maggard (2021). For example, the present value of a fertilization cost (\$87 per acre) at age 5 years can be calculated as follows:

$$PV \text{ fertilization} = \frac{\$87}{(1+0.03)^5} = \$75 \text{ per acre}$$

If there is a second and third fertilization at ages 12 and 16 years (\$87 per acre each), the costs would be calculated like this:

$$\begin{aligned}
PV \text{ costs} &= \text{present value of fertilization 1} + \text{present value of fertilization 2} \\
&+ \text{present value of fertilization 3}
\end{aligned}$$

$$PV \text{ costs} = \frac{\$87}{(1+0.03)^5} + \frac{\$87}{(1+0.03)^{12}} + \frac{\$87}{(1+0.03)^{16}} = \$190 \text{ per acre}$$

Fertilization is a more common practice in pine plantations. In natural forests costs may be those associated with pesticide and herbicide applications to help protect forest health. There may also be some annual costs that are assumed to have the same value over time, such as maintenance of property boundaries, legal fees, and property taxes. The formula to calculate the present value of a cost that occurs every year and is of the same value is:

$$PV \text{ of static cost} = C \left[\frac{(1+r)^t - 1}{r(1+r)^t} \right] \quad (6)$$

where C is the annual management cost. For example, if the annual management cost is \$52 per acre, the present value of this amount over 25 years is

$$52 \left[\frac{(1 + 0.03)^{25} - 1}{0.03(1 + 0.03)^{25}} \right] = \$905 \text{ per acre}$$

If you are planting a new forest, most of the planting costs occur in the first year, so these values do not need to be discounted. In this example the planting cost is \$376 per acre (e.g., costs of seedlings, site preparation, physical planting of the seedlings).

The difference between the present value of cash from the timber harvest and the present value of management costs gives the *net present value* (NPV) of that management scenario at a 25-year rotation interval (Table 8).

Table 8. Determination of the net present value (NPV).

PV of timber benefits (\$ per acre)	PV establishment costs (\$ per acre)	PV fertilization costs (\$ per acre)	PV annual costs (\$ per acre)	Total PV of costs (\$ per acre)
4,195	376	190	905	1,471
Benefits – costs = \$4,195 – \$1,471 NPV= \$2,724				

Scenario B: Financial Plans for a Reforestation Carbon Sequestration Project

This section describes the value of investing in tree planting for the purpose of carbon sequestration services (i.e., reforestation). The baseline amount of carbon is zero because there are no trees yet. Any carbon sequestered in the woody biomass grown over the next 25 years can be considered additional carbon and receive payment. Keep in mind that reforestation carbon projects are often intended to establish a permanent forest, depending on the type of project. Payments may occur for a limited number of years.

Assume that after 25 years 1 acre of slash pine sequesters a total of 110,000 pounds of carbon, or 50 metric tons of carbon. The amount of carbon sequestered each year increases as the trees grow, up to a certain point. Carbon sequestration values are estimated for each year based on the amount of carbon sequestered between two periods of time. For example, if the amount of carbon stored during year 2 is 0.08 metric tons per acre, and the carbon price is \$10 per metric ton, then the value of carbon sequestered in year 2 is \$0.80 per acre. This value can be realized only at the end of year 2, so the present value of carbon benefits at year 2 are:

$$PV \text{ carbon benefits between years 1 and 2} = \frac{\$0.80}{(1+0.03)^2} = \$0.76 \text{ per acre}$$

Present values for carbon benefits are always calculated at the end of each year and should not include the values from previous years. Each year must be discounted separately because the amount of carbon stored each year differs as the trees grow. At the end of the contract the present value of each year is summed to provide a total present value, as shown in the following equation.

$$PV \text{ carbon benefits} = PV \text{ carbon benefits at age 1} + PV \text{ carbon benefits at age 2} + PV \text{ carbon benefits at age 3} + \dots + PV \text{ carbon benefits at harvest age} \quad (7)$$

You can see how calculations are made for each year by following the payments schedule in Table 9. It shows that the total net present value of carbon sequestration at year 25 is \$320 per acre.

Table 9. Total net present value (NPV) of carbon sequestration in metric tons.

Year	Total carbon stored (metric tons)	Annual difference in carbon stored (metric tons)	Revenue x carbon (\$/acre)	PV of carbon (\$/acre) ^a	Annual total NPV of carbon (\$/acre)
1	0.03	0.03 - 0 = 0.03	\$10 x 0.03 = \$0.30	\$0.3/1.03 ¹ = \$0.29	\$0.29
2	0.11	0.11 - 0.03 = 0.08	\$10 x 0.08 = \$0.80	\$0.8/1.03 ² = \$0.76	\$0.29 + \$0.76 = \$1.05
3	0.28	0.28 - 0.08 = 0.17	\$10 x 0.17 = \$1.70	\$1.7/1.03 ³ = \$1.56	\$1.05 + \$1.56 = \$2.62
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
24	47.9	.	.	.	. = \$309.10
25	50.2	50.2 - 47.9 = 2.3	\$10 x 2.28 = \$22.80	\$22.80/1.03 ²⁵ = \$10.90	\$309.10 + \$10.90 = \$320.00

^a PV of carbon = change in value of C sequestered over last year (\$) / (1 + discount rate)^t

The most notable finding here is that timber production is still the more profitable land use when carbon payments to owners are at \$10 per metric ton of CO₂. The carbon payments would have to approach \$23 per metric ton of CO₂ to start competing with timber production as a financial investment in this scenario. Since the benefits of selling carbon in a reforestation project may not be realized for several decades, programs that lease the land from the owner for a reforestation project can help provide revenues to owners more quickly, because the payments are part of the lease and not the carbon sequestration service.

Scenario C: Financial Plans for a Delay-in-Harvest Scenario

The example in this section focuses on an owner who decides to delay harvest to sequester more carbon. The owner was offered \$10 per acre per year to delay harvest for 5 years in a 25-year-old stand. It had already been determined that the total amount of carbon in the 25-year-old stand was 110,000 pounds or 40 metric tons per acre, and this would serve as the baseline. Assume the the amount of carbon stored in the coming year is 2.3 metric tons per acre. At \$10 per metric ton of carbon, the first payment would be \$23.00 per acre, but this value can be realized only at the end of year 1. So, at a discount rate of 3% the present value of carbon benefits at the end of the year 1 delay are:

$$PV \text{ carbon benefits between years 0 and 1} = \frac{\$23.00}{(1+0.03)^1} = \$22.33 \text{ per acre}$$

Just as before, the present value for each year is calculated separately and summed to calculate a total present value for this scenario. The total present value of carbon sequestration at year 5 of the delay is \$114.22 per acre (Table 10).

Table 10. Total NPV of carbon sequestration in metric tons after 5 years.

Harvest delay year	Total carbon stored	Annual difference in carbon stored	Price x carbon	PV of carbon	Annual total NPV of carbon
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	(metric ton)	(metric ton)	(\$/acre)	(\$/acre)	(\$/acre)
1	40	42.3- 40.0=2.3	\$10 x 2.3= \$23.00	\$23.00/1.03 ¹ = \$22.33	\$22.33
2	42.3	44.7- 42.3=2.4	\$10 x 2.4= \$24.00	\$24.00/1.03 ² = \$22.62	\$22.33+\$22.62=\$44.95
3	44.7	47.2- 44.7=2.5	\$10 x 2.5= \$25.00	\$25.00/1.03 ³ = \$22.87	\$44.95+\$22.87= \$67.83
4	47.2	49.8- 47.2=2.6	\$10 x 2.6= \$26.00	\$26.00/1.03 ⁴ = \$23.10	\$67.83+\$23.10= \$90.93
5	49.8	52.5- 49.8=2.7	\$10 x 2.7= \$27.00	\$27.00/1.03 ⁵ = \$23.29	\$90.93+\$23.29= \$114.22

To help determine when it is economically efficient to delay harvest, it is important to compare rates of change in value over time. The rate at which the carbon payment increases the total value of the stand should be faster than the rate of losses due to a delay in timber revenues. In this example, carbon payments increase the value of the stand by \$114.22 per acre. The value of the stand also increases by \$287 per acre due to new forest growth, but that value today is worth only \$236 per acre, due to discounting. So, waiting 5 years to harvest increases the total value of the stand by \$350.22 per acre (\$114.22 + \$236.00). There are some important caveats to consider however:

- At some point in the future the value of adding carbon payments may not exceed the cost of waiting to harvest. This is because the rate of carbon sequestration will start to slow down, as trees mature. The value of the harvest may also decline if it is set far enough into the future. Rates of change can vary across forest types, management strategies, and site quality.
- It difficult to predict future land values. Timber markets may change. An extreme event (e.g., storm, wildfire, disease) may decrease the total value of the stand within the delay period, by releasing the stored carbon, or causing damage to timber stocks.
- A discount rate of 3% is typically used in forestry projects, but this may not represent real costs of delay for all forest owners. If the owner is in debt at a higher interest rate, the cost of waiting for revenues could be more expensive. It may make more sense to pay down the total debt with a harvest instead of using the carbon payments to pay off the interest. It is important to account for all types of costs in a financial plan.
- Similarly, some owners may not have enough financial flexibility to wait until the end of a carbon contract to get paid, even if land values increase significantly by waiting.
- Delaying harvest for a short period (e.g., 5–10 years) can also impact revenues for the next generation, because the next generation will have to wait just that much longer before the stand is at optimal age for harvest. However, this may not always be the case for uneven-aged stands and when select harvesting methods are used.

Cut or wait decisions are common among forest owners, even if carbon programs are not available. Owners who have a strong land ethic are generally interested in making decisions that help protect forests in the future, as part of their stewardship legacy. Involving forestry professionals in the planning process is important for including the unique characteristics of individual properties and addressing the financial goals of the forest owner.

Closing Thoughts

The slash pine illustrations used here are based on densely planted, even-aged, fast-growing pine species and not typical of all forests. The estimated values are for illustration only and not intended to directly represent any individual property. Financial estimates can be dramatically different for every case depending on forest type, costs, and market prices.

Not every financial plan needs to be economically efficient or justified. Some owners may be willing to forgo revenues because they care about being a climate steward or simply want to enjoy the forest aesthetics. It is important for owners to have a clear understanding of which management objectives are a priority so that personal values are also included in decision-making.

The price of CO₂ on the voluntary market was generally around \$5 per metric ton for forest projects in 2022. When making a financial plan, keep in mind that the price of carbon traded in a carbon market may not reflect how much a forest owner may be paid. Owners who consent to shorter commitments to delay harvest provide fewer climate change mitigation benefits and this may impact payment levels. Commission payments for project investors and managers are also represented in carbon market prices.

Tips for Teaching

- Encourage learners to think about how they approach decisions for auto and home loans, which are also long-term investments with different rates of return.

Resources for Teaching

- Long-Term Financial Planning for Timber and Carbon. FOCCE article # 06-02-2022 <https://extension.psu.edu/long-term-financial-planning-for-timber-and-carbon>
- Determining the Net Present Value of Timber Investments and Comparing Investments of Different Rotations. University of Florida Extension. <https://edis.ifas.ufl.edu/publication/FR421>

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Part 4: Preparing Owners to Be Part of the Carbon Economy

Chapter 12: What Should Forest Owners Think about Before Signing a Carbon Contract?

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A key part of enrolling in a carbon program is signing a contract that spells out landowner responsibilities and administrative details.

Learning Outcomes for This Section

- Stewardship values and finding a contract with a good fit
- Expectations for forest owners
- Types of carbon credits
- Clauses and exemptions
- Oversight and accountability

Finding a Good Fit

Many owners are interested in enrolling in a carbon program to help support the costs of forest ownership. However, owners should also consider how involvement in a carbon program aligns with their broader management objectives, since many contracts constrain which management actions can be taken and some require long commitments. To help navigate this decision, it is important for owners to work with a professional forester. Professional foresters can point out the long-term implications of certain management actions within a stand and make recommendations that support the owner's long-term management objectives.

Enrolling in a program is more than a financial opportunity; it is also an implied collaboration with the project developer and the organizations buying the carbon offsets. Most carbon offset programs that work with family forest owners are new and looking to scale up. This means landowner enrollment in their program is essential to their success. Forest owners may want to consider if their own values and ethics are reflected in the transactions and who they sell the carbon to. Owners can learn more about an organization by talking to their representatives, other participating landowners, and conservation professionals, and by reviewing the company's website. Many carbon offset programs will share a list of their buyers upon request.

Taking part in a new market will involve some up-front time commitment on the owner's part. This is because owners should learn and consider all the program options available in the area, have discussions with trusted advisers, and work with the representatives of the carbon program to determine whether their forest may qualify. If their forest does qualify, then setting up a contract may also take some time since the carbon being sold needs to be verified and negotiations should be made with the advice of forestry and legal professionals. In some cases, delaying the decision to enroll may be the best option until certain concerns are resolved or new opportunities become available.

Management Obligations

Management is the most important part of a carbon payments program, as management activities done (or not done) impact the forest, surrounding ecosystems, and climate for decades. Carbon

programs pay forest owners to change their management practices so that the forest sequesters more carbon than it would have otherwise. This “additional carbon” storage is the product being sold to buyers who want to offset their carbon footprint.

Carbon offset project developers have criteria for selecting which forests and participants are more likely to provide additional carbon storage. This is why carbon brokers will often target specific landowners with a phone call, flyer, and other advertisements. Forest owners also have an ethical obligation to determine whether their own forest is a good fit for climate change mitigation. They can do this by asking themselves two important questions:

- (1) Are the requested management activities a real change from the management activities I already planned to do?
- (2) Are the requested management activities still in alignment with my broader management objectives and will they keep my forest healthy?

The answer to the first question points to whether the change in carbon storage was intentional and additional. The answer to the second question points to whether changes in management will be sustained into the future.

It is highly unlikely that management obligations will be the same from program to program, or even contract to contract. This is because project managers are constantly updating protocols and procedures for managing and measuring carbon in forests. Some programs may also make customized management recommendations for your forest. Most carbon programs prefer to use protocols that are easy to scale up and provide an expected return on investment for their organization. This means that some options may not work for the needs and conditions of some forest owners. If the opportunities available currently are not a good fit for a landowner, it is reasonable to expect that new options may come up in the future as programs evolve.

Carbon registries are responsible for approving carbon offset project protocols, and they also track the selling and buying of carbon. Some of the more well-known forest carbon registries are Verra and the American Carbon Registry.³ Registries determine the types of forest management practices that are well suited for sequestering additional carbon. The practices with the highest assurance of additional carbon storage typically involve creating new forests in places where forests have been removed or are unlikely to occur (e.g., minelands).

In places where forests already exist, “improved forest management” (IFM) practices are often recommended. The goal of these practices is to extend the life of the forest, help the forest grow more quickly, and/or manage at higher stand densities. Specific activities may include extending harvest rotations, placing limitations on how much wood may be removed from the stand, and reducing carbon emissions associated with harvesting activities. Beyond IFM are other climate-smart forest practices, including activities that help reduce risk of wildfire, pests, and disease and improve natural regeneration (i.e., successful growth of younger trees). Carbon payment

³ The authors do not endorse the organizations mentioned.

programs are generally focused on incentivizing a few select practices, depending on the original condition of the forest.

Carbon program representatives will often initiate discussions by describing the types of management practices generally required in their programs. However, the activities outlined in the contract will likely be specific to the owner's property. To review specific activities, look for a section in the contract titled "Responsibilities." Owners should verify that the obligations in the contract reflect prior discussions and what they have come to understand during the negotiation process. It is also important that owners verify that they are only selling the carbon that will be stored on their land, or their "carbon rights," and not any other non-agreed-upon rights, such as timber or mineral rights. If the owner finds something new or confusing when reviewing the contract, they should not sign it. Owners should ask the program representative for clarification and solicit advice from legal professionals.

Time Commitments

Specific time commitments are also generally found in the "Responsibilities" section of the contract. Like management obligations, time commitments can also vary from program to program and even contract to contract. Programs that require very long contracts are usually constrained by the protocols that they follow.

The protocols advanced by the California Air Resources Board ([CARB](#)) require payments for the landowner for around 25 years and then an additional 100-year monitoring period in which there is no payment. Projects that use CARB-supported protocols are generally able to sell carbon on the California-Quebec Carbon Market, which is a regulated market. Regulated markets are controlled so that prices increase as new caps are put on CO₂ emissions. The average price of carbon credits sold on a regulated market is typically higher than credits sold on an unregulated market.

Programs that do not work with CARB-supported protocols are very often selling into the voluntary carbon market. The voluntary market is more independent and uses third-party verification procedures to support claims that a carbon project meets a set of standards for generating a legitimate carbon unit that can be sold. Programs that sell carbon on the voluntary market can use protocols that allow for shorter contract periods, ranging from 1 to 100 years, but many have terms of 20–40 years.

Carbon Units

The carbon units sold vary in how they are formulated, which can be confusing for some forest owners. The reason for developing different carbon accounting approaches is to attract different kinds of carbon offset buyers. For example, the protocols approved by Verra are used to issue "Verified Carbon Units." The protocols approved by the American Carbon Registry are used to issue "Emission Reduction Tons." In both cases, the unit or credit that is being traded is a guarantee that the impacts from 1 ton of CO₂e emissions (carbon dioxide and equivalent greenhouse gases) will be offset for at least 100 years.

Payments

The payment schedule generally has its own section in the contract. Each carbon program differs in the allocation of payments for carbon credits. Some programs provide payment based on the

types of management practices implemented and are similar to a cost-share arrangement (e.g., dollars per acre per year). Other programs provide payment based on how many metric tons of emissions have been offset within a designated time frame.

The shorter the contract, the more likely the payment will arrive at the end of the contract, after verification procedures are done. For longer contracts and for some management practices, payments are arranged in a variety of ways so that up-front costs are covered, but future payments may also be expected.

In some contracts, owners may be offered a percentage of the credit sale each year (e.g., revenue sharing). This percentage can be spread evenly throughout the contract or weighted more heavily at certain periods (e.g., the beginning or the end). Owners should verify if a percentage of credit sale allows them to benefit from changes in carbon prices.

Sometimes the program will allow the owner to negotiate a price and possibly respond to market conditions. However, this may be a challenge for some owners since the market price of carbon credits can be different from project to project, and many landowners do not completely understand the opportunity costs for family forest owners. It may be helpful to consider what other forest owners think is fair compensation for forgoing certain land uses.

Project developers, managers, and other project partners (e.g., consultants) receive a commission for organizing the project. The commission rate and how it is allocated is generally not disclosed in a contract with forest owners. If this information is important to the owner, they should ask the program representative. Keep in mind that sometimes commissions can be based on thresholds in landowner enrollment.

In general, most landowners prefer to receive more money up front. Having money up front allows them to buy seedlings and perform needed management activities, and acknowledges the uncertainty related to future conditions. Most carbon programs, however, prefer to weight payments toward the end of the contract to ensure that landowners will comply with the program. It is important for owners to decide which payment arrangements are acceptable before entering negotiations; otherwise the owner may end up with “less” money than expected because some payments are available only in the future. To address this concern, some programs will offer an advance or down payment to encourage entry into the program and then a regular schedule of payments for the remainder of the contract.

Time Value of Money

Understanding the value of money in the future is critical for making economically efficient decisions about forest investments. The ability to acquire wealth depends on making accurate comparisons between alternative outcomes. Given the slow growth of trees, it can take 1–125 years for a carbon contract to be completed. While this may be a short time for trees, it is a long time for people. The financial impact of changing management activities can be very different under different payment structures.

Some other considerations also need to be made when payments occur in the future, such as predicting what may happen in the meantime. Delaying harvest can come with some risks. For

example, at year 3 a hurricane could blow down the forest, which would kill the trees and make a future harvest impossible or much less valuable. In this case, the interest rate used to generate estimates for planning and decision-making could be adjusted to reflect the owner's assessment of risk level.

Clauses/Exemptions/Violations

As with all contracts, it is very important for landowners to thoroughly read and understand what is expected when things go to plan, and what can be expected when things do not go to plan. Landowners need to read all the clauses in the contract, as they provide a legal and binding definition of important points, such as how to handle land transition and what may cause the contract to be terminated. Many carbon programs also have specific methods for designating property heirs or specific reporting requirements for land management actions.

Many contracts contain "exclusion clauses," which describe how a party to the contract may be eliminated with no fault (e.g., a flood wipes out a forest). The "limitation clauses" describe limits to compensation for certain unexpected damages. Landowners also need to understand what the contract defines as "an act of God," what is "intentional," and how disputes are resolved.

In most cases, activities such as collecting firewood and recreation are allowable. Other legal arrangements, such as hunting leases and conservation easements, may also be allowable under certain circumstances. Prescribed fire could be an allowable management practice if it is recognized as an approved management practice in the standards and protocols used by the project developers.

An accidental release is when a natural disturbance (e.g., wildfire, hurricane, pests) causes many unexpected tree deaths, which increases carbon emissions from the forest via conditions that are deemed "unavoidable." Carbon programs that use approved protocols often have a carbon pool or buffer that they use to cover any accidental release. Owners need to understand if they may benefit from these types of insurance protocols wrapped into a project.

An intentional release is when more harvesting occurs than is allowable by the legal forest carbon contract within the designated area and during a given period. This action increases the expected carbon emissions from the forest via activities that are deemed "avoidable."

When landowners sign a carbon contract, they are fully responsible for ensuring that the management laid out in the contract is carried out, so it is critical for them to understand the management obligations that they have agreed to. For some owners, certain management obligations may not be feasible or may be overly burdensome. Owners should try to negotiate what they think are overly challenging parts of the contract with the help of a legal professional. If negotiations fail, they should not hesitate to walk away. There are other programs available and violating a contract may end up costing more than the contract is worth. Keep in mind that it is much easier to address questions or disagreements about the contract or clauses prior to signing.

New carbon programs are coming online quickly and are looking to grow. Many are in the early stages of implementation. The contracts they create will likely evolve as they gain more

experience working with landowners. In the meantime, don't expect that carbon programs will be able to fully account for the owner's interests when designing a contract. Carbon programs have legal representatives who give them advice about how to protect their investments, and owners should take the same consideration when it comes to their own assets. It is good practice to work with legal and forestry professionals before signing a contract to check for unreasonable risk and alignment with landowner objectives. Keep in mind that since carbon markets are relatively new, it may be difficult to find professionals who work specifically with carbon markets, but some expert advice is better than none.

Accountability and Oversight

The buyers of carbon credits want to know that the offsets they are buying are real, so carbon programs include assurances that participating landowners are complying with the contract. As such, owners should expect that buyers and third-party verifiers may want to access their property throughout the duration of the contract, and possibly a short time after completion of the contract. While on the property, the verifiers or the carbon contract holder may conduct measurements to assess carbon sequestration and examine forest management activities. At the end of the contract period, additional verification will also likely occur before final payments for the contract can be issued.

Contract Renewal

Once a contract is completed, owners may consider renewing their carbon contract. To help with this decision, owners should take occasional notes about their experience in the program to help remember things such as disputes and how they were resolved, if there were opportunities missed, or what good outcomes came from being enrolled. Forest owners also need to consider that over the length of the contract their forest will change—trees age, forest pests attack, and weather events happen. As the end of the contract approaches, forest owners should work with a professional forester to assess the condition of their forest to determine (1) if their forest can still qualify, and (2) if re-enrollment in the program still aligns with the landowner's broader management objectives. If the property is inherited with a carbon contract, a renewal should be considered only if the objectives of the new owner are still in alignment with the program's requirements. Forest owners should always thoroughly read the contract and work with legal and forestry professionals before renewing a contract.

If the owner is considering enrollment in two different programs, one right after the other, it is important to consider if the second program has a conflict with this approach. Carbon projects differ in the types of protocols they use to quantify carbon. Project developers also must make some assumptions about landowners' "business-as-usual" behaviors, which indicate how much carbon they have available to sell and how to avoid double counting the carbon. Be sure to talk to carbon program representatives to find out if back-to-back enrollment is allowed or if a time delay in between is required.

Tips for Teaching

- It may be useful to have an example contract to show owners what to expect; however, carbon programs may change their contracts from time to time.

Resources for Teaching

- What Should I Think about Before Signing a Forest Carbon Contract? FOCCE article # 08-01-2022 <https://extension.psu.edu/what-should-i-think-about-before-signing-a-forest-carbon-contract>
- Questions to Ask Before Joining a Carbon Program. FOCCE article 12-1-2021. <https://extension.psu.edu/questions-to-ask-before-joining-a-carbon-program>

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Chapter 13: Stories from Landowners Who Have Enrolled in a Carbon Contract

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Landowners often learn what to expect from a new program by talking to other landowners. This section presents stories from five landowners who enrolled in a carbon incentive program.

Learning Outcomes for This Section

- How owners compared different carbon programs in their area
- What it is like to enroll in a carbon program
- How owners see carbon programs as a fit for their management objectives

Case Study 1: The Wilsons

The Wilsons are active forest landowners in Bedford County, PA. They own roughly 135 acres of land; 130 acres are forest, and the other 5 acres are gardens, chicken coops, and native habitat. They have owned the land for more than 35 years, and they manage the forest to enhance biodiversity and conserve it for future generations. In 2010, they donated the development rights to the Western Pennsylvania Conservancy through a conservation easement. The management they conduct includes harvesting timber and deer, installing deer fencing, and controlling invasives species to help promote healthy forests.

To help improve their management activities, the Wilsons are always looking to learn new things about their forest. For example, they have worked with their local Pennsylvania Department of Conservation and Natural Resources (DCNR) service forester, USDA Natural Resources Conservation Service (NRCS) forester, Penn State Extension agent, Forests for the Bay staffer, and PA Game Commission wildlife diversity biologist, and are certified Forest Stewards. These experiences and relationships led them to join the Golden-Winged Warbler Conservation Program (the golden-winged warbler is a near-endangered bird that needs early successional habitat). With funding through the USDA Environmental Quality Incentives Program (EQIP), a conservation program that helps farmers, ranchers, and forest landowners integrate conservation into working lands, they conducted a seed tree harvest on 30 acres of their forest in 2014. This harvest opened the canopy and created excellent habitat for the golden-winged warbler.

Through their experiences, the Wilsons were made aware of forest carbon markets and became interested in learning how their forest could help support climate change solutions. Of primary importance to the Wilsons was being able to create small openings in the canopy to support a

diversity of birds and native plants by harvesting timber. Another important objective was to protect the forest for future generations, so they were willing to consider a multiyear contract. After investigating their options, they figured out that they would likely qualify for programs offered by the [Natural Capital Exchange](#) (NCX) and by the [Family Forest Carbon Program](#) (FFCP) of the American Forests Foundation.

One of the ways they learned more was by talking to their friends. After exchanging some emails, they predicted that enrolling in NCX and delaying harvest for 1 year would provide about \$8 an acre. Applying this value to their 100 acres of mature forest, this would provide a total of \$800 for 1 year. The Wilsons had to talk to a representative at the FFCP to learn more about how they may qualify. The FFCP offered the Wilsons \$280 an acre to help with competing plant control in the 30 acres of warbler habitat (as part of FFCP's Enhancing the Future Forests program) and \$230 an acre for the 100 acres of mature forest (through FFCP's Growing Mature Forests program), which totaled \$31,400 over a 20-year contract. To help make comparisons between programs, the authors of this chapter estimate that the FFCP payments for the Wilsons would have an average annual net present value of \$4.00 per acre (3% discount rate). Assuming they would get about \$8 per acre from NCX for the next 20 years, the authors of this chapter estimate the NCX payments would have an average annual net present value of \$2.60 per acre (3% discount rate). All NCX contracts are for 1 year and payment levels are renegotiated each year, which means future payment levels could increase or decrease based on supply and demand. Since the FFCP incentivized management activities were in line with their forest management objectives, the Wilsons elected to participate in the FFCP program.

Joining FFCP involved a multistep process. They already had a forest management plan, but joining FFCP meant they needed a new forest management plan written by an approved forester. Forests for the Bay had offered almost \$1,000 to help them write a new forest management plan and FFCP also gave them \$800 to supplement the cost of writing a plan, but it was a challenge for them to find a forester who would write one for under \$2,000. After 2 months of trying to find a forester, they were finally able to find a forester who wrote a plan that met the criteria for both programs. The Wilsons are now fully enrolled in the FFCP. After this article was initially published, FFCP updated their policy to allow foresters on their staff to write plans for landowners. This may reduce the barriers to entry for landowners and reduce time to enrollment.

Case Study 2: Linda

Linda had been a small business owner in Philadelphia, but with the economic crunch caused by COVID-19, concerns over her aging parents, and a desire to return to the land, she sold her business and moved back to her family's farm. The farm was a small dairy that was struggling to get by, and they could not afford the new equipment needed to maximize output. The new technology that they needed to keep the farm functioning was also becoming too complicated for them.

After taking a serious look at the farm's budget and accounts, speaking to her local extension educators, and doing some deep thinking Linda made the tough decision to get out of dairy and to invest in a horse boarding business. To make the transition, she dipped into her savings and built a new barn with a place for guests to stay along with several hoop houses for growing

vegetables and medicinal herbs. She also sought out ways to diversify the farm's income, so with help from the PA DCNR she planted a multiuse riparian buffer with pawpaw, raspberries, and fruit trees. The buffer would both protect the stream from pollutants and produce fruits that could be turned into jams and preserves. She also got an EQIP grant to turn several of the pastures into pollinator habitat with trails for her boarders to ride through and enjoy.

After maximizing income from the farm, she turned to the 37 acres of forest surrounding the farm. Linda's cousin suggested harvesting the forest to help fund the farm upgrades, but the forest had been high-graded several times and the standing trees had little economic value so harvesting was not an option. She began farming mushrooms and investigated forest carbon market opportunities. Since she needed income rapidly, she decided it would be faster and more straightforward to put in a bid at NCX. However, her bid of \$22 a credit was too high. They rejected her bid, and she was not able to sell the additional carbon stored in her forest that year.

Next, she considered the FFCP and found her forest qualified for the Growing Mature Forests program. Linda was offered \$200 per acre over 20 years, for a total of \$7,400. The authors of this chapter estimate that the net present value of the FFCP payments averages about \$1.30 per acre per year for Linda's property (3% discount rate). The somewhat lower payment than the Wilsons' was likely due to having fewer merchantable trees in her forest, the result of historical high grading practices. Carbon payments are associated only with trees that are at high risk of being harvest. It took her a month to find and hire a forester to write the required plan, but she was eventually able to join the program. Linda believes that while the money from selling carbon is not substantial, it does give her guaranteed income that can offset the costs of her other investments in the farm and help preserve the aesthetic values of the property that she and her boarders enjoy.

Case Study 3: Jack

Jack owns 325 acres of forests that have been in his family since 1915. The forest is predominately pine species but also includes some hardwood species. Jack enjoys walking in the forest with his family and wants to pass his forest legacy to future generations. He also places a great importance on the timber, firewood, wildlife, and scenic beauty benefits provided by his forest.

Jack has a forest management plan developed in consultation with a professional forester. He uses practices such as thinning, harvesting, maintaining fire lines, and controlling invasive plant species to help enhance forest health and sustainable use. Some technical and financial assistance was recently provided to Jack by the USDA Conservation Reserve Program (CRP) to help with erosion control on part of the forest. Jack has also participated in the Healthy Forests Reserve Program offered by NRCS to support wildlife and their habitats.

Forest carbon projects were of interest to Jack because of his concerns about how climate change may impact forest health and sustainability and the condition of his forest for future generations. His hope is to use carbon payments as another form of financial assistance for managing his forest. Jack considered several programs over the past 10 years, but they never quite worked for him or his forest. He decided to enroll in the NCX after learning about their carbon program. He

applied at the NCX website by entering his contact details, zip code, property type, street address, and the boundaries of his property. Soon he was contacted by an NCX representative via email with a proposal that contained information about his forest (e.g., age of trees, type, and density of the forest stands) that NCX collected at one point using remote sensing technology. The proposal also outlined what they determined was the likely quality of his forest stands and potential carbon storage capacity in the form of an HDC.

Jack found out that 280 acres of his forest qualified for NCX payment, because the average stand age was greater than 15 years. Jack also found out that he had a total of 509 HDCs available that he could sell to NCX at an auction.

Jack was agreeable to delaying all harvesting for 1 year in the designated stands, as outlined in the proposal. The proposal then became the contract in which bids could be placed. Jack submitted his bid in person at an NCX auction (held four times a year) where he was able to select from a range of bid levels. Other local forest owners were there as well, and they each used a paper survey to submit a silent bid. To help inform their decisions, participants were provided information about past bids on forests in the same area. It was Jack's understanding that NCX would consider the bids collectively and provide the same counteroffer to all the bidders. After a few weeks, Jack was offered a counter bid of \$12 for each credit from the auction, for a total payment of \$6,100. The payment would be distributed after the performance period, at the end of the 12-month contract period in the form of a check sent by mail. It was Jack's understanding that after the contract ended, he could manage his forest any way that he wanted. However, Jack intends to submit a bid to NCX every year, except for the year that he plans to do a select harvest. When he does harvest, his HDC will likely decrease because of the changes in stand density and mean stand age. Jack assumed that he would be able to enroll in another carbon payments program after his contract with NCX ended. He was pleased with the process and thought the experience was excellent.

Case Study 4: Gary

Gary is a retired forester, and he owns 130 acres, of which 120 acres are forests and 10 acres are reclaimed mine land. The benefits he receives from his forest include firewood for heating, maple syrup, and recreational services. He also sees his forests as important to his mental health by inspiring positive emotions like calmness, creativity, and joyfulness. "The most satisfying and neat feeling is to listen to the whistling wind touching the evergreens on the top of forested hills," said Gary.

Gary's forest and wildlife management goals includes growing quality timber, maintaining forest canopy, controlling invasive plants, diversifying tree species, and controlling deer population. To achieve these goals, he hunts deer, kills invasive plants with herbicides, does noncommercial thinning, and plants trees on the reclaimed mine land. He is also involved with the Deer Management Assistance Program offered by the Pennsylvania Game Commission to manage deer and meet land use goals. His tree plantings and invasive plants control operations are funded through the USDA-NRCS cost-share EQIP program and Conservation Stewardship Program.

As a professional forester and being a landowner himself, Gary had known about HDCs for quite a while. He knew about NCX at their launch and was looking forward to the opportunity to sign up. Gary signed up at the NCX website by submitting his contact information and information about his property. This involved outlining his property boundary on a map and including a zip code and street address. He was then contacted by an NCX representative with information about his forest characteristics and eligible carbon volume. Gary was offered a total of 56 HDCs to not harvest trees for 1 year on 120 acres of his forest. After agreeing to the proposal, the proposal became the contract in which Gary could submit a bid. He was told the bid could range from \$1 to \$30 per HDC. Gary bid \$10, but NCX provided a counter offer of \$12, totaling \$680 for the contract year. The counteroffer from NCX was higher because other forest owners at the auction bid higher. The bids of all owners were used to create an average bid that NCX then used to determine the same counteroffer for all participants in the auction.

After 1 year and the harvest deferral commitments from his forest were verified, Gary was paid in the form of check. It took around 15 months to complete the whole process (including 12 months of no harvesting). He used the income to improve his forest and pay his property taxes. Gary also encourages other owners to sign up with NCX. The NCX program pays 2% of the aggregate price for each of the credits he sold as incentive to others who help enroll landowners. However, Gary feels it is important that owners get more information about forest carbon management, such as information offered by extension education, to help make more informed management decisions.

During the interview, Gary also expressed that he would have liked to have more opportunities to manage for different types of forest carbon. He recognizes that currently most carbon payments are associated with delay in harvest methods. However, he is also interested in supporting the climate benefits provided by wood products such as lumber, plywood, and furniture. “It is important to think about options to store carbon in transformed wood in the future,” said Gary.

Case Study 5: Jannette

Jannette is a forest landowner in Blair County, Pennsylvania. In 2016, she inherited 10 acres of forest after her parents passed away. She enjoys walking in the forest, collecting berries, and eating the game her nephews harvest in her small patch of woods. Because of these positive experiences, she bought another 30 acres of forest from her neighbor in 2019. To help fund the purchase and to make smart forest management decisions, she hired a forester and conducted a shelterwood harvest on all 40 acres of forest.

Unfortunately, shortly after the harvest, mile-a-minute vine, an invasive plant, took over 25 acres of forest and began strangling out all the plants in the forest. Another invasive plant, Japanese stiltgrass, grew thick on the skid trails and started invading the forest. There was also plenty of multiflora rose and bush honeysuckle, which competed with the native vegetation. Ticks became more common because of the habitat opportunities provided by the invasive plants, and wildlife became less common as the native plant forage disappeared. In the end, the changes in forest health caused by the invasive plants prevented her from enjoying her forest. Because of this, Jannette became more open to considering new types of financial opportunities if they helped her restore the health of her forest.

She applied for financial assistance through the USDA EQIP program. Unfortunately, funding was limited in her area and her property was not selected. In late 2020, she used the [WoodsCamp](#) website to find opportunities for financial assistance and discovered FFCP. A few months into 2021, she got an email that the FFCP program had expanded into Blair County and her property could qualify. The FFCP representative came to her property and examined the invasive plant problems in her forest. It was determined that her forest could benefit from the Enhancing the Future Forests program under the FFCP and she was offered \$280 per acre over 10 years to control the invasive plants, for a total of \$11,200. She initially received \$196 per acre to begin management, which was enough to hire a pesticide applicator. The next two payments were \$27.77 per acre at year 5 and \$8.51 per acre at year 10 (net present value at a 3% discount rate). She used the money from FFCP to hire her uncle, a recently retired Pennsylvania Department of Transportation pesticide applicator, who has started managing the invasives by spraying them with herbicides.

Closing Thoughts

These owners are good examples of early adopters who want to use carbon payments to help achieve a variety of management objectives. They also expressed strong ethical views about stewardship and managing forests for future generations.

Most owners had experience enrolling in a variety of state-sponsored financial and technical assistance programs. This may have made the idea of enrolling in a new incentive program seem less risky. Some owners had to wait a long time to find a program that was a good fit for them and their forest. Gary would have also liked to support carbon projects that use wood products to provide climate benefits.

The greatest obstacle in these case studies was engaging a qualified forester. This is because of a lack of foresters in Pennsylvania and because few of them are certified to work with forest carbon programs, since carbon markets are a new industry. Joining a carbon program was easiest when the owner was already working with a forester before their carbon market inquiries.

All the owners were willing to manage carbon for an extended period of time; however, some did like the flexibility provided by a shorter contract. Jack was interested in the option of switching to another program in the future. Because the process and contracts offered could change in the future, these owners' experiences may not be everyone's experience.

Tips for Teaching

- Give experienced landowners the opportunity to share in your program. This can help build community around carbon in forest management.

Resources for Teaching

- Case Study 1: Two Landowners' Experiences With Carbon Payment Programs *FOCCE* #08-04-2022 <https://extension.psu.edu/case-study-1-two-landowners-experiences-with-carbon-payment-programs>

- Case Study 2: Three Landowners' Experiences with Climate Smart Forest Programs
FOCCE #08-03-2022 <https://extension.psu.edu/case-study-2-three-landowners-experiences-with-climate-smart-forest-programs>

Information Sources

- *Interviews were conducted in fall 2021 and 2020.*

Part 5: A Lesson Plan for the Peers and Pros–360° Method

“Let’s Talk about Forest Carbon Programs and Incentives”

Sanford “Sandy” Smith, teaching professor in forest resources, Penn State

Melissa Kreye, assistant professor, Penn State

The Peers and Pros 360° Method is a novel teaching approach that uses a group activity to promote collaborative learning among peers in groups. It can be implemented almost anywhere (e.g., inside or outside) and in conjunction with other extension events (e.g., field tours, presentations, meetings). The approach initiates short meaningful discussions in peer groups using previously identified topics and discussion points. Experts provide clarifications on technical details, wrap-up thoughts, and advice at the conclusion of the discussions.

Benefits of this approach include:

- *Enjoyment.* Peers frequently enjoy the expression of diverse opinions and learning from each other.
- *Clarification.* Group discussions help fill in partial understandings of complex issues.
- *Trust.* Peer validation provides credibility to the discussion, in addition to the content provided by university or agency experts.
- *Community.* Everyone can receive valuable social and learning benefits, regardless of their prior knowledge and experience.
- *Impact.* Educators gain a better understanding of the information needs, experiences, and opinions of the peer learners in real time while teaching a session, and to inform future extension activities.

Steps for Implementing the Peers and Pros–360° Method

Step 1. In preparation for a peers and pros discussion, the educator hosting the event should identify topics most participants (1) care about and/or (2) have confusion about. A declarative statement, representing a peer landowner’s opinion, is created for each topic area and printed on index cards in the style or language of a landowner. The goal is to use the cards to initiate a group discussion among landowners, so the statements do not need to be technically correct.

Step 2. The educator decides where and when this method will be most useful. It can be initiated before or after a presentation, as part of a meeting, or part of a field tour with designated stops. The goal is to bring people together so they can collectively process what they have previously learned by sharing and adding to their own knowledge and experiences with their peers.

Step 3. At the designated stops, the peers and pros are asked to stand in a circle (360°) and the cards are passed out to the peers. Facing each other in a circle helps equalize the status of participants and improve listening and comprehension. The educator then requests that the peers with the cards read the statements out loud. The cards are numbered to facilitate this step. The educator then asks the peer group how they would respond if they heard a friend or other peer

say any of these statements. After the peers have discussed the statements among themselves, the experts (a.k.a. “pros”) gently correct and balance what they heard by adding follow-up clarifications and mediation. Care must always be shown to never call someone out about what they said or didn’t know.

Tips for making this work:

- Use only 2–3 statements per theme or discussion session.
- During the session discussions it is important that pros encourage participation and avoid making remarks themselves since the initial goal is for the peers to share insights from their own knowledge and experiences with each other. The pros need to be listeners only.
- After most participants have weighed in with each other, the educator or subject matter expert can then provide clarifications. People are generally receptive to clarifications if they feel that they have been given enough time and space to explain their thoughts.
- The educator can also present additional information and closing thoughts to help round out the discussion, if needed. Suggested talking points for forest carbon incentives are provided in this lesson plan.
- Participant feedback will be important for understanding how this approach can benefit your program. An example evaluation survey is provided at the bottom of this handout and can be used in conjunction with this type of event.

Potential “Peer” Statements (in quotes) and Suggested “Pro” Talking Points (lettered)

Theme I: Carbon Market and Carbon Credit Terminology

1. “A carbon credit is the money you get from a big company to not to cut your trees.”
 - a. A carbon credit can be generated by changing forest management practices to store more carbon. If the carbon stored is verified as being additional, it can be converted into a carbon credit.
 - b. Additional carbon storage is the service being sold to buyers. Buyers can offset their carbon footprint by paying others (e.g., landowners) to reduce their carbon emissions instead. This typically involves moving from a business-as-usual forest management plan to a climate-smart plan. The emission reduction benefits that come from the landowner changing management plans are then credited to the buyer.
 - c. A conventional carbon credit represents 1 ton of carbon dioxide emissions offset for at least 100 years.
 - d. Carbon credits generated by family forests are often sold to buyers using a network of brokers. When the purchase of carbon credits is voluntary, or not required by state law, these exchanges are often referred to as the “voluntary carbon market.”
2. “Carbon offset registries are the same thing as a carbon market.”

- a. Carbon offset registries work in partnership with project developers to generate carbon credits from a land-based project.
 - b. Initial funding for carbon projects comes from banks and investors, until the project can be sustained from the sale of carbon credits.
 - c. Carbon offset registries have two main jobs. They provide instructions for quantifying carbon benefits, using established protocols and verification procedures. They also track the sale of carbon credits from a project, but they are not a market platform where buyers and sellers come together to arrange trades.
3. “You can get money for the carbon in your woods because it is not going into the air.”
- a. Carbon dioxide is a greenhouse gas that exists naturally in the atmosphere. Greenhouse gases help keep our planet warm from the coldness of space.
 - b. Recent increases in the concentration of CO₂ in the atmosphere have elevated global temperature by an average of 1°C (1.8°F). Many people consider this change undesirable.
 - c. Forests that help regulate or reduce the amount of CO₂ in the air are considered valuable because they help reduce the impacts of climate change.
 - d. Market systems help distribute environmental benefits by connecting producers of environmental goods with consumers and citizens. Market systems alone are not enough to address the problems of climate change.
 - e. The recent U.S. Inflation Reduction Act is directing over \$4 million in federal funds to state forest stewardship programs to support climate-smart forestry practices on private lands.
4. “Privately owned forests are important to reduce climate change.”
- a. Up to 70% of forests in the United States are privately owned. Family forests are a major category of private ownership.
 - b. Up to 80% of U.S. domestic timber supply comes from private lands.
 - c. Voluntary slowdowns in harvesting on public and private lands helped offset up to 12% of U.S. greenhouse gas emissions in 2019.
 - d. According to the Forest Inventory Analysis database of the U.S. Forest Service, the average forest acre on private lands sequesters 0.5 metric ton of carbon each year. If this service was classified as “additional” carbon storage, it would offset about 2 metric tons of carbon dioxide emissions per acre per year.
 - e. Preventing forest loss on 1 acre of private forestlands (due to land use change) can help avoid the release of 83 metric tons of carbon dioxide emissions, on average.
5. “Big companies are the most frequent buyers of carbon credits.”
- a. Many corporations are looking to reduce their carbon footprint in order to improve their environmental, social, and corporate governance (ESG) ratings.

- b. Corporations often prefer to buy carbon credits from a nature-based offset project, because the credits can be cheaper than technology-based offsets or paying a carbon tax.
- c. About 35% of carbon credits come from nature-based carbon offset projects.
- d. Nongovernmental organizations and conservation groups also like to support nature-based carbon offset projects because they can help advance conservation goals.

Theme II: Climate-Smart Forest Management

- 6. “Trees pull carbon from the soil, preventing it from getting into the air.”
 - a. Through the process of photosynthesis, plants absorb light and CO₂ from the air to create energy. This energy is in the form of carbon-based sugar molecules known as glucose.
 - b. Forest soils do absorb oxygen and release CO₂ as part of microbial respiration.
 - c. Soil microbial functions are linked to forest structure and composition, as well as soil water content, soil carbon, and soil pH.
- 7. “Carbon sequestration and carbon storage mean the same thing.”
 - a. *Carbon sequestration is the creation of glucose in the plant through the process of photosynthesis. Carbon storage is the building of plant structures by converting glucose into cellulose and lignin.*
 - b. Management practices that either (1) increase the rate of carbon sequestration or (2) prevent the loss of carbon storage in forests can qualify for carbon incentives.
 - c. To quantify the benefits of adopting new management practices, the change in carbon storage is calculated based on the counterfactual condition (i.e., what would have happened to the carbon if the new management practices were not implemented).
- 8. “Most of the carbon in a forest is not in the trees.”
 - a. On average, half of forest carbon is belowground in the soils. A quarter of forest carbon is in the aboveground living biomass (i.e., trees, shrubs). About 5% of forest carbon is stored off site in long-lived wood products (i.e., furniture, buildings).
 - b. Managing forest carbon often involves managing trees and preventing soil loss.
 - c. Large changes in forest carbon are mostly due to changes in stand structure and the amount of living woody biomass on the landscape.
- 9. “Some forests are better than others for storing carbon.”

- a. All forests are important for carbon storage. However, forests that are managed at high densities and contain mature trees and organic soils tend to have high carbon stocks per unit area.
 - b. Forest management alters carbon storage over time by changing stand structure and the amount of woody biomass per acre.
 - c. Forests are considered a leaky reservoir for carbon, because the carbon cycles in and out of the forest as plants grow, die, and grow back again. This is why most carbon accounting methods calculate total carbon gains versus losses in a project area over time.
 - d. Having a forest management plan can help owners understand how to enhance carbon storage while also engaging in other forest land uses.
 - e. Mature or old growth forests are valuable for carbon storage. Young forests grow at a faster rate, making them valuable for sequestering carbon in a shorter period.
10. “Forests are at risk of losing carbon under climate change.”
- a. Forests are more resilient when they are healthy, meaning they can better handle threats that come from things like wildfire, pests, and disease.
 - b. Climate change is expected to reduce forest health by adding another layer of stress on forests, due to changes in temperature, rainfall, and growing season.
 - c. Increased tree mortality can reduce total carbon stocks, or how much carbon is in a forest. Protecting forest health helps the forest continue being a carbon sink.

Theme III: Benefits of Managing Forest Carbon

11. “The benefits of managing forest carbon can be different across forest owners.”
- a. Land ownership sizes sometimes determine which owners can participate in carbon incentive programs.
 - b. Some carbon programs require owners to have a forest management plan. Owners who don’t have a plan may see this requirement as burdensome or a barrier to participation.
 - c. How much compensation is directed to the forest owner is a function of how much CO₂ emissions are offset by their forest. Some owners may receive higher payments because their forest stand characteristics exceeds the minimum standards set by the offset project developers.
 - d. Landowners who are the first to enroll in a carbon program are sometimes classified as “early adopters.” Early adopters are often willing to accept a lower payment compared to all other owners and are generally less risk averse when

making investments. They may also see carbon management as an important part of forest stewardship.

12. “Managing forest carbon can sometimes be in conflict with other management objectives.”
 - a. Most management objectives are compatible with carbon storage, but it depends on the original condition of the forest and what the owner is willing to do.
 - b. In a nature-based project, landowners are incentivized to increase the amount of live woody biomass on the landscape. If the owner is looking to reduce live woody biomass, improve wildlife habitat, or reduce wildfire hazard, a carbon program may not be a good fit for their management objectives.
 - c. Forests that contain commercially valuable tree species at harvestable ages are more likely to qualify for delay harvest carbon payments. Forests comprised of species with low commercial value may qualify for incentives that help support forest health and regeneration.
 - d. Owners who place a high priority on revenues may prefer shorter contracts so they can obtain both the carbon payments and revenues from the eventual harvest.
 - e. Owners who want to manage their forest for future generations may see forest health incentives and long contracts as compatible with their management objectives.
13. “A dollar earned today is worth more than a dollar earned tomorrow.”
 - a. Waiting for income benefits can reduce the value of the benefit to the owner. This reduction in benefits over time is often described using discount rates. Discount rates for forest projects are generally set at 3%.
 - b. Forests generally increase in value over time because of tree growth, to a certain point. For benefits to accrue, the rate at which the value of the forest increases should be greater than the discount rate of waiting for income benefits.
 - c. Calculating the “present value” of future costs and benefits can help bring back those potential revenues from the future and compare them with other options today using the same baseline.
 - d. Land expectation value, in this case, is the expected value of a piece of land managed for timber and carbon. This value is often influenced by site quality, tree species composition, and management activities. Financial decisions that help increase land expectation value provide more benefits to owners over time.

Theme IV: Taking Part in the Carbon Economy

14. “Carbon contracts require really long commitments.”

- a. Commitments can vary in length (e.g., 1–100+ years) depending on the program. Contract lengths are often determined by the business plan and the type of protocols used in a carbon offset project.
 - b. Owners who agree to longer contracts can receive higher compensation. Buyers are often willing to pay more for carbon credits that come with stronger assurances, which are easier to achieve with longer landowner commitments.
 - c. Longer contracts tend to come with more support for landowners, to help ensure that they will succeed. For example, if there is an accidental release of carbon on the property due to a natural disturbance (e.g., wildfire), the program may minimize the harm by drawing from a buffer pool of extra carbon credits, so the owner is not held responsible.
 - d. Programs with shorter contracts tend to place more responsibility on the landowner to meet contract obligations. If obligations are not met, the owner may have to give back any payments that were accrued, which may be seen as reasonable because it was a short contract.
15. “Carbon contracts can lock up your land.”
- a. Programs with longer contracts could tie certain obligations to the property and not the landowner, so if the property changes ownership the obligations in the contract are still carried forward.
 - b. Longer contracts also generally come with some opportunities to withdraw with fewer penalties (e.g., every 6 years). However, the carbon payments would have to be refunded.
 - c. Opportunity costs represent the value of an alternative outcome that is lost when taking a specific action. Opportunity costs should be carefully examined before entering a long contract.
16. “I want to be paid every year for managing my forest for carbon.”
- a. Carbon gains are often based on verified changes in the amount of live woody biomass per area over time, but this assessment may not be done on an annual basis.
 - b. Carbon programs that work with many landowners have higher verification costs. Measuring carbon gains every several years (instead of each year) can help reduce the costs associated with carbon accounting procedures. Still, some programs do decide in their business plan to provide owners an annual payment.
 - c. It is important to account for all types of costs in a personal financial plan. For example, it may make more sense to pay off a debt by conducting a harvest today rather than using carbon payments to pay off the interest on the debt over the next few years.

17. “You don’t need a lawyer when reviewing a carbon contract.”

- a. Many carbon programs are in the early stages of implementation. The contracts they create will likely evolve as program staff gain more experience working with landowners. In the meantime, don’t expect that carbon programs will be able to fully account for the owner’s interests when designing a contract. Get expert advice.
- b. Legal advisers don’t have to be familiar with carbon programs to be helpful. The language used in legal documents can be confusing. It is important that the owner understand their legal obligations, and who is responsible if things do not go to plan.

Evaluation of the Peers and Pros Method

The impact of using this method with landowners can be assessed by looking for evidence of collaborative learning benefits. These include change in knowledge and benefits that come from positive social interactions. The Likert scale below measures these benefits and can be included in your program evaluation surveys.

How strongly do you agree with the following statements about today’s peers and pros discussion?(select one response per row)					
	Strongly disagree (1)	Disagree (2)	Neither agree or disagree (3)	Agree (4)	Strongly Agree (5)
Participants felt free to communicate their opinions.	☐	☐	☐	☐	☐
I really enjoyed listening to other people’s points of view.	☐	☐	☐	☐	☐
The discussions helped broaden my understanding of the issue.	☐	☐	☐	☐	☐
The participants probably learned something from each other today.	☐	☐	☐	☐	☐
I feel more comfortable talking about these issues with my peers in the future.	☐	☐	☐	☐	☐

Glossary

Term	Definition	Extension article for more information
Accidental release	When a natural disturbance (e.g., wildfire, hurricane, pests) causes a large number of unexpected tree deaths, which increases carbon emissions from the forest via conditions that are deemed “unavoidable.”	What Should I Think about Before Signing a Forest Carbon Contract? Questions to Ask Before Joining a Carbon Program
Annual rate of carbon sequestration	The average amount of carbon sequestered per unit area per year. Rates are often used to make predictions about the volume of carbon storage over time to inform investments.	Carbon Accounting in Forest Management
Biological drivers of climate regulation	Living organisms take in and release carbon molecules through the processes of photosynthesis, respiration, decomposition, and combustion.	Forest Carbon Pools: Where Are They?
Buyers of carbon offsets credits	1. Corporations and organizations that are voluntarily looking to reduce their carbon footprint, often motivated by a desire to improve their ESG ratings by meeting their own reduced emissions goals. 2. Businesses in emissions-capped sectors (per government regulation) whose emissions exceed their determined allowable emissions. 3. Individuals who are concerned about climate change and want to reduce their carbon footprint.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
California- Quebec Carbon Market, a	A compliance market or regulated marketplace that facilitates the exchange of	Forest Carbon Market Structures and Mechanisms

Cap-and-Trade Program	carbon credits between project developers and corporate buyers. The California Cap-and-Trade Program is designed to reduce the emissions of 450 businesses in California that are responsible for around 85% of California GHG emissions. Offset projects that include family forests are <i>not</i> typically sold on this market.	How a Forest Carbon Offset is Made and Sold
Carbon credit	A permit that allows a business or organization to produce GHG emissions because they are paying someone else to reduce emissions (e.g., owners of forestlands). " A guarantee made by the offset project developer that the impact of 1 ton of CO₂e emissions will be offset for 100 years. A tradable certificate representing a verified reduction in net carbon emissions or additional carbon sequestration. Credits can be exchanged on voluntary or compliance carbon markets, where they may be considered synonymous with carbon offsets accounting for excess emissions.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon dioxide (CO ₂) and air pollutants	CO ₂ is the primary greenhouse gas that affects the Earth's climate. Currently, CO ₂ is not considered an air pollutant under federal laws. It is considered a pollutant under some state laws that regulate emissions.	Forest Carbon Market Structures and Mechanisms

Carbon offset market	Trading systems through which carbon credits are bought and sold.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project	A project constituting verified activities that aim to help reduce, remove, or avoid greenhouse gas emissions relative to a baseline, or business as usual, behavior. Nature-based carbon offset projects often involve private forestlands or the establishment of forests on non-forested land.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project developers	Individuals and organizations that generate plans for carbon offset projects in specific locations in order to generate carbon credits that can be sold.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project investors	Corporations and financial institutions seeking a return on investment from funding carbon offset projects that generate carbon credits for sale.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project managers	Individuals who oversee the development and implementation of a specific carbon offset project.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project partners	Governmental and nongovernmental organizations that help developers implement projects and programs in regions of interest.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset project representatives	Individuals who help carry out procedures in data management, forestry, and marketing related to a carbon	Forest Carbon Market Structures and Mechanisms

	offset project. They may be employees or independent consultants.	How a Forest Carbon Offset is Made and Sold
Carbon offset protocols	A set of approved program rules and requirements for measuring, monitoring, reporting, and verifying additional carbon sequestration and storage. in order to generate carbon credits. Rules must meet a certain set of industry approved standards (see below).	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon offset registry	Standard-setting bodies have carbon offset registries that serve as publicly available platforms for reporting and tracking project documents, credits, ownership, sale, and retirement of credits.	Forest Carbon Market Structures and Mechanisms How a Forest Carbon Offset is Made and Sold
Carbon sequestration	The creation of glucose in a plant through the process of photosynthesis.	<u>What Do Forest Carbon “Sequestration” and “Storage” Mean?</u>
Carbon sink	When a system (e.g., a forest) absorbs more carbon from the atmosphere than is released.	<u>How to Manage Forests for Carbon</u>
Carbon stock	A system that has the capacity to store or release carbon.	<u>Forest Carbon Pools: Where Are They?</u> <u>The Economic Value of Private Forests and Climate Change Mitigation</u>
Carbon storage	The building of plant structures by converting glucose into cellulose and lignin.	<u>What Do Forest Carbon “Sequestration” and “Storage” Mean?</u>
Climate change	Shifts in global temperatures and weather patterns over decades and centuries.	<u>Climate Regulation and Change: What Is Causing it?</u>
Climate change mitigation activities	Actions that limit climate change by reducing emissions of greenhouse gases (GHGs).	Forest Carbon Market Structures and Mechanisms

Climate-smart forestry practices	A wide variety of practices that aim to prepare all kinds of forests to adapt to and/or mitigate climate change and support ecosystem services and cultural values.	<u>How to Manage Forests for Carbon</u>
CO ₂ e emissions	CO ₂ stands for “carbon dioxide.” The letter “e” stands for equivalent greenhouse gases.	<u>Climate Regulation and Change: What is Causing it?</u>
Conventional carbon credit	A guarantee made by the project developer that 1 ton of CO ₂ e emissions will be offset for 100 years.	How a Forest Carbon Offset is Made and Sold
Cutting cycle	Frequency with which individual trees are selected and harvested over a period of time.	<u>Long-Term Financial Planning for Timber and Carbon</u>
Delay harvest scheme	Owners are paid to intentionally delay timber harvesting or extend harvest rotations to increase overall carbon sequestered by a forest. Typically applied to working timberlands	<u>How to Manage Forests for Carbon</u> <u>Carbon Accounting in Forest Management</u>
Discount rate	A rate representing the reduced value of money that is available only in the future. Most forest projects use a 3% discount rate.	<u>Long-Term Financial Planning for Timber and Carbon</u>
Dry wood weight	The weight of wood when it is dried in a kiln to a moisture content of 10%. About half of the dry weight of wood is carbon.	<u>Conversions Commonly Used When Comparing Timber and Carbon Values</u>
Factors that affect how people experience climate change	Latitude, elevation, mountains, and large water bodies influence the circulation of warm and cold air masses across the earth’s surface.	<u>Climate Regulation and Change: What is Causing it?</u>
Forest carbon	Carbon-based sugar molecules (e.g., glucose, cellulose).	<u>What Do Forest Carbon “Sequestration” and “Storage” Mean?</u>

Forest carbon contract	Legal arrangements between a project developer and the landowner detailing which management obligations are required by the landowner, the amount of carbon the project developer will purchase, and the level of payment provided to the landowner. The project developer generally sells the carbon credits (generated by the owner's forest) to a buyer as a separate activity.	<u>What Should I Think about Before Signing a Forest Carbon Contract?</u>
Forest carbon gains and losses	The amount of carbon that enters and exits a forest due to various processes, including photosynthesis, respiration, decomposition, combustion, and harvesting (i.e., carbon dynamics).	<u>Carbon Accounting in Forest Management</u> <u>Forest Carbon Pools: Where are they?</u>
Forest carbon payment programs	Programs implemented by project developers to broker deals with landowners so their land can be included in a nature-based carbon offset project.	<u>The Economic Value of Private Forests and Climate Change Mitigation</u>
Forest carbon pools	Forest carbon tends to accumulate into five different pools: aboveground biomass, belowground biomass, dead wood, forest floor litter, and soils. Harvested wood products and solid waste are carbon pools found in human settings.	<u>Forest Carbon Pools: Where Are They?</u>
Forests and CO ₂ emissions	When 1 unit of forest carbon (cellulose) decomposes, it turns into 3.6667 units of carbon dioxide emissions.	<u>Conversions Commonly Used When Comparing Timber and Carbon Values</u>
Global warming	Rapid increase in global temperatures due to elevated levels of CO ₂ and other greenhouse gas (GHGs) emissions in the atmosphere.	<u>Climate Regulation and Change: What is Causing it?</u>

Greenhouse gases (GHGs)	Gases in the earth’s atmosphere that trap heat like a blanket. Carbon dioxide is a major GHG.	<u>Climate Regulation and Change: What is Causing it?</u>
Human drivers of climate change	The release of CO ₂ and other greenhouse gases through the combustion of fossil fuels and other anthropogenic processes to support energy production, transportation, agriculture, and development.	<u>Climate Regulation and Change: What is Causing it?</u>
Improved forest management	Specific practices that help increase carbon stocks within forests and/or reduce greenhouse gas emissions from forestry activities (compared to business-as-usual practices).	<u>How to Manage Forests for Carbon</u>
Intentional release	When more harvesting occurs than is allowable by the legal forest carbon contract within the designated area and during a given period. This action increases the expected carbon emissions from the forest via activities that are deemed “avoidable.”	<u>What Should I Think about Before Signing a Forest Carbon Contract?</u> <u>Questions to Ask Before Joining a Carbon Program</u>
Land expectation value	The expected value of a tract of land used for growing timber or carbon (including management costs).	<u>Long-Term Financial Planning for Timber and Carbon</u>
Metric ton	1 metric ton (mt) is equal to 1.10231 U.S. tons (t). Carbon credit units are metric tons.	<u>Conversions Commonly Used When Comparing Timber and Carbon Values</u>
Net present value	The current value of a future stream of payments from a company, project, or investment.	<u>Long-Term Financial Planning for Timber and Carbon</u>
Opportunity cost	The value of an alternative outcome that is lost when taking a specific action.	<u>How Much Should I Be Paid for Forest Carbon?</u> <u>Long-Term Financial Planning for Timber and Carbon</u>
Private landowners	Private landowners may enroll in a program that allows project developers to track the	

	generation of carbon credits on their land and broker the sale of carbon credits.	
Reforestation	When new trees are planted in locations where forests are absent or in decline.	<u>How to Manage Forests for Carbon</u>
Risk of harvest	The likelihood that a stand will be harvested in the foreseeable future. Risk is often based on tree species, trunk diameter, and distance to mills and forest products manufacturers.	<u>How to Manage Forests for Carbon</u>
Social cost of CO ₂ e	The expected economic impact (e.g., including jobs, human health, infrastructure damage) of allowing additional CO ₂ e to be emitted to the atmosphere. The social cost of not mitigating climate change, set by the Biden administration, is \$51 per metric ton CO ₂ e.	<u>The Economic Value of Private Forests and Climate Change Mitigation</u>
Standard of “additionality”	Carbon storage must be real and additional to the amount of carbon that would have occurred if a forest was not enrolled in a carbon program. To determine how much carbon storage is “additional” due to forest management, project managers must estimate how much carbon would have been stored and sequestered under a business-as-usual scenario, (i.e., without the intervention). The projected emissions amount in the business as usual scenario constitutes the baseline carbon values. Additional net carbon sequestration is the difference between the real, measured emissions resulting from a change or changes in forest	<u>How to Manage Forests for Carbon</u> <u>Carbon Accounting in Forest Management</u> How a Forest Carbon Offset is Made and Sold

	management versus the projected baseline value.	
Standard of “nonleakage”	Project developers must defend that their additional carbon storage has not led to additional carbon losses outside the project area, (i.e., that their projects will not be “canceled out” due to shifts in activity elsewhere). Leakage refers to a measurable increase in GHG emissions outside of the project area as a result of emission-related activities being limited within the project area. For example, leakage occurs when a project activity (e.g., delayed harvest) reduces the production of a commodity and, in doing so, causes an increase in activity (e.g., harvest) elsewhere to meet continuing market demand.	<u>Carbon Accounting in Forest Management</u> How a Forest Carbon Offset is Made and Sold
Standard of “permanence”	Project developers must defend that the carbon stored by their program/project, and the resulting credits generated, will provide long-term carbon benefits, similar to the fossil fuels never having been extracted in the first place. For nature-based projects, this means that total carbon gains must exceed carbon losses over the lifetime of the project, where the lifetime of the project can be up to 100 years <i>beyond</i> a project’s credit-generation period.	<u>Carbon Accounting in Forest Management</u> How a Forest Carbon Offset is Made and Sold
Standard-setting bodies or offset programs	Independent organizations that develop protocols, or approved project methodologies.	Forest Carbon Market Structures and Mechanisms

		How a Forest Carbon Offset is Made and Sold
Time value of money	The idea that a dollar earned in the future is worth less than a dollar earned today.	<u>Long-Term Financial Planning for Timber and Carbon</u>
Voluntary market	Project developers sell carbon credits directly to buyers or through a broker (i.e., an unregulated market). Almost all offset projects that include family forests are sold on the voluntary market.	Forest Carbon Market Structures and Mechanisms
Weather	The current state of the atmosphere, ranging from a few minutes to weeks.	<u>Climate Regulation and Change: What is Causing it?</u>
Woody biomass	The trunks, limbs, tops, needles, leaves, and all other woody parts grown in a forest.	<u>Methods for Estimating Carbon Within Forests</u>