Carbon Budget

Overview

About 98% of the state of Vermont is comprised of forests, farmlands, grass and shrublands, wetlands, lakes, ponds, rivers, and other ecosystems[1]. Because plants can capture carbon dioxide (CO_2) from the air and store the carbon in wood and soil, it is important to quantify how much CO_2 is contained in these ecosystems and at what rate CO_2 is taken out of the atmosphere. Human decisions can alter the rate of CO_2 uptake by plant-based ecosystems, at times resulting in net emissions of CO_2 back to the atmosphere. As such, management decisions, like timber harvests, land-use conversion, and farming practices must be included in these estimates for a comprehensive picture of the influence of agriculture, forestry, and other land uses (AFOLU) on Vermont's net greenhouse gas (GHG) emissions.

The 2021 *Carbon Budget for Vermont*[2] represents the first attempt to provide a high-level, comprehensive picture of the AFOLU sector on the balance of the State's GHG emissions[3]. The *Carbon Budget* presents carbon stocks and fluxes for the AFOLU sector. A carbon stock is how much CO_2 has been stored in an entity, like a tree or an acre of land. Carbon flux is the rate at which CO_2 is taken in from or released to the atmosphere. Positive fluxes represent CO_2 emissions to the atmosphere (also called a carbon source) and negative fluxes represent sequestration of CO_2 from the atmosphere (also called a carbon sink). The net carbon flux is the sum or balance of emissions (sources) and sequestration (sinks).

Within the AFOLU sector, the *Carbon Budget* includes the following sub-sectors: forests (includes forestland, harvested wood products [includes wood products used for energy and heat, wood products in use, and wood products in landfills], and land use change to/from forest), agriculture, grasslands and shrublands, urban and developed lands, and wetlands and water bodies. The *Carbon Budget* includes other GHGs in addition to CO_2, specifically methane (CH_4) and

[1] USGS. 2019. National Land Cover Database. https://www.mrlc.gov/
[2] Galford G, Darby H, Hall F, and Kosiba AM. 2021. *A Carbon Budget for Vermont*.
[3] The concept of a carbon budget for Vermont was informed by other carbon budgets, like the *Global Carbon Budget* (Friedlingstein et al. 2020. Earth System Science Data, 12(4), pp. 3269-3340) and *State of Maine Carbon Budget* (Bai et al. 2020. https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/). The term carbon budget here refers to the net flux of all greenhouse gas emissions and carbon sequestration related to agriculture, forestry, and other land use (AFOLU) sector. While it may also be considered a carbon inventory, the use of "budget" also helps distinguish it from Vermont's *Greenhouse Gas Emissions Inventory* (VT DEC). This use aligns with the newest IPCC report (AR6) that has the proposed terms: "carbon budget" and "remaining carbon budget" (see draft glossary https://www.ipcc.ch/report/sr15/glossary/).

nitrous oxide (N_2O); for easier comparison these other GHGs were converted into metric tons of CO_2 equivalents (CO_2e) using 100-year global warming potentials (GWP).

The *Carbon Budget* is distinct from the annual *Vermont GHG Emissions Inventory and Forecast: 1990-2017* by the Air Quality and Climate Division of the Vermont Department of Environmental Conservation[4] that is used to establish state-level GHG emissions targets outlined in the Global Warming Solutions Act. The *GHG Emissions Inventory* includes anthropogenic, fossil fuel-based emissions and does not include the AFOLU sector, except for agricultural emissions[5]. In contrast, the *Carbon Budget* focuses on quantifying net GHG emissions from and carbon storage in the AFOLU sector. For context with statewide emissions, the *Carbon Budget* presents the difference between the net flux of CO_2e taken in by the AFOLU sector and the amount of CO_2e emitted according to the *GHG Emissions Inventory*, in other words, the approximate amount of anthropogenic GHG emissions that remain in the atmosphere (i.e., Vermont's net emissions). The Global Warming Solutions Act includes a goal of net zero emissions by 2050 but does not outline which sectors should be included and how to quantify fluxes. The *Carbon Budget* provides a cursory framework for accounting and by elevating questions for further research and analysis such as: which land use sectors and standards should be included in the net calculation? What are the current available data sources and what are their respective limitations? How can we accurately measure all fluxes on an annual basis?

Findings

The *Carbon Budget* estimates that the annual net GHG balance for the AFOLU sector is -2.95 million metric tons (MMT)[6] CO_2e for the most recent year of data (2020, 2018 for forests; see Table 1), in other words, the AFOLU sector is a net carbon sink. However, some sub-sectors are a net source of emissions, namely agriculture (+0.49 MMT CO_2e in 2020), followed by grasslands and shrublands (+0.05 MMT CO_2e in 2020). The other three AFOLU sectors account

[4] Vermont Department of Environmental Conservation, Air Quality and Climate Division. 2021. *Vermont GHG Emissions Inventory and Forecast: 1990-2017*. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

[5] Emissions from the agriculture sector include emissions from animals (enteric fermentation), stored manure, and agricultural soils—including decomposition of crop residue and application of organic (manure, compost, sewage) and inorganic fertilizer (nitrogen, urea, limestone, dolomite) through various pathways of volatilization, leaching and runoff (see VT DEC 2021).

[6] Negative fluxes indicate net sequestration (additional carbon storage). Positive fluxes represent net emissions to the atmosphere.

for net sequestration: forest sector (-3.2 MMT CO2-e in 2018, includes forests, land use change to/from forests, and harvested wood products), urban and developed [urban trees] (-0.28 MMT CO_2e in 2020), and wetlands and water bodies (-0.01 MMT CO_2e in 2020). When combined with Vermont's gross GHG emissions from other sectors (+7.22 MMT CO_2e), the net is +4.27 MMT CO_2e in 2020, or a 41% reduction in emissions to the atmosphere.

Table 1[7]. Estimates of carbon stocks and fluxes from Vermont's agriculture, forestry, and other land use (AFOLU) sector compared to the state's greenhouse gas (GHG) emissions[8].

AFOLU sub-sector	Carbon storage (MMT CO_2e)	Net carbon flux (MMT CO_2e per year)[9]			Components
	2020	1990	2005	2020	
Agriculture	63	+0.70	+0.61	+0.49	Crops (including hay), fertilizers, livestock, management
Forests	1,859	-5.1	-3.2	-3.2[10]	Forests, conversion to/from forests, harvested wood products (combustion, decay, and storage in use and in landfill)
Grasslands and shrublands	41	+0.06	+0.05	+0.05	Unmanaged and managed (e.g., pasture)
Wetlands and water bodies	57	-0.01	-0.01	-0.01	Wetlands and water bodies
Urban and developed	15	-0.26	-0.27	-0.28	Trees
Net for AFOLU sector	**2,035[11]**	**-4.61**	**-2.82**	**-2.95**	**AFOLU sectors and components listed above**
VT GHG emissions[12]		+7.41	+8.68	+7.22	Electricity, heating, transportation, fossil fuel industry, industrial processes, waste management[13]
Net of AFOLU sector and VT GHG emissions[14]		**+2.8**	**+5.86**	**+4.27**	**All sectors listed above**

[7] Vermont Department of Environmental Conservation, Air Quality and Climate Division. 2021. *Vermont GHG Emissions Inventory and Forecast: 1990-2017*. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

[8] Table was modified from Table ES in Galford G, Darby H, Hall F, and Kosiba AM. 2021. *A Carbon Budget for Vermont*.

[9] Negative fluxes indicate net sequestration. Positive fluxes represent net emissions to the atmosphere.

[10] Data for forests is for the year 2018.

[11] The net flux for the AFOLU sector was incorrectly presented as 1,978 MMT CO_2e in Table ES of *A Carbon Budget for Vermont* (Galford et al. 2021).

[12] Vermont Department of Environmental Conservation, Air Quality and Climate Division. 2021. Vermont GHG Emissions Inventory and Forecast: 1990-2017. https://dec.vermont.gov/sites/dec/files/aqc/climate-change/documents/_Vermont_Greenhouse_Gas_Emissions_Inventory_Update_1990-2017_Final.pdf

[13] Agriculture sector emissions included in the *GHG Emissions Inventory* were subtracted from the gross emissions total to avoid double counting with the AFOLU sector. This differs from the GHG emissions values used in *A Carbon Budget for Vermont*, which included the agriculture sector emissions.

The *Carbon Budget* shows a 36% decline in the strength of Vermont's AFOLU carbon sink since 1990 (decline from -4.61 to -2.95 MMT CO_2e). Though carbon flux estimates should be interpreted with caution because of data limitations, methodological differences, and lack of uncertainty around estimates, the largest change in net flux over this time occurred in the forest sector. Since 1990, wetland and waterbodies, grasslands and shrublands, and urban and developed lands saw fairly stable annual net flux rates, and emissions from the agricultural sector declined. Further investigation into this declining forest sector sink is warranted.

Vermont's AFOLU sector provides dual GHG mitigation benefits due to its ability to store carbon and prevent it from being emitted to the atmosphere and to sequester additional carbon from the atmosphere, and at the same time, provide other critical ecosystem services, like cycling water, reducing flooding, providing food, fiber, wood, and affording habitat to flora and fauna. The capacity of Vermont's AFOLU sector to continue to sequester and store carbon depends on its continued existence (e.g., land use conversion to development releases stored carbon and prevents future sequestration), health (e.g., AFOLU sector can be negatively affected by climate change, pollution, and degradation), and human decisions on land and water management, all of which can affect the rates of carbon sequestration and GHG emissions.

Recommendations for next steps

The 2021 *Carbon Budget* represents an important first step to support the Vermont Climate Council in quantifying and tracking the GHG flux of Vermont's AFOLU sector. An important concept highlighted by this effort is that landowner and land manager actions can influence the net flux. To continue to improve our understanding of the carbon dynamics of the AFOLU sector, the following considerations are recommended as next steps:

(1) Examine methodological gaps among GHG emission inventory tools and datasets used by the State of Vermont for the AFOLU sector and alignment with the Intergovernmental Panel on Climate Change (IPCC), Environmental Protection Agency (EPA), and peer states. Specifically,

- Compare the three quantification tools informing the Global Warming Solutions Act (EPA State Inventory Tool [SIT], Low Emissions Analysis Platform [LEAP] and Ex-Ante Carbon Balance Tool [Ex-ACT]), plus the DeNitrification-DeComposition (DNDC) and DAYCENT models which are used by other states [i.e., California]);
- Conduct background research describing the IPCC rationale for using net GHG emissions

quantification in AFOLU sectors, and peer state's deliberations on accounting GHG in AFOLU as net or gross;

- Describe the additional staff or technical support needed to include more accurate and nuanced GHG accounting of the AFOLU sector; and
- Research data sets that track land use change in Vermont and/or support efforts to track land use via remote sensing (e.g., satellite, LiDAR).

(2) Establish a periodic and consistent *Carbon Budget* for Vermont. To develop and update the *Carbon Budget* on an annual basis, the Vermont Climate Council, in coordination with the Secretaries of Administration, of Natural Resources, of Transportation, of Agriculture, Food and Markets, and of Commerce and Community Development, and the Commissioner of Public, should aggregate all existing statewide data on GHG fluxes and stocks. Future updates to a subsequent version of a *Carbon Budget* should consider the following:

- In addition to net flux, report gross emissions and sequestration;
- Incorporate uncertainty or error estimates for all stocks and fluxes.
- In addition to reporting the total flux per sub-sector, report all fluxes on a per area basis (i.e., MMT CO_2e per acre per year).
- Investigate any stocks or fluxes not included in the 2021 *Carbon Budget*. For example: (1) The Urban and Developed sector only includes trees, and not grasses, turf, shrubs, or other plants; (2) Further investigate urban soil stocks and fluxes, which were presented as negligible in the *2021 Carbon Budget*, yet in Maine urban soils were estimated to contribute three times as much sequestration as urban plants[15]. (2) Investigate inclusion of the lateral movement of carbon from land to water bodies (i.e., sedimentation). (3) Investigate the inclusion of outgassing from water bodies. (4) Include land use change for conversions other than to/from forests (e.g., wetlands to development). (5) On agricultural land, consider accounting for isolated trees or small groups of trees that do not constitute a forest, which are currently not included. (6) Clarify whether the wetland and water bodies sub-sector include lakes and ponds.
- Address issues of possible double counting. For example, land use conversion is counted

[15] Bai et al. 2020. *State of Maine Carbon Budget*. https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/)

as an immediate source of emissions to the atmosphere, but in forest clearing, there are often harvested wood products that are extracted that end up in products that store carbon for some length of time.

- Consider standardizing soil carbon methodology across all AFOLU sectors. In the *2021 Carbon Budget*, forest soils are assessed to a depth of 1 meter, but other soils (agriculture, wetlands and waterbodies) are assessed to a depth of 0.3 meter—deeper soil depth accounts for more stored carbon.
- Either integrate pasture (managed grassland) as an Agriculture source; or split into formal IPCC AFOLU sources, i.e., cropland, grassland, livestock, etc. Also review management assumptions used for agriculture per source (e.g., crop residue retained, carbon input, manure, pasture degradation) and update as data sets are reviewed and updated.
- Update the Executive Summary Table (Table ES in the 2021 *Carbon Budget*) as follows: (1) clarify that the net AFOLU carbon stock is 2,035 not 1,978 MMT CO_2e as published (see Table 1). (2) Clarify that 'fossil fuel' emissions from the GHG Emissions Inventory includes agricultural emissions that are also included in the agriculture and grasslands/shrubland sub-sectors of the *Carbon Budget* and are thus double counted (see Table 1). (3) Modify the data citations to indicate the source of input data used to create the *Carbon Budget*.
- Clarify AFOLU terminology and category as it relates to attributions of sources of carbon emission (pg. 7) and update language within the body of the report to clarify that the EPA SIT does not account for agricultural stocks in the GHG Emissions Inventory as found on page 12.
- Clarify the amount of Urban and Developed land. Page 56 identifies Urban and Developed land as having between 375,000 to 400,000 acres. This figure is in conflict with 118,000 acres of urban and developed land referenced on page 28 of the report.

Glossary

- AFOLU: agriculture, forestry, and other land uses
- Carbon budget: the net flux of all greenhouse gas emissions and carbon sequestration related to the agriculture, forestry, and other land use (AFOLU) sector.
- Carbon flux: the rate at which CO_2 is taken in from or released to the atmosphere. Positive

fluxes represent CO_2 emissions to the atmosphere (also called a carbon source) and negative fluxes represent sequestration of CO_2 from the atmosphere (also called a carbon sink). The net carbon flux is the sum or balance of emissions (sources) and sequestration (sinks).

- Carbon stock: how much CO_2 has been stored in an entity, like a tree or an acre of land.