

Vermont Greenhouse Gas Emissions Inventory and Forecast: Brief
1990 – 2016

Prepared by the Air Quality and Climate Division
in accordance with 10 V.S.A. § 582
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Note to Readers

Vermont Greenhouse Gas Emissions Inventory and Forecast reports are designated as either “Comprehensive” or as “Brief.” Comprehensive reports will coincide with the calendar year releases of the triennial National Emissions Inventory (NEI) produced by the U.S. Environmental Protection Agency (EPA) and will provide a greater level of detail on certain sectors and graphics than the reports designated as “Brief.” This is due mainly to the fact that several sectors in the inventory report are based on calculations and data from the NEI, as well as various other tools and datasets from the EPA and other agencies. In many cases EPA’s release of this national level inventory enables more robust analyses for the given year and provides additional emissions estimate checks for individual sectors.

The following report for the 1990 – 2016 inventory and forecast is designated as Brief. The next Comprehensive report will be the 1990 – 2017 inventory and forecast, to be released later in 2020.

This and previous reports may be found at the following link:

<https://dec.vermont.gov/air-quality/climate-change>

List of Previous Reports:

- *Greenhouse Gas Emissions Inventory Update: Brief (1990 – 2015)*
- *Greenhouse Gas Emissions Inventory Update: Comprehensive (1990 – 2014)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2013)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2012)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2011)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2009)*
- *Greenhouse Gas Emissions Inventory Update (1990 – 2008)*
- *Greenhouse Gas Inventory and Reference Case Projections - Governor's Commission on Climate Change (1990 - 2030)*

Primary author: Collin Smythe, Vermont DEC – AQCD: collin.smythe@vermont.gov

Executive Summary

Greenhouse gases (GHGs) are gases in the earth's atmosphere that absorb solar radiation and trap that energy as heat in the atmosphere. Changes in atmospheric GHG concentrations and the emissions of these gases drive global climate change and are associated with a wide range of impacts on global and local scales. Understanding the sources and scale of contributions of these emissions informs appropriate strategies to meet the state's statutory GHG emissions reduction targets (Figure ES-1).

The *Vermont Greenhouse Gas Emissions Inventory and Forecast* reports are required by 10 V.S.A. § 582 to track emissions levels in Vermont related to the statewide goals established in 10 V.S.A. § 578. The reports use methodologies consistent with the *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030*,¹ U.S. EPA emissions inventory tools, and the Intergovernmental Panel on Climate Change (IPCC) guidelines for greenhouse gas inventories to develop emissions estimates for each applicable sector in the state. Data are utilized from multiple federal and state agencies and datasets. Inventory reports are released as the necessary datasets become available, generally two to three years after the year in which the emissions occurred.

Total gross GHG emissions in Vermont for 2016 were approximately 13% above the 1990 baseline emissions levels, despite a decline of approximately 0.43 million metric tons of carbon dioxide equivalent (MMTCO₂e), or 4%, from 2015 levels. Overall emissions reductions from 2015 to 2016 were driven by the Residential/Commercial/Industrial (RCI) sector and the Electricity sector. Emissions in the remaining sectors remained fairly constant from 2015 to 2016 with a small decrease in emissions from the Waste and Agricultural sectors and minor increases in the Industrial Processes, Fossil Fuel Industry, and Transportation sectors.

The removal of CO₂ from the atmosphere by forest carbon sequestration is an important piece of the net GHG fluxes in Vermont. Total sequestration from Vermont forests has been declining slightly over time from the 1990 baseline and continued to do so from 2015 to 2016. Sequestration offsets emissions in the state, but Vermont is still a net emitter of GHGs despite its large percentage of forested land.

An attempt has been made in this report to provide both preliminary GHG estimates for 2017 and 2018 and five and ten year (2021 and 2026) emissions forecasts by estimating or projecting emissions for years after 2016. The estimates for calendar years 2017 and 2018 are based on the standard methodologies where possible, and on extrapolations where data are not available. Utilizing these methods, the total emissions for all sectors continues to decline over the two-year period with a value of 9.41 MMTCO₂e in 2017 and a value of 9.02 MMTCO₂e in 2018. The five and ten year forecasts are less certain as many additional factors, variables, and uncertainties come into play. Emissions are generally forecasted using percent changes based on different projected indicators for each sector or using historical rates of change. The five and ten year time horizons are specified in statute and are forecasted to have lower emissions than each

¹ Vermont DEC website: <http://dec.vermont.gov/air-quality/climate-change>

preceding forecast. Total emissions for 2021 have been projected at 8.53 MMTCO₂e and emissions for 2026 have been projected at 7.79 MMTCO₂e. These forecasted values suggest that GHG emissions from Vermont may decline in coming years, but future conditions are difficult to predict as they are prone to many uncertainties.

Although GHG emissions decreased from 2015 to 2016, the 2016 levels are still well above the future targets and the 2012 target passed unrealized (Figure ES-1). Additional actions will be necessary, particularly in the larger contributing sectors (Figure ES-2), to provide emissions reductions to make real progress toward these goals in the years ahead.

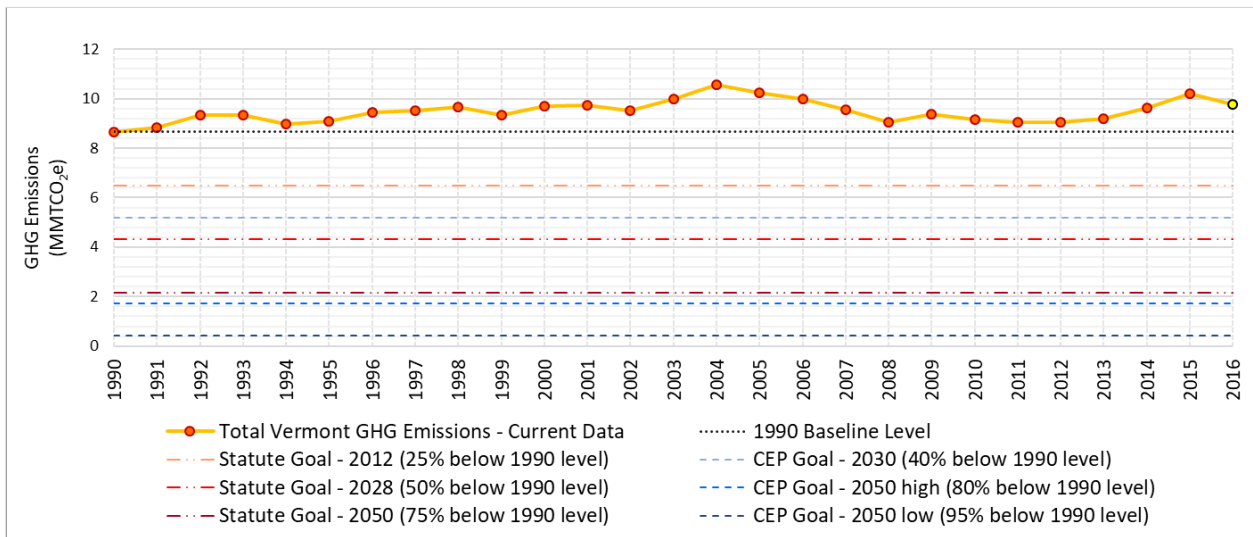


Figure ES-1: Vermont statewide greenhouse gas emissions and levels of GHG emissions targets as defined in 10 V.S.A. § 578 and in the Comprehensive Energy Plan (CEP) published by the Vermont Department of Public Service.

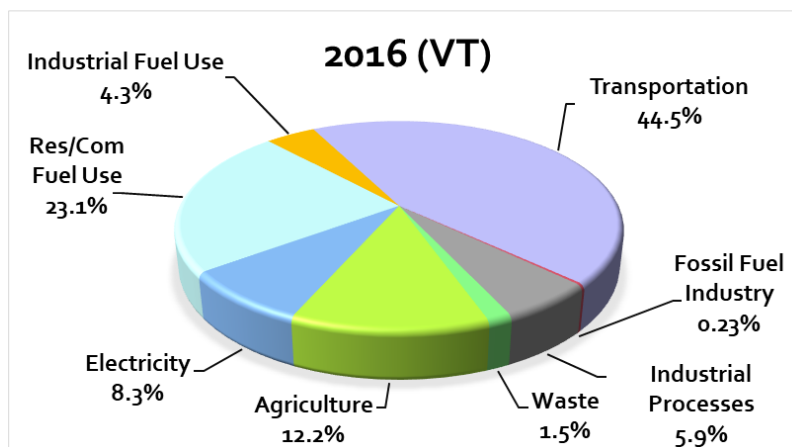


Figure ES-2: Vermont greenhouse gas emissions in 2016, percent contribution by sector.

Introduction

Vermont Greenhouse Gas Emissions Inventory and Forecast reports are generated annually in accordance with 10 V.S.A. § 582. The report details the emissions of greenhouse gases (GHGs) by sector for the state of Vermont and draws upon data and methodologies from multiple state and federal agencies.

The annual gross greenhouse gas emissions generated in Vermont declined slightly from 2015 in calendar year 2016, decreasing from 10.19 million metric tons CO₂ equivalent (MMTCO_{2e}) to 9.76 MMTCO_{2e}. This decrease puts the state approximately 13% above the 8.65 MMTCO_{2e} 1990 baseline value in 2016. Although emissions totals do show a reduction in 2016 compared to 2015 and interrupt the upward emissions trajectory seen from 2011 - 2015, steep reductions are needed in the coming years if the state is going to make progress toward meeting its GHG reduction goals² (Figure 1).

The global warming potential (GWP) values in this report are from the IPCC AR4 report and are consistent with those in the previous report (1990-2015³). Data sources and methodologies are consistent between the 2015 and 2016 reports except for the ozone depleting substances substitutes (ODS Substitutes) subsection of the Industrial Processes sector for which the estimation methodology was updated. Historical emissions estimates in this report may be different from previous reports due to updates and improvements in historical federal dataset values, emission factors, and methodologies. Therefore, values in this inventory supersede all values in previous reports.

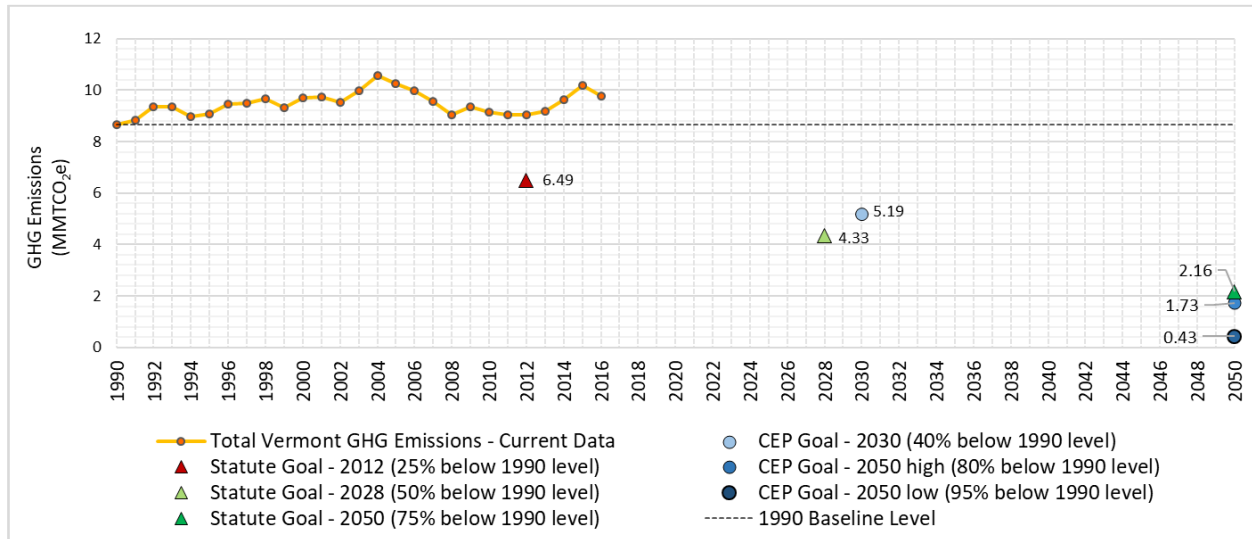


Figure 1: Vermont Historic GHG Emissions Estimates and Future Emissions Reduction Goals^{2,4}

² 10 V.S.A. § 578: <http://legislature.vermont.gov/statutes/section/10/023/00578>

³ Source: [Vermont Greenhouse Gas Emissions Inventory Update \(1990 – 2015\)](#)

⁴ Vermont Comprehensive Energy Plan (CEP) 2016: https://publicservice.vermont.gov/publications-resources/publications/energy_plan

The largest source sectors of GHG emissions in Vermont continue to be the transportation, residential commercial and industrial (RCI) fuel use, agriculture, and electricity sectors. In 2016 emissions from the RCI sector, the electricity sector, and the waste sector decreased from 2015.

This report inventories greenhouse gas emissions totals for the state of Vermont from 1990 through 2016 which are detailed in Appendix B. The gases included in this inventory are based on those named by the United Nations Framework Convention on Climate Change (UNFCCC) in the Kyoto Protocol⁵ and include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). Nitrogen trifluoride (NF₃) has also been included as it was added to the original list of six GHGs previously specified in the Kyoto Protocol.

The emissions estimates generated for this report have been developed using methodologies consistent with the *Final Vermont Greenhouse Gas Inventory and Reference Case Projections, 1990-2030* developed by the Center for Climate Strategies (CCS), the most up-to-date State Inventory Tool (SIT) modules from the U.S. Environmental Protection Agency, and methodologies developed by the Vermont Agency of Natural Resources and the Vermont Department of Public Service, utilizing data available from a variety of in-state and national sources including the Vermont Agency of Transportation, Vermont Legislative Joint Fiscal Office (JFO), the Vermont Department of Public Service, U.S. Department of Energy, U.S. Department of Agriculture, and others. Greenhouse gas emissions data have been calculated and are summarized by sector from 1990-2016 in the tables and graphs that follow.

⁵ United Nations Climate Change: http://unfccc.int/kyoto_protocol/items/3145.php

Emissions Comparison Between Vermont and the United States

Greenhouse gas emissions from Vermont contributed 0.15 percent to total U.S. emissions in 2016 (Figure 2). Although GHG emissions declined from 2015 to 2016, emissions were 13% greater in 2016 than in 1990, the baseline year defined by statute (Figure 3). Vermont has had a lower rate of CO₂e emissions per capita than the national average, but the difference between the two has been decreasing in recent years (Figure 4). While Vermont’s per capita GHG emissions are lower than those of the nation as a whole, the state has greater per capita emissions than the other New England states and New York (Figure 5). The Transportation, Residential / Commercial Fuel Use, and Agriculture sectors contributed the largest proportions of GHG emissions in Vermont (Figure 6).

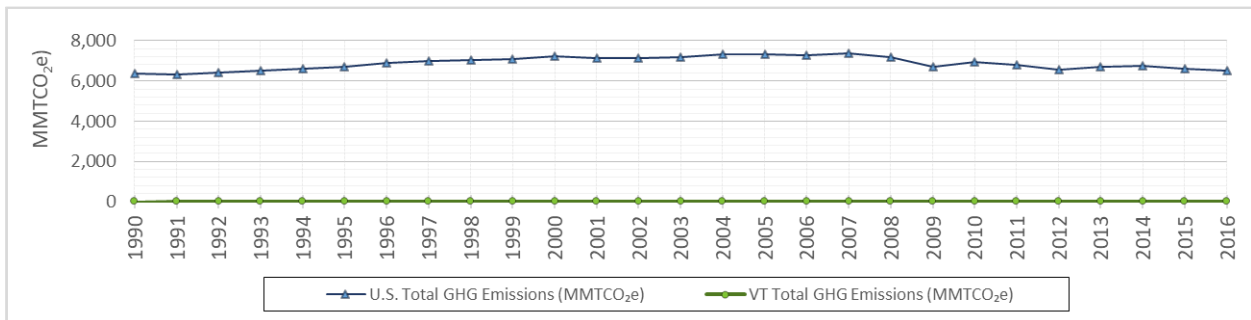


Figure 2: Vermont and the U.S. – Historical Gross GHG Emissions Comparison (1990 – 2016).



Figure 3: Vermont Historical Gross GHG Emissions (1990 – 2016).

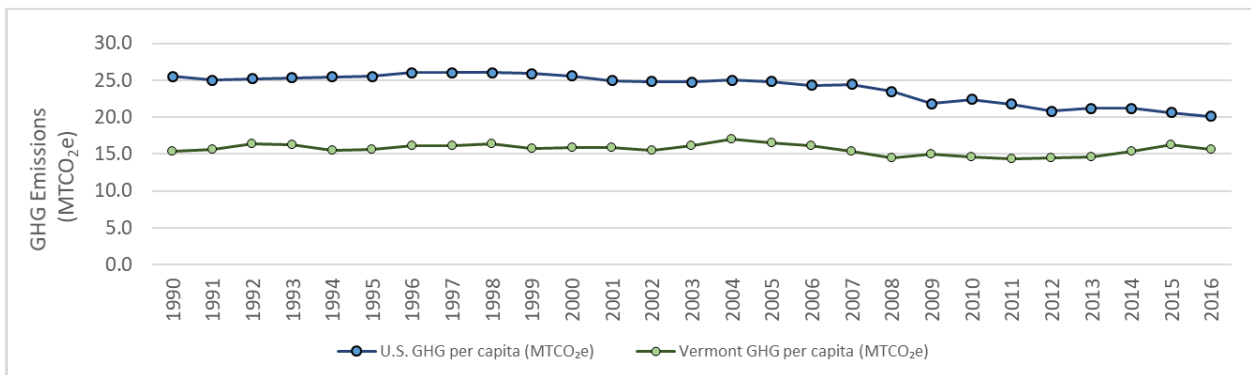


Figure 4: Comparison of GHG emissions per capita from Vermont and the U.S., (1990 – 2016).

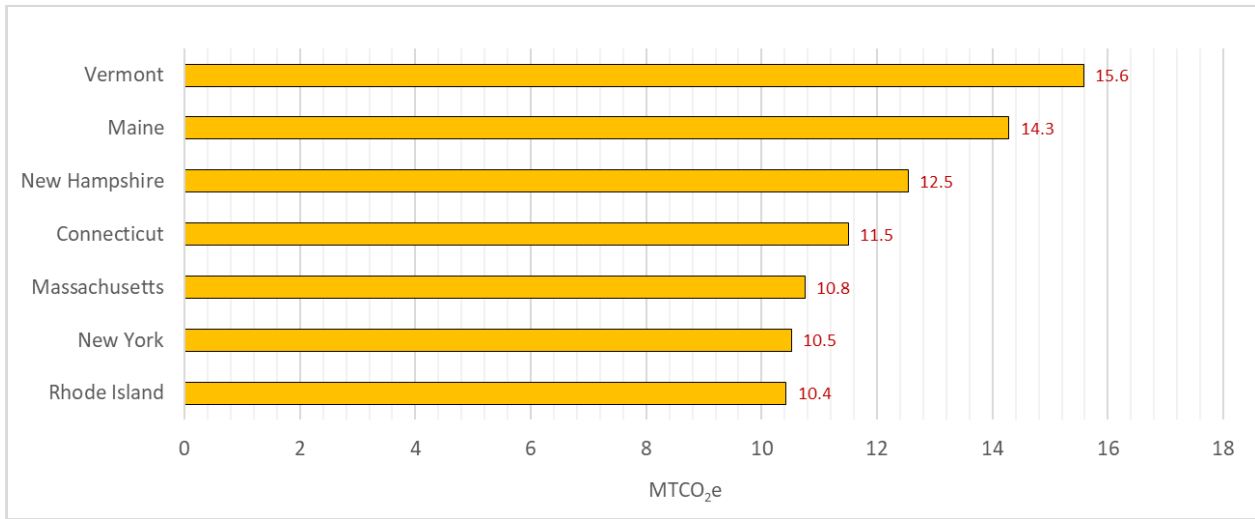


Figure 5: Comparison of GHG emissions per capita in northeastern states in 2016⁶ in MMTCO₂e.

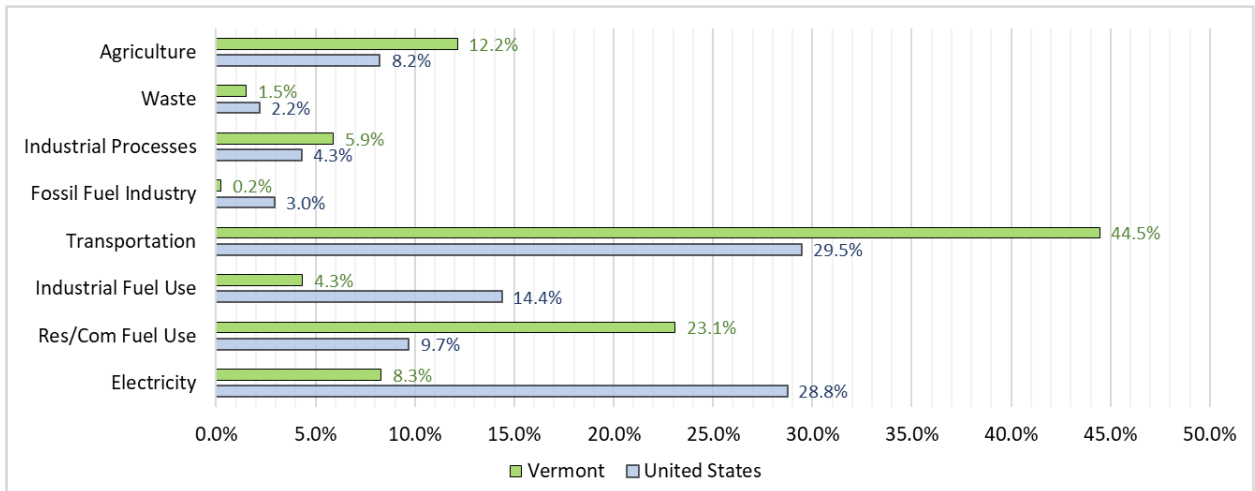


Figure 6: Comparison of percent contribution by sector of Vermont and U.S. GHG emissions for 2015.⁷

Note: Electricity sector emissions for Vermont include the emissions associated with the generation of all electricity consumed by Vermonters annually, not exclusively electricity generated within the state.

⁶ Data from ME is for 2015 and values from NH are estimated based on EIA energy related emissions for 2016. State population data is from the July 1, 2018 census data estimates from the U.S. Census Bureau.

⁷ U.S. source: [Inventory of U.S. GHG Emissions and Sinks: 1990 – 2017](https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf) (April 2019). (recategorized to match Vermont sector categories).

<https://www.epa.gov/sites/production/files/2019-04/documents/us-ghg-inventory-2019-main-text.pdf>

Vermont Greenhouse Gas Emissions by Sector

The Vermont greenhouse gas emissions goals are based on combined gross annual emissions totals for the sectors outlined below. Evaluating emissions from each sector individually enables a more robust and meaningful understanding of sector contributions. Combined contributions and changes by sector are illustrated in Figure 7 through Figure 10, below. Historical emissions graphs for each individual sector are shown in Figure 11 through Figure 17.

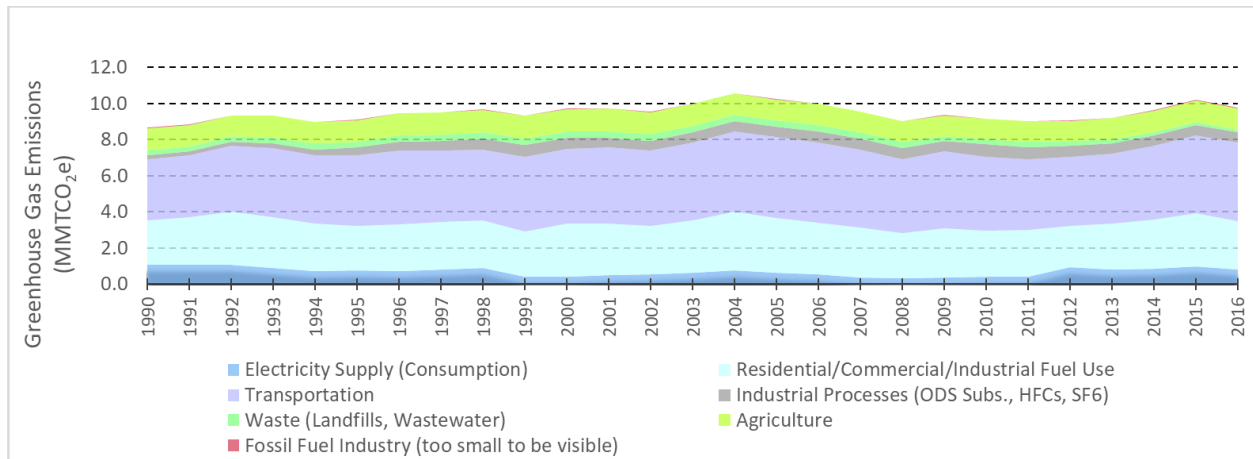


Figure 7: Annual Gross Vermont GHG Emissions (1990 – 2016).

Sector	Million Metric Tons CO ₂ Equivalent: MMTCO ₂ e								Change relative to 1990	Change relative to 2015
	1990	1995	2000	2005	2010	2014	2015	2016		
Electricity Supply & Demand (consumption based)	1.09	0.77	0.43	0.64	0.43	0.84	1.00	0.81	↓	↓
Residual System Mix	1.03	0.75	0.35	0.62	0.36	0.81	0.96	0.79		
Residential / Commercial / Industrial (RCI) Fuel Use	2.45	2.45	2.90	3.00	2.53	2.71	2.92	2.68	↑	↓
Oil, Propane & Other Petroleum	2.06	2.00	2.34	2.49	2.01	2.06	2.20	1.95		↓
Transportation	3.38	3.91	4.15	4.49	4.09	4.10	4.33	4.34	↑	→
Onroad Gasoline	2.64	2.81	3.20	3.29	2.90	3.03	3.16	3.19		→
Onroad Diesel	0.41	0.84	0.66	0.69	0.70	0.54	0.57	0.54		
Fossil Fuel Industry	0.018	0.016	0.016	0.017	0.017	0.018	0.019	0.023	↑	↑
Natural Gas Transmission	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02		↑
Industrial Processes	0.21	0.42	0.59	0.57	0.67	0.56	0.57	0.58	↑	→
Waste Management	0.27	0.33	0.36	0.34	0.28	0.21	0.16	0.15	↓	↓
Solid Waste	0.21	0.27	0.30	0.28	0.21	0.14	0.10	0.08		↓
Agriculture	1.23	1.19	1.24	1.18	1.13	1.18	1.19	1.19	↓	→
TOTAL GROSS EMISSIONS	8.65	9.09	9.70	10.24	9.15	9.62	10.19	9.76		
Change relative to 1990 (baseline)	—	+ 5%	+ 12%	+ 18%	+ 6%	+ 11%	+ 18%	+ 13%		

Figure 8: Directional indicators for changes in emissions levels by sector for 2016 as compared to 1990 baseline and 2015 levels. Only subsectors shown are those which contributed significantly to the positive or negative emissions changes within the sector.

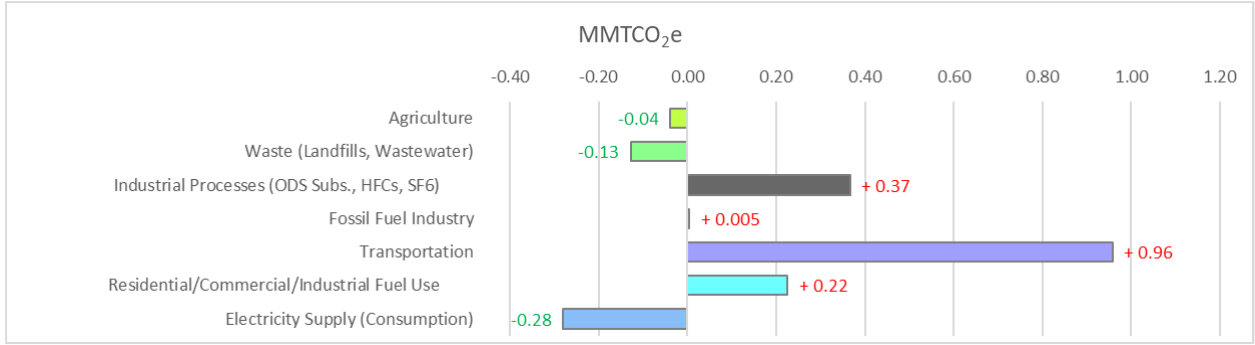


Figure 9: Net changes in GHG Emissions by sector (1990 baseline to 2016).

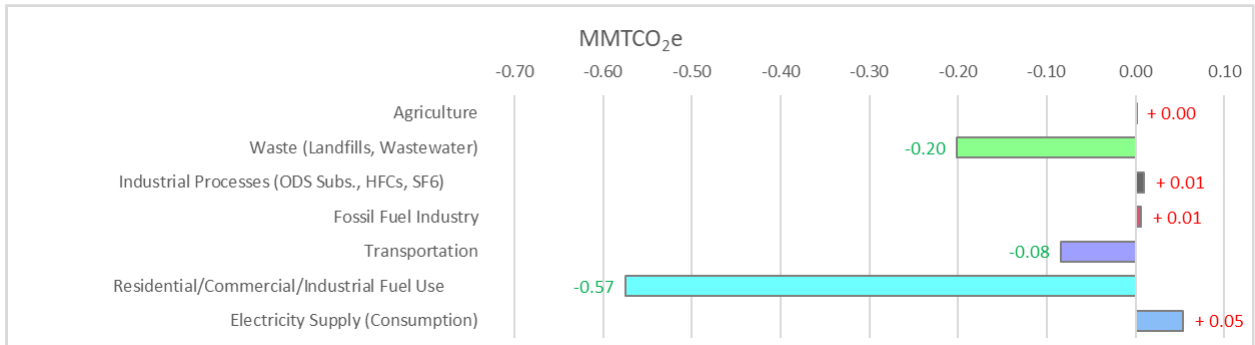


Figure 10: Net changes in GHG Emissions by sector (2004 peak to 2016).

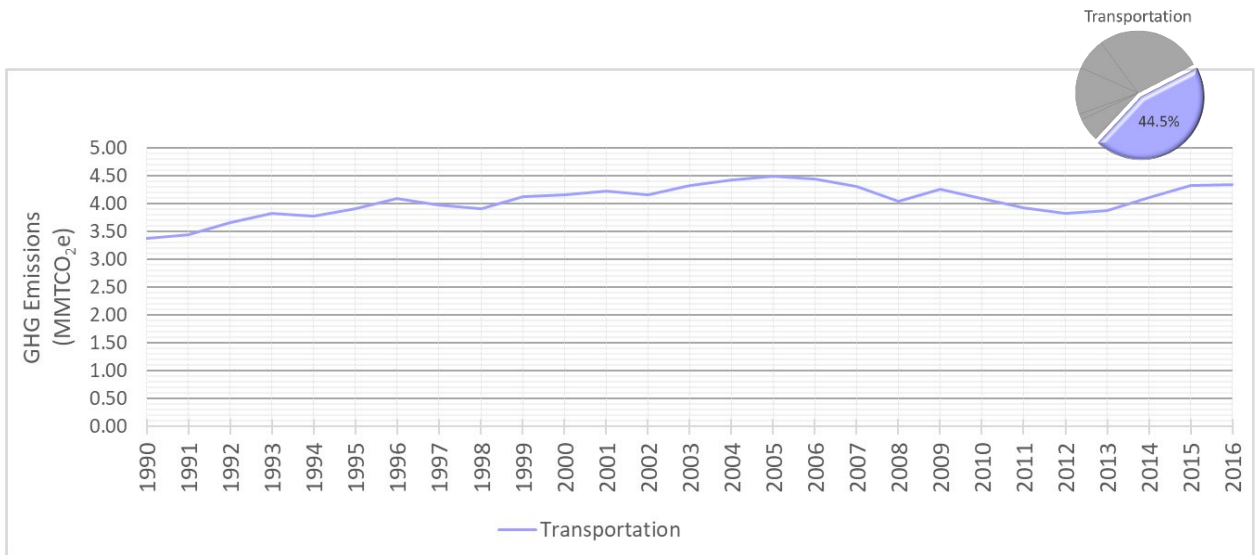


Figure 11: Vermont Transportation Sector GHG Emissions (1990 – 2016).

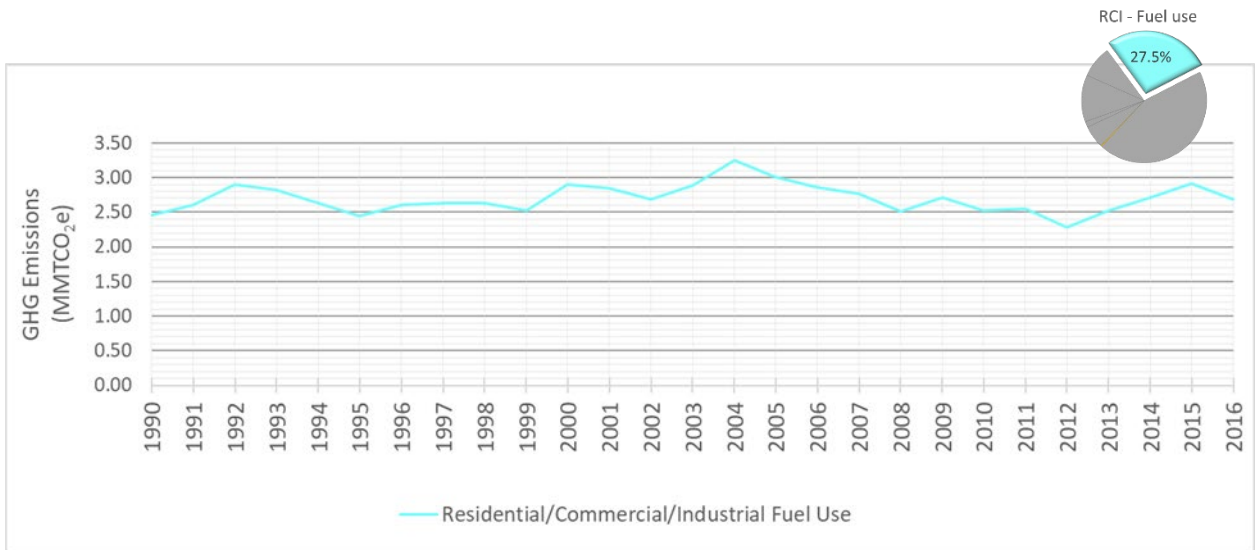


Figure 12: Vermont Residential/Commercial/Industrial Fuel Use Sector GHG Emissions (1990 – 2016).

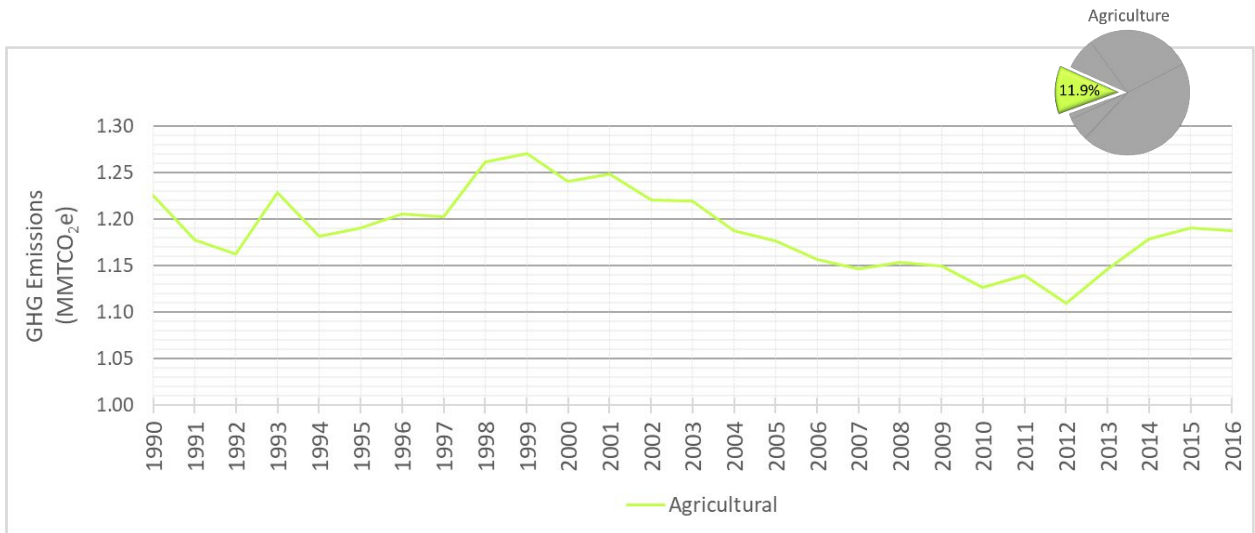


Figure 13: Vermont Agricultural Sector GHG Emissions (1990 – 2016).

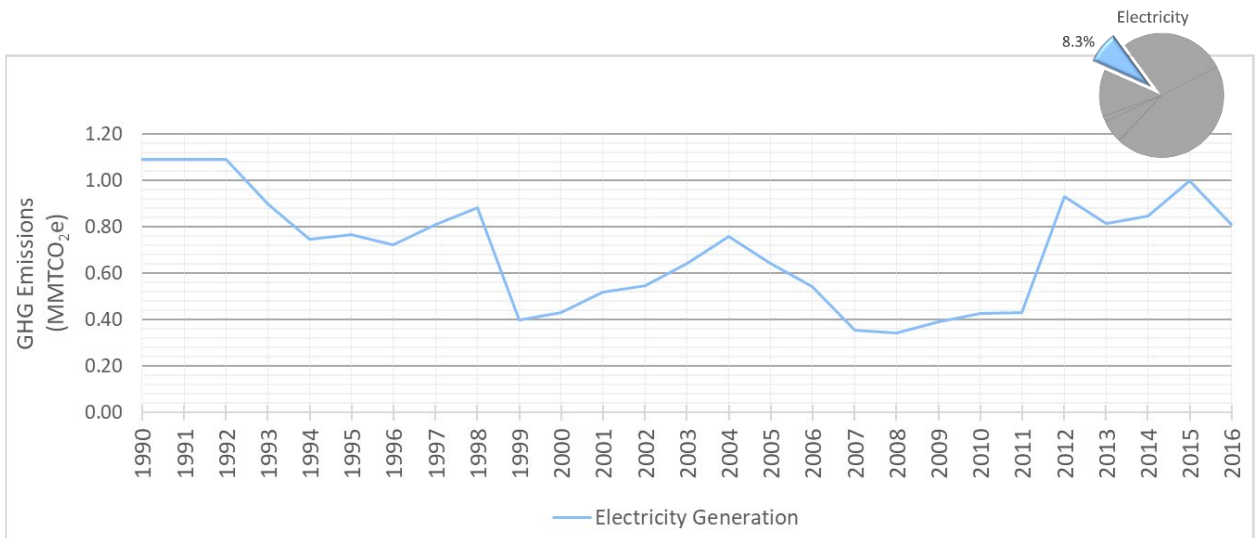


Figure 14: Vermont Electricity Sector GHG Emissions (1990 – 2016).

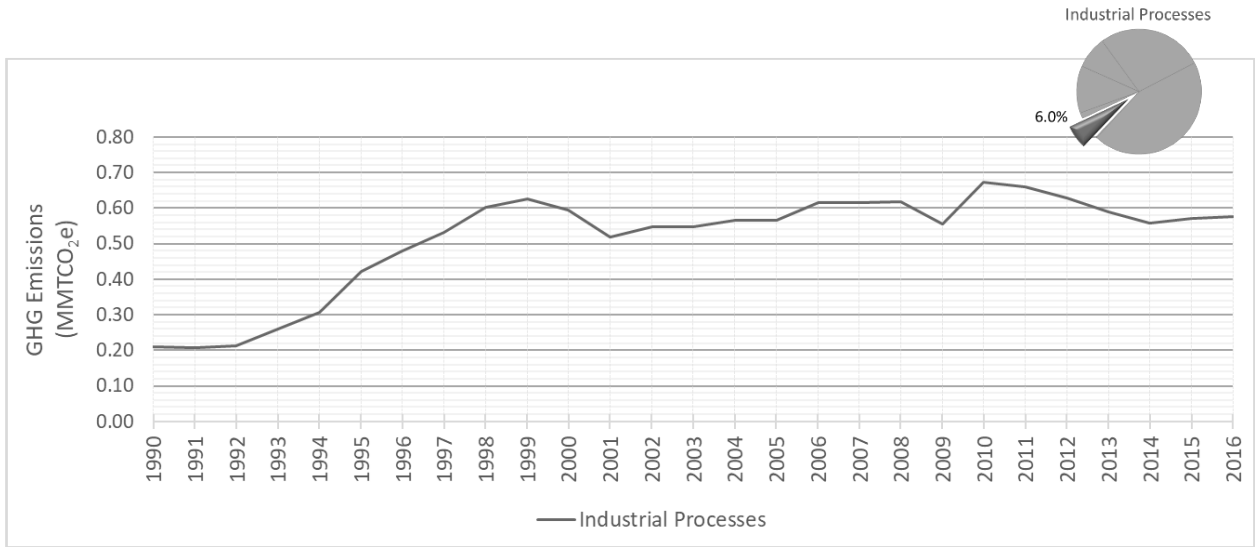


Figure 15: Vermont Industrial Process Sector GHG Emissions (1990 – 2016).

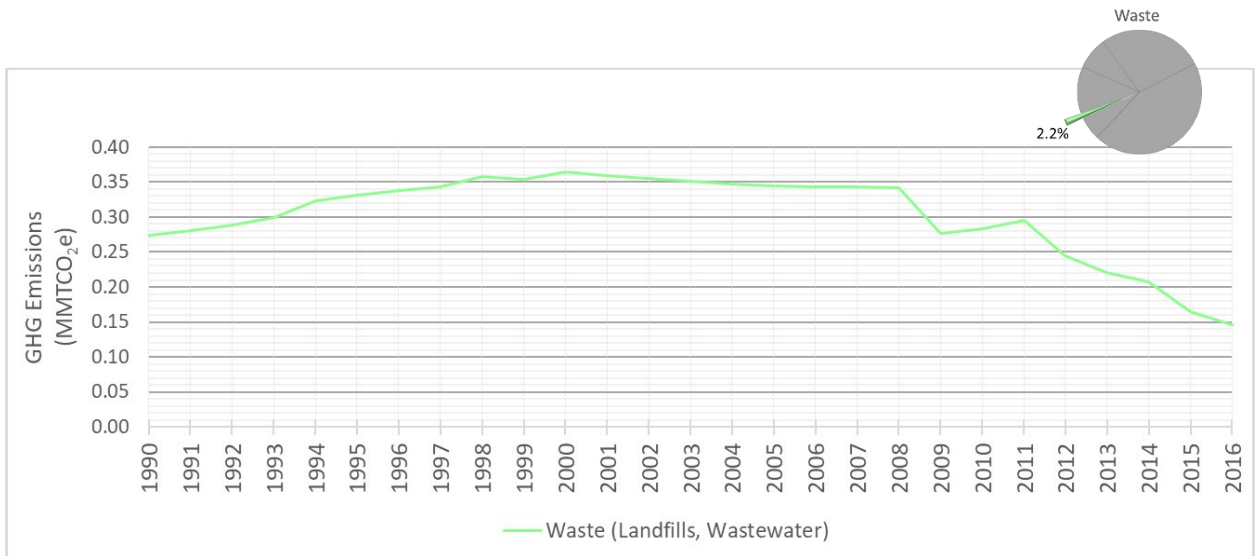


Figure 16: Vermont Waste (Landfills and Wastewater) Sector GHG Emissions (1990 – 2016).

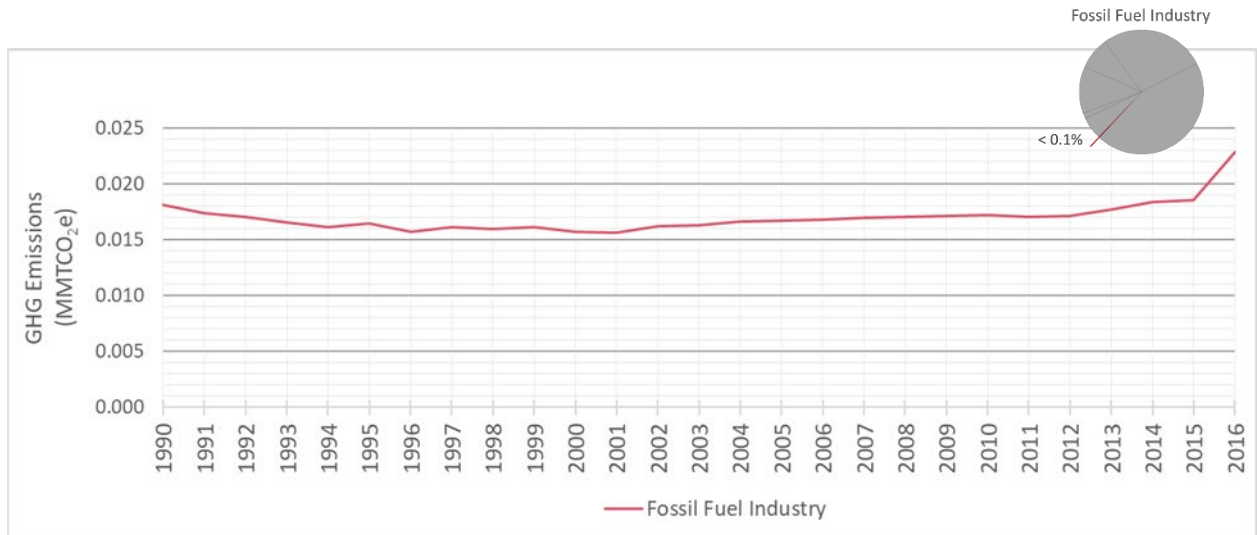


Figure 17: Vermont Fossil Fuel Industry Sector GHG Emissions (1990 – 2016).

Additional Climate Forcing Factors to Consider

Forestry and Land Use

Forests and other vegetation remove (sequester) CO₂ from the atmosphere and convert it into stored biological material through the process of photosynthesis. This process is an important factor when estimating net greenhouse gas emissions, particularly for a heavily forested state like Vermont. Estimating carbon sequestered and stored in forests is complex. Sequestration estimates for Vermont (Figure 17) have been provided by the U.S. Forest Service.⁸ The estimates of carbon sequestration by forests and urban trees in Vermont are included in this section, however these totals are not reflected in the gross values shown in Appendix B.

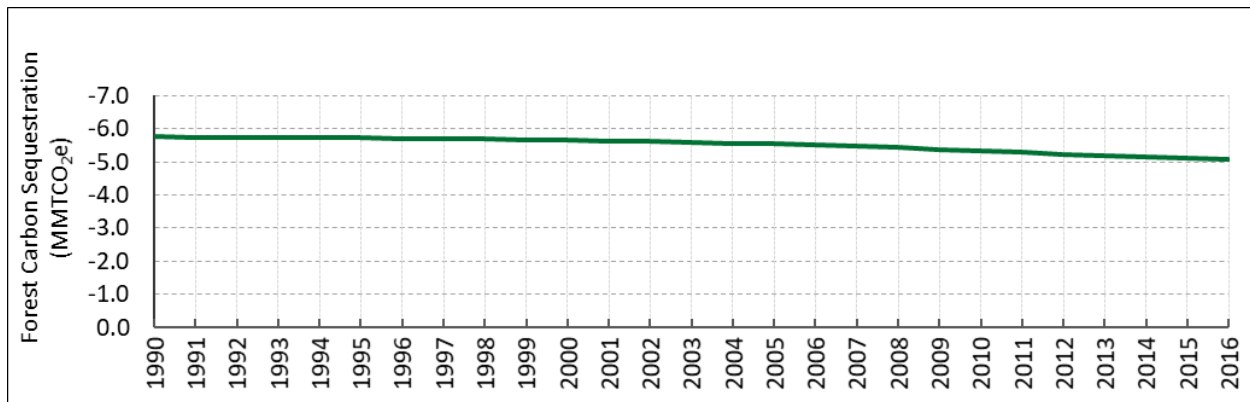


Figure 18: Estimates of carbon sequestration by forests and urban trees in Vermont. Negative values represent carbon sequestration (as opposed to positive emissions values).

Black Carbon

Estimates of black carbon (BC) emissions for Vermont were shown in the 2014 Vermont Greenhouse Gas Emissions Inventory Update⁹ and were extracted as the elemental carbon (EC) fraction of PM_{2.5} emissions from the 2014 National Emissions Inventory (NEI) version 2 data. Black carbon emissions will be updated in the 2017 inventory report which coincides with the availability of the 2017 NEI data.

⁸ Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Smith, James, E.; Ogle, Stephen M.; Coulston, John W. 2019. Greenhouse gas emissions and removals from forest land and urban trees in the United States, 1990-2017. Resource Update FS-178. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 4 p. <https://doi.org/10.2737/FS-RU-178>. In US Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017. EPA 430-R-19-001.

⁹ VT DEC Greenhouse Gas Emissions Inventory Update 1990-2014: <https://dec.vermont.gov/air-quality/climate-change>

Emissions Forecasts

Preliminary Greenhouse Gas Emissions Estimates for 2017 and 2018

The release of the *Vermont Greenhouse Gas Emissions Inventory and Forecast* reports depend on the availability of a large amount of data and tools from multiple federal agencies. In order to provide as accurate a statewide emissions estimate as possible, it is important to have complete datasets to work with. Since some inventory sectors depend much more heavily on large federal datasets and tools than others there are certain sectors in the inventory for which data are already available for calendar years 2017 and even for 2018. For sectors where the data required for the standard methodologies are not available, some values may be extrapolated based on appropriate indicators for the sector, and others are carried forward from the last available calendar year. Additional calculations and extrapolations have been performed for this inventory to provide complete GHG emissions estimates through 2018 (Table 1). Values calculated using the standard inventory methodologies are shown in black, values that were carried forward from the previous calendar year are shown in red, and values that have been extrapolated based on data or methodologies that differ from the normal inventory processes are shown in blue.

Table 1: Preliminary GHG Emissions Estimates for 2017 and 2018 in MMTCO₂e.

Sector	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electricity Supply & Demand (Consumption - based)	0.43	0.43	0.93	0.81	0.84	1.00	0.81	0.49	0.19
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Oil	0.04	0.04	0.01	0.01	0.02	0.01	0.00	0.00	0.00
Wood (CH ₄ , N ₂ O)	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Residual System Mix	0.36	0.37	0.90	0.78	0.81	0.96	0.79	0.47	0.17
Residential/ Commercial/ Industrial (RCI) Fuel Use	2.53	2.56	2.29	2.52	2.71	2.92	2.68	2.69	2.72
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.44	0.45	0.43	0.51	0.57	0.64	0.65	0.65	0.65
Oil, Propane, & Other Petroleum	2.01	2.03	1.78	1.93	2.06	2.20	1.95	1.96	1.98
Wood (CH ₄ , N ₂ O)	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Transportation	4.09	3.93	3.83	3.88	4.10	4.33	4.34	4.32	4.22
Onroad Gasoline	2.90	2.75	2.70	2.73	3.03	3.16	3.19	3.21	3.13
Onroad Diesel	0.70	0.65	0.63	0.62	0.54	0.57	0.54	0.54	0.52
Jet Fuel & Aviation Gasoline	0.09	0.10	0.10	0.10	0.09	0.11	0.12	0.10	0.10
Rail/Ships/Boats/Other Nonroad	0.41	0.43	0.40	0.43	0.44	0.50	0.49	0.48	0.48
Fossil Fuel Industry	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03
Natural Gas Distribution	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas Transmission	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Industrial Processes	0.67	0.66	0.63	0.59	0.56	0.57	0.58	0.57	0.56
ODS Substitutes	0.25	0.26	0.28	0.29	0.31	0.32	0.33	0.34	0.34
Electric Utilities (SF ₆)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Semiconductor Manufacturing (HFC, PFC & SF ₆)	0.39	0.36	0.32	0.25	0.21	0.21	0.21	0.19	0.18
Limestone & Dolomite Use	0.02	0.02	0.02	0.03	0.04	0.03	0.03	0.03	0.03
Soda Ash Use	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urea Consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	0.28	0.29	0.24	0.22	0.21	0.16	0.15	0.14	0.15
Solid Waste(CH ₄ , N ₂ O)	0.21	0.23	0.18	0.15	0.14	0.10	0.08	0.07	0.08
Wastewater	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Agriculture	1.13	1.14	1.11	1.15	1.18	1.19	1.19	1.16	1.16
Enteric Fermentation	0.62	0.63	0.62	0.64	0.64	0.64	0.63	0.63	0.63
Manure Management	0.21	0.21	0.20	0.20	0.20	0.19	0.19	0.19	0.19
Agricultural Soils	0.29	0.29	0.28	0.30	0.32	0.31	0.31	0.29	0.29
Liming and Urea Fertilization	0.01	0.00	0.00	0.01	0.03	0.05	0.05	0.05	0.05
Gross Emissions Total	9.15	9.03	9.04	9.19	9.62	10.19	9.76	9.41	9.02

Five and Ten Year Forecasting

Forecasting emissions estimates into the future has more layers of complexity and is more prone to uncertainties than estimating values for years with limited data availability. The farther into the future the estimate, the more difficult it is to account for unknown variables. Emissions were estimated for all sectors at five and ten year milestones from the 2016 calendar year, or 2021 and 2026 respectively (Table 2), as specified in statute.

Since the number of variables to consider is so large and the emissions trajectories for many sectors depend on information that is nearly impossible to predict these values are more indicators of the directionality of emissions for each sector than actual predictions of emissions levels in the future. Qualitative descriptions of some of the major influencing factors have been provided below by sector to help understand the rationale for these projections.

Transportation

The transportation sector is both the largest contributing sector in the inventory and one of the more complex for which to make emissions projections. This is due to the many uncertain factors which could have large impacts on emissions levels from the sector. Some of these factors include oil prices, zero emission vehicle (ZEV) battery prices and vehicle adoption rates, future state and federal policies or incentives to reduce transportation sector emissions, and applicable vehicle emissions standards. Vehicle standard specific considerations include the expected rollback of the federal fuel economy standards and greenhouse gas emission standards and the revocation of the waiver which enables California to establish more stringent greenhouse gas emissions vehicle standards and achieve emissions reduction goals by requiring automobile manufacturers to offer for sale the cleanest vehicles available including ZEVs, and for other states, including Vermont, to adopt more stringent standards.

The transportation values for 2021 and 2026 in Table 2 have been estimated from percent changes to the 2018 value based on projected future vehicle miles traveled (VMT) for Vermont produced by the UVM Transportation Research Center (TRC) with the Vermont Travel Model. The VMT data were adjusted by emission standard mandated average vehicle fuel economy improvements as modeled in the Energy Information Administration (EIA) Annual Energy Outlook 2019 (AEO2019)¹⁰ fuel economy data.

Residential/Commercial/Industrial (RCI) Fuel Use

Projecting emissions in the RCI sector into the future is also difficult due to the annual variability in the sector. This variability is mainly due to the amount of oil and propane combusted and is dependent on winter temperatures and heating demand. Emissions levels in this sector can also be influenced by oil prices, and the rate of home weatherization and electrification of heating systems in the future and potential programs and incentives to change these adoption and weatherization rates.

The projections in Table 2 are based on percent changes in EIA AEO2019¹⁰ residential, commercial, and industrial fuel consumption estimates in New England for natural gas, propane, and distillate fuel oil.

Electricity Consumption

Emissions from the electricity sector are also difficult to predict, however emissions levels from this sector are given more certainty due to the implementation of the Renewable Energy Standard (RES)¹¹. This is complicated, however, by a decrease in the amount of electricity purchased from the residual mix in 2018, potentially driven by RES requirements, and an increase in nuclear purchases which brought emissions for 2018 to only 0.19 MMTCO_{2e} for the sector. Since the 2018 emissions totals are already quite low, making further emissions reductions more difficult to achieve, the 2018 value was carried forward through 2026 in Table 2.

¹⁰ Annual Energy Outlook (AEO) 2019: <https://www.eia.gov/outlooks/aeo/>

¹¹ Renewable Energy Standard (RES): <https://puc.vermont.gov/electric/renewable-energy-standard>

Industrial Processes

Emissions from the Industrial Processes sector are dominated by ODS substitutes and semiconductor manufacturing. Projections for the sector in Table 2 have been based on these two subsectors. ODS substitutes values are based on a tool developed by California for U.S. Climate Alliance states to estimate emissions from the sector and include the implementation of high global warming potential HFC phaseout regulations such as Vermont Act 65 (S.30).¹² Semiconductor manufacturing emissions have been declining in recent years so the recent rate of decrease was continued through 2021 and then carried forward at the 2021 level through 2026.

Agriculture

Emissions in the agriculture sector have been carried forward in Table 2 from calculated 2017 values through 2026 due to a lack of reliable forecast information and uncertainty in sector trends. Totals in this sector may be influenced by different practices and initiatives including changes in soil management practices.

Waste Management

Waste management sector emissions have been declining by approximately 0.5% on average over the past several years. This rate of reduction has been carried forward in the values in Table 2 through 2026. This is potentially complicated by landfill expansion and landfill gas generation rates; however, those potential increases will likely be offset by the slowing of landfill gas production from closed landfills in the state.

Fossil Fuel Industry

Totals in Table 2 for the fossil fuel industry are expected to increase in the coming years as additional lines and services are added in Vermont. It is unclear what the rate of expansion will be so a rate of increase consistent with the average increase from 1990 – 2018 was used to project the 2018 emissions for the sector through 2026.

Table 2: Greenhouse gas forecasts for 2021 and 2026 in MMTCO₂e.

Sector	2021	2026
Transportation	3.95	3.57
Residential/ Commercial/ Industrial (RCI) Fuel Use	2.54	2.38
Electricity Supply & Demand (Consumption - based)	0.19	0.19
Industrial Processes	0.53	0.52
Agriculture	1.16	1.16
Waste Management	0.14	0.12
Fossil Fuel Industry	0.03	0.03
Total	8.53	7.97

¹² Vermont Act 65 (S.30):

<https://legislature.vermont.gov/Documents/2020/Docs/ACTS/ACT065/ACT065%20As%20Enacted.pdf>

Conclusions

Estimates of gross emissions of greenhouse gases in Vermont for 2016 show a decline from 2015 estimates, dropping from an estimated 10.19 MMTCO_{2e} in 2015 to 9.76 MMTCO_{2e} in 2016. Even with this decline 2016 emissions levels are still 13% above the 1990 baseline levels. Much of the decrease was attributable to a reduction in the use of propane and fuel oil in 2016 and the associated emissions reductions in the RCI sector. Reductions also occurred in the electricity sector due to less of the higher emitting residual systems mix electricity being purchased than in 2015. Emissions from the electricity sector show continued declines through 2018 and with the implementation of the RES in 2017 requiring electric distribution utilities have at least 55% renewable energy in their portfolios in 2017 and to increase that percentages to 75% by 2032 the emissions totals from the sector are not expected to rise significantly. Although progress in the electricity sector is encouraging, the transportation sector remains by far the largest contributor to our gross emissions total and there have been few emissions reductions from this sector. Annual greenhouse gas emissions in Vermont remain at levels well above the reduction goals established in state statute (10 V.S.A. § 578)² and in the Comprehensive Energy Plan⁴ (Figure 1). Although 2016 exhibited a decrease in overall gross emissions levels, more significant and sustained reductions will be required to make meaningful progress toward Vermont's emissions reduction goals.

Appendix A – Acronyms & Abbreviations

AR4: Intergovernmental Panel on Climate Change Fourth Assessment Report

AEO2019: Annual Energy Outlook 2019 Report

BC: black carbon

CCS: Center for Climate Strategies

CO₂: carbon dioxide

CH₄: methane

EC: elemental carbon

EIA: Energy Information Administration

EPA: Environmental Protection Agency

GHG: greenhouse gases

GWP: global warming potential

HFC: hydrofluorocarbon

IPCC: Intergovernmental Panel on Climate Change

JFO: Joint Fiscal Office

MMTCO_{2e}: million metric tons carbon dioxide equivalent

NEI: National Emissions Inventory

NF₃: nitrogen trifluoride

ODS: ozone depleting substances

PFC: perfluorocarbon

RCI: Residential/Commercial/Industrial

RES: Renewable Energy Standard

SF₆: sulfur hexafluoride

SIT: State Inventory Tool

UNFCCC: United Nations Framework Convention on Climate Change

VMT: Vehicle Miles Traveled

Appendix B - Vermont Historic Greenhouse Gas Emissions by Sector ^{13,14,15}

Sector	Million Metric Tons CO ₂ Equivalent: MMTCO ₂ e																			
	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
Electricity Supply & Demand (consumption based)	1.09	0.77	0.43	0.52	0.55	0.64	0.76	0.64	0.54	0.35	0.34	0.39	0.43	0.43	0.93	0.81	0.84	1.00	0.81	
Coal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Natural Gas	0.05	0.00	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	
Oil	0.01	0.01	0.06	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.04	0.04	0.04	0.01	0.01	0.02	0.01	0.00	
Wood (CH ₄ & N ₂ O)	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	
Residual System Mix	1.03	0.75	0.35	0.47	0.51	0.59	0.71	0.62	0.51	0.31	0.29	0.34	0.36	0.37	0.90	0.78	0.81	0.96	0.79	
Residential / Commercial / Industrial (RCI) Fuel Use	2.45	2.45	2.90	2.84	2.69	2.88	3.25	3.00	2.86	2.77	2.51	2.71	2.53	2.56	2.29	2.52	2.71	2.92	2.68	
Coal	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Natural Gas	0.31	0.37	0.50	0.41	0.44	0.44	0.45	0.44	0.42	0.47	0.46	0.45	0.44	0.45	0.43	0.51	0.57	0.64	0.65	
Oil, Propane & Other Petroleum	2.06	2.00	2.34	2.36	2.19	2.37	2.74	2.49	2.37	2.23	1.98	2.18	2.01	2.03	1.78	1.93	2.06	2.20	1.95	
Wood (CH ₄ & N ₂ O)	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	
Transportation	3.38	3.91	4.15	4.22	4.16	4.32	4.42	4.49	4.44	4.31	4.05	4.26	4.09	3.93	3.83	3.88	4.10	4.33	4.34	
Onroad Gasoline	2.64	2.81	3.20	3.21	3.19	3.27	3.28	3.29	3.19	3.19	3.04	3.03	2.90	2.75	2.70	2.73	3.03	3.16	3.19	
Onroad Diesel	0.41	0.84	0.66	0.66	0.68	0.69	0.69	0.69	0.73	0.70	0.65	0.61	0.70	0.65	0.63	0.62	0.54	0.57	0.54	
Jet Fuel & Aviation Gasoline	0.08	0.06	0.07	0.06	0.03	0.05	0.09	0.17	0.16	0.13	0.11	0.21	0.09	0.10	0.10	0.10	0.09	0.11	0.12	
Rail / Ship / Boats / Other Nonroad	0.25	0.20	0.23	0.29	0.26	0.30	0.36	0.34	0.36	0.29	0.25	0.41	0.41	0.43	0.40	0.43	0.44	0.50	0.49	
Fossil Fuel Industry	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	
Natural Gas Distribution	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Natural Gas Transmission	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	
Industrial Processes	0.21	0.42	0.59	0.52	0.55	0.55	0.57	0.57	0.61	0.61	0.62	0.55	0.67	0.66	0.63	0.59	0.56	0.57	0.57	
ODS Substitutes	0.00	0.07	0.17	0.18	0.18	0.18	0.18	0.18	0.20	0.21	0.22	0.23	0.25	0.26	0.28	0.29	0.31	0.32	0.33	
Electric Utilities (SF ₆)	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Semiconductor Manufacturing (HFCs, PFCs & SF ₆) ¹⁵	0.16	0.28	0.37	0.29	0.32	0.33	0.33	0.33	0.39	0.38	0.37	0.29	0.39	0.36	0.32	0.25	0.21	0.21	0.21	
Limestone & Dolomite Use	0.00	0.03	0.02	0.02	0.02	0.02	0.03	0.03	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.04	0.03	0.03	
Soda Ash Use	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Urea Consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Waste Management	0.27	0.33	0.36	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.28	0.28	0.29	0.24	0.22	0.21	0.16	0.15	
Solid Waste	0.21	0.27	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.21	0.21	0.23	0.18	0.15	0.14	0.10	0.08	
Wastewater	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	
Agriculture	1.23	1.19	1.24	1.25	1.22	1.22	1.19	1.18	1.16	1.15	1.15	1.15	1.13	1.14	1.11	1.15	1.18	1.19	1.19	
Enteric Fermentation	0.70	0.67	0.69	0.68	0.67	0.66	0.65	0.63	0.63	0.64	0.64	0.64	0.62	0.63	0.62	0.64	0.64	0.64	0.63	
Manure Management	0.18	0.19	0.22	0.23	0.23	0.24	0.22	0.23	0.22	0.21	0.22	0.21	0.21	0.21	0.20	0.20	0.20	0.19	0.19	
Agricultural Soils	0.35	0.34	0.33	0.33	0.31	0.32	0.31	0.31	0.30	0.29	0.29	0.30	0.29	0.29	0.28	0.30	0.32	0.31	0.31	
Liming and Urea Fertilization	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.03	0.05	0.05	
TOTAL GROSS EMISSIONS	8.65	9.09	9.70	9.72	9.53	9.98	10.55	10.24	9.98	9.55	9.03	9.36	9.15	9.03	9.04	9.19	9.62	10.19	9.76	
Change relative to 1990 (baseline)	-	+ 5%	+ 12%	+ 12%	+ 10%	+ 15%	+ 22%	+ 18%	+ 15%	+ 10%	+ 4%	+ 8%	+ 6%	+ 4%	+ 5%	+ 6%	+ 11%	+ 18%	+ 13%	

¹³ Note: Grey text in the transportation sector indicates that the data were extrapolated from the EPA MOVES Model results in the National Emissions Inventory for 2014.

¹⁴ Totals may not sum exactly due to independent rounding.

¹⁵ Semiconductor data from 2011 – 2016 are from the [EPA FLIGHT Tool](#), projected back to 1990 based on sector trends from the U.S. Emissions Inventory “[Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014](#)” and National SIT values.

Appendix C – Biogenic CO₂ Emissions and Forest Carbon Sequestration

As described in the IPCC guidelines for greenhouse gas inventories, carbon dioxide emissions from the combustion or decomposition of short lived biologically based materials (biogenic CO₂) have been estimated and tracked separately from the total of the gross annual emissions calculated for each sector. Calculations have been completed to estimate and track the “at-the-stack” biogenic CO₂ emissions from the residential/commercial and industrial (RCI) fuel use sector, as well as for the electricity generation sector. Estimates of biogenic CO₂ from the waste and agricultural sectors have not been included at this time.

Emissions totals in Appendix B do not reflect carbon sequestration by forests or emissions of biogenic CO₂. Several issues influence the decision to separate forest carbon sequestration and biogenic CO₂ including the complexity in estimating forest carbon sequestration and carbon storage on a large scale and the desire to maintain consistency with previous reports. Figure 18 illustrates several scenarios relating to the inclusion of sequestration and biogenic CO₂. The actual net emissions are likely in the range of the dashed black line, which includes both biogenic CO₂ emissions and carbon sequestration.

The assumption of carbon neutrality of biogenic CO₂ is based on the idea that the emissions associated with the combustion or decomposition of the material will eventually be recaptured (sequestered) by appropriately managed vegetation (mainly forests). There are many factors that influence the claim of carbon neutrality from wood combustion specifically. The main assumptions are related to the sustainability of the forest management practices, whether the wood fuel being considered is a residue from an already occurring forestry practice or being cut for fuel, and the timescale under consideration.¹⁶ The issue with using non-residue wood materials is that when the wood material is combusted all of the previously stored carbon is released as CO₂. The problem comes with the amount of time it takes for the CO₂ released from the combustion to be re-sequestered by forests, which can be well outside the timeframe of the state greenhouse gas reduction goals.

Carbon dioxide emitted from short lived biogenic sources is generally preferable to CO₂ from the combustion of carbon in much longer-term storage (e.g. fossil fuels), especially over longer timescales, but considering these biogenic sources to be truly carbon neutral on the timescales of our state goals is potentially problematic.

¹⁶ Source - <https://iopscience.iop.org/article/10.1088/1748-9326/aaac88/pdf>

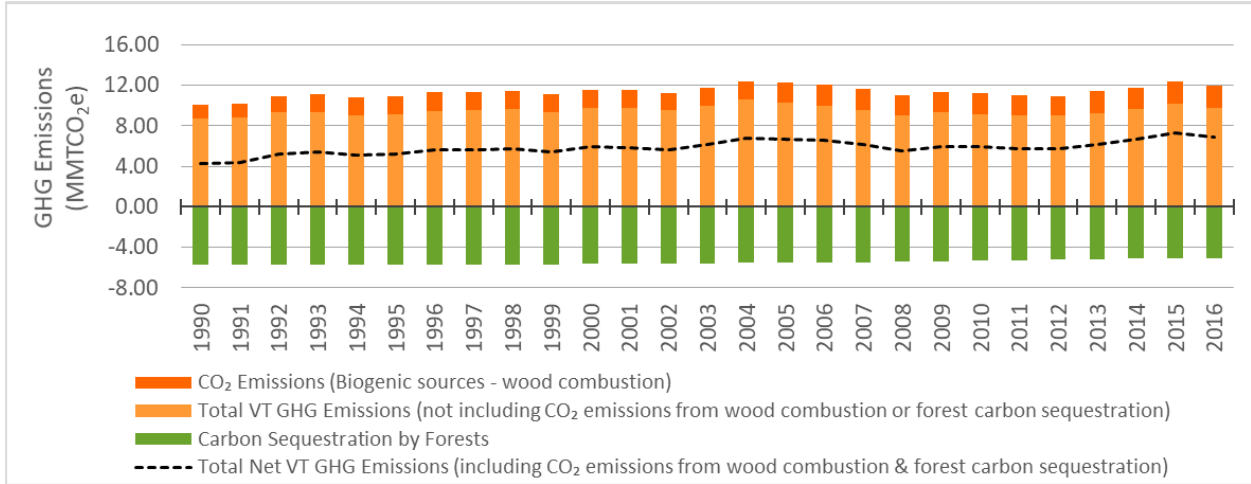


Figure 19: Vermont GHG emissions scenarios including biogenic CO₂ and forest carbon sequestration.