Hawaii Greenhouse Gas Emissions Report for 2015

Final Report

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Prepared for:

Prepared by:

Acknowledgments

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Acronyms and Abbreviations

AAPFCO	Association of American Plan Food Control Officials
AFOLU	Agriculture, Forestry, and Other Land Use
BAU	Business as usual
Bbtu	Billion British Thermal Units
Btu	British Thermal Units
BOD	Biochemical oxygen demand
CAFE	Corporate average fuel economy
CARB	California Air Resources Board
CH_4	Methane
CO_2	Carbon dioxide
DBEDT	Department of Business, Economic Development, and Tourism
DCA	Division of Consumer Advocacy
DLNR	Department of Land and Natural Resources
DOC	Department of Commerce
DOE	Department of Energy
DOH	Department of Health
DOT	Department of Transportation
E3	Energy & Environmental Economics
EEPS	Energy Efficiency Portfolio Standard
EF	Emission Factor
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EV	Electric Vehicle
FHWA	Federal Highway Administration
FOD	First order decay
GHG	Greenhouse gas
GSP	Gross state product
GWP	Global warming potential
GHGRP	Greenhouse Gas Reporting Program
HAR	Hawaii Administrative Rule
HDV	Heavy-duty vehicle
HECO	Hawaiian Electric Company
HELCO	Hawaiian Electric Light Company
HEI	Hawaii Electric Industries
HFC	Hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use

KIUC	Kauai Island Utility Cooperative
kg	kilogram
kt	kilotons
LDV	Light-duty vehicle
LNG	Liquefied natural gas
LULUCF	Land-use, land-use change and forestry
MCF	Methane conversion factor
MECO	Maui Electric Company
MMBtu	Million British Thermal Units
MMT	million metric tons
MSW	Municipal solid waste
NASS	National Agriculture Statistics Services
NEO	Non-energy uses
NEX	Nitrogen Excretion
N_2O	Nitrous oxide
NOAA-CCAP	National Oceanic and Atmospheric Administration's Coastal Change Analysis Program
NPDES	National Pollutant Discharge Elimination System
ODS	Ozone Depleting Substance
PFC	Perfluorocarbon
PRP	Pasture-Range and Paddock
PSIP	Power Supply Improvement Plan
QA/QC	Quality Assurance and Quality Control
RDF	Refuse-derived Fuel
RPS	Renewable portfolio standard
SEDS	State Energy Data System
SLEIS	State and Local Emissions Inventory System
SF_6	Sulfur hexafluoride
SIT	State Inventory Tool
TAM	Typical animal mass
TJ	Terajoule
UCS	Union of Concerned Scientists
UHERO	University of Hawaii Research Organization
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
VMT	Vehicle miles traveled
VS	Volatile solids
WMS	Waste management system

Executive Summary

The State of Hawaii is committed to reducing its contribution to global climate change and has taken efforts to measure and reduce statewide greenhouse gas (GHG) emissions. In 2007, the State of Hawaii passed Act 234 to establish the state's policy framework and requirements to address GHG emissions. The law aims to achieve emission levels at or below Hawaii's 1990 GHG emissions by January 1, 2020 (excluding emissions from airplanes). In 2008, the State of Hawaii developed statewide GHG emission inventories for 1990 and 2007. To help Hawaii meet their emissions target, Hawaii Administrative Rules, Chapter 11-60.1 was amended in 2014 to establish a facility-level GHG emissions cap for large existing stationary sources with potential GHG emissions at or above 100,000 tons per year. In an effort to track progress toward achieving the state's 2020 GHG reduction goal, this report presents updated 1990 and 2007 emission estimates;[1] inventory estimates for 2010 and 2015; and emission projections for 2020 and 2025.

This information will be used by the state to evaluate whether current and planned actions are sufficient to achieve the statewide GHG emissions target. Based on the analysis presented in this report, net GHG emissions in 2020 (excluding aviation) are projected to be slightly lower than net GHG emissions 1990. These estimates and projections will be reviewed and updated, and presented along with GHG estimates for 2016 and 2017 in forthcoming inventory and projection reports. Therefore, while this report finds that Hawaii is currently on track to meet the 2020 target, this finding will be reassessed in the forthcoming reports.

Background

GHGs are gases that trap heat in the atmosphere by absorbing infrared radiation and thereby warming the planet. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The amount of warming caused by each GHG depends on how effectively the gas traps heat and how long it stays in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) developed the Global Warming Potential (GWP) concept to compare the ability of each GHG to trap heat in the atmosphere relative to the reference gas, CO_2 (IPCC 2014). Throughout this report the relative contribution of each gas is shown in million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). The GWP values used in this report are from the *IPCC Fourth Assessment Report* (IPCC 2007), assuming a 100-year time horizon.

[1] It is best practice to review GHG emission estimates for prior years and revise these estimates as necessary to take into account updated activity data and improved methodologies or emission factors that reflect advances in the field of GHG accounting.

Inventory Scope and Methodology

The GHG emission estimates presented in this report include anthropogenic[2] GHG emissions and sinks for the state of Hawaii for 1990, 2007, 2010, and 2015 from the following four sectors: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry, and Other Land Use (AFOLU), and Waste. As it is best practice to review GHG emission estimates for prior years, this report includes revised estimates for 1990 and 2007, and newly developed estimates for 2010 and 2015. ICF relied on the best available activity data, emissions factors, and methodologies to develop emission estimates presented in this report. Activity data varies for each source or sink category; examples of activity data used include fuel consumption, vehicle-miles traveled, raw material processed, animal populations, crop production, land area, and waste landfilled. Emission factors relate quantities of emissions to an activity (EPA 2017a). Key guidance and resources included the *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP), the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015*, and EPA's State Inventory Tool (SIT).

Quality Assurance and Quality Control (QA/QC)

A number of quality assurance and quality control measures were implemented during the process of developing this inventory to ensure inventory accuracy as well as to improve the quality of the inventory over time. This includes the evaluation of the quality and relevance of data inputs; proper management, incorporation, and aggregation of data in a series of Excel workbooks; review of the numbers and estimates; and clear documentation of the results and methods. As part of these activities, the results were reviewed by representatives from the Department of Health (DOH) as well as a group of other government entities.[3] Comments and feedback provided by the review team were then incorporated into this report.

Uncertainty of Emission Estimates

Some level of uncertainty in GHG estimates is associated with all emission inventories. This uncertainty can be attributed to a number of factors, such as incomplete data, uncertainty in the activity data collected, the use of average or default emission factors that may not reflect the specific nature of how emissions are generated from certain sources, the use of national data where state-specific data were unavailable, and uncertainty in scientific understanding of emission pathways. Quantitative estimates of uncertainty have not yet been developed for Hawaii; however, a quantitative uncertainty analysis will be conducted on statewide GHG estimates in forthcoming inventory reports in order to help identify areas for improvement and prioritize future actions to improve GHG emission estimates for Hawaii. As fuel combustion in Hawaii accounts for about 85 percent of total emissions, uncertainty around this source (which is typically lower than other sources) drives the uncertainty around the inventory totals.

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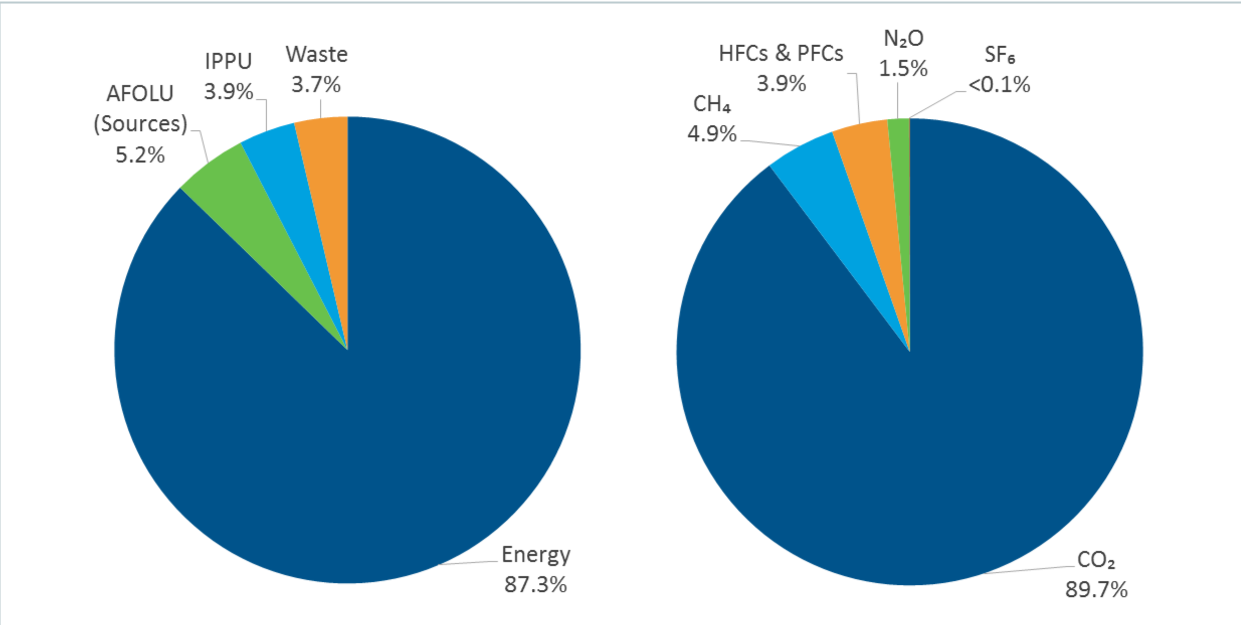
[2] Anthropogenic greenhouse gas emissions are those that originate from human activity.
[3] The review team included representatives from the Department of Business, Economic Development and Tourism (DBEDT), the Division of Consumer Advocacy (DCA), the Department of Land and Natural Resources (DLNR), Hawaii County, and the City and County of Honolulu.

Emission Results

In 2015, total GHG emissions in Hawaii were 21.28 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). Net emissions, which take into account carbon sinks, were 17.75 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (87 percent) of total emissions in Hawaii, followed by the AFOLU sector (5 percent), the IPPU sector (4 percent), and the Waste sector (4 percent). Carbon dioxide was the largest single contributor to statewide GHG emissions in 2015, accounting for roughly 90 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). Methane is the second largest contributor (5 percent), followed closely by HFCs and PFCs (4 percent), N_2O (2 percent), and SF_6 (less than 0.1 percent). Figure ES-1 shows emissions for 2015 by sector and gas.

Figure ES-1: Hawaii 2015 GHG Emissions by Sector and Gas



Note: Percentages represent the percent of total emissions excluding sinks.

Emission Trends

Total GHG emissions in Hawaii grew by 13 percent between 1990 and 2007 before falling 7 percent between 2007 and 2010 and another 8 percent between 2010 and 2015. Total emissions in 2015 were roughly 4 percent lower than 1990 levels. Net emissions were lower by roughly 7 percent in 2015 relative to 1990. Figure ES-2 shows emissions for each inventory year by sector. Emission by source and year are also summarized in Table ES-1.

Figure ES-2: Hawaii GHG Emissions by Sector (1990, 2007, 2010 and 2015)

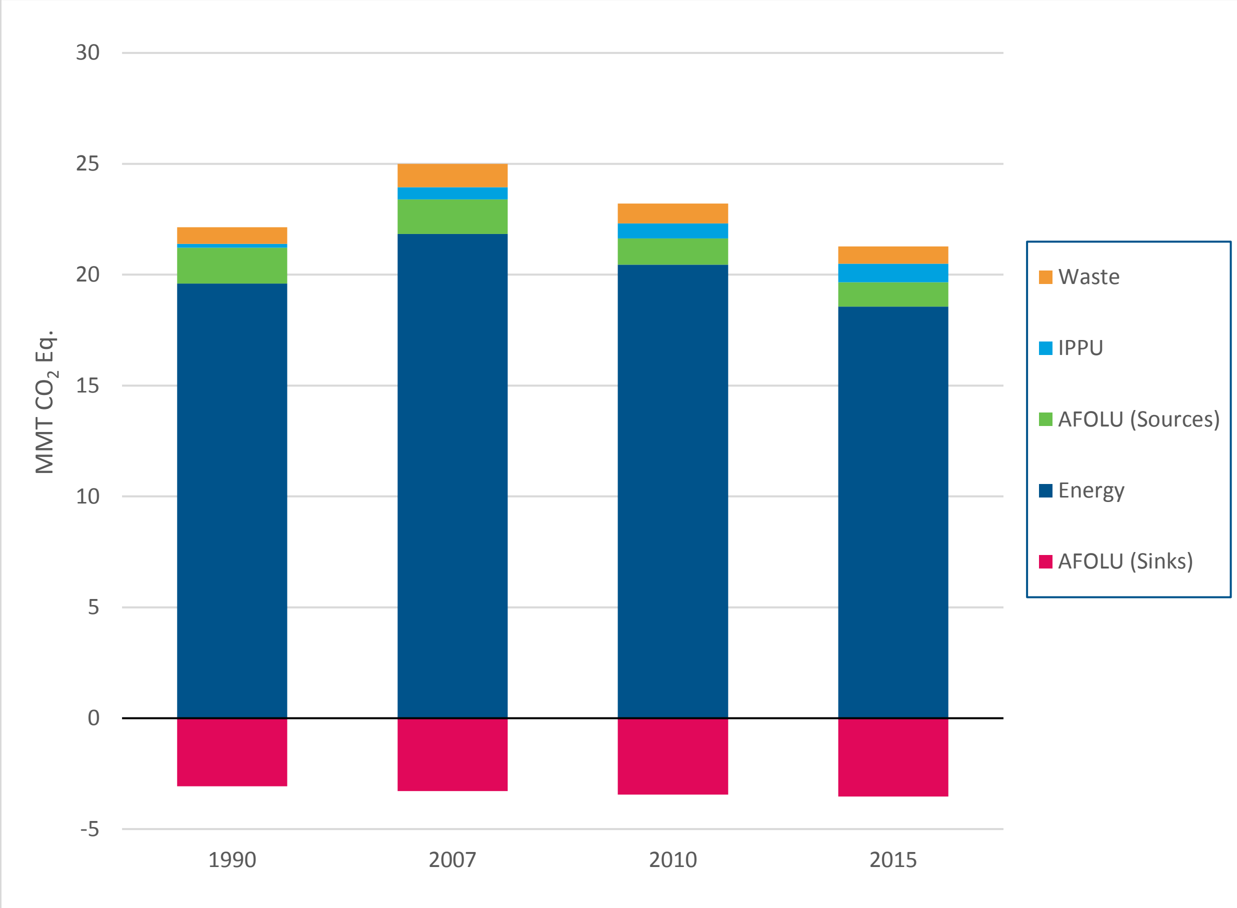


Table ES-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010 and 2015 (MMT CO_2 Eq.)

Sector/Category	1990	2007	2010	2015
Energy[a]	19.61	21.84	20.46	18.57
IPPU	0.17	0.54	0.67	0.83
AFOLU (Sources)	1.61	1.56	1.18	1.10
AFOLU (Sinks)	(3.06)	(3.28)	(3.44)	(3.54)
Waste	0.75	1.05	0.89	0.78
Total Emissions (Excluding Sinks)	**22.15**	**25.00**	**23.21**	**21.28**
Net Emissions (Including Sinks)	**19.08**	**21.71**	**19.77**	**17.75**
Domestic Aviation[b]	4.66	4.42	2.87	3.23
Net Emissions (Including Sinks, Excluding Aviation)[b]	**14.43**	**17.29**	**16.90**	**14.52**

[a] Emissions from International Bunker Fuels are not included in totals, as per IPCC (2006) guidelines.

[b] Domestic aviation emissions, which are reported under the transportation source category under the Energy sector, are excluded from Hawaii's GHG emissions reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

As the largest source of emissions in Hawaii, the Energy sector is a major driver of the overall emissions trends, accounting for 78 percent of the emissions increase from 1990 to 2007 and 88 percent of reductions between 2007 and 2015. Relative to 1990, emissions from the Energy sector in 2015 were lower by roughly 5 percent. Transportation emissions, which increased between 1990 and 2007 and decreased between 2007 and 2015, accounted for the largest share of Energy sector emissions in all inventory years. Stationary combustion emissions is the second largest share, and increased between 1990 and 2010 and decreased between 2010 and 2015, largely driven by emissions from energy industries (i.e., electric power plants and petroleum refineries).

Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2015, falling by about 30 percent and 25 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 53 percent from 2007 to 2015. Relative to 1990, emissions from the IPPU sector in 2015 were almost four times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances. Carbon removals from AFOLU sinks have also grown since 1990, increasing by roughly 15 percent between 1990 and 2015.

Emission Projections

A combination of top-down and bottom-up approaches were used to develop projections of GHG emissions for the year 2020 and 2025. For some sources, the University of Hawaii Economic Research Organization (UHERO) Macroeconomic Forecast was used to project GHG emissions. For other smaller emission sources and sinks, emissions were projected by forecasting activity data using historic trends and published information available on future trends, and applying the same calculation methodology used to estimate 2015 emissions. For large GHG emitting sources for which there has been substantial federal and state policy intervention (i.e., energy industries and transportation), the team used a more comprehensive sectoral bottom-up approach to project GHG emissions.

Total GHG emissions are projected to be 20.90 MMT CO_2 Eq. in 2020 and 18.46 MMT CO_2 Eq. in 2025. Net emissions, which take into account carbon sinks, are projected to be 17.34 MMT CO_2 Eq. in 2020 and 14.86 MMT CO_2 Eq. in 2025. Relative to 2015, total emissions are projected to decrease by 2 percent by 2020 and 13 percent by 2025. Over the same period, net emissions are projected to decrease by 2 percent and 16 percent, respectively. This decrease is largely due to a projected decrease in emissions from energy industries (i.e., fuel combustion from electric power plants and petroleum refineries) that are projected to meet the state’s Renewable Portfolio Standard (RPS) and Energy Efficiency Portfolio Standard (EEPS) targets. Figure ES-3 show emissions and sinks for 1990 to 2025 for inventory years by sector. Projections of statewide emissions and sinks by sector for 2020 and 2025 are also summarized in Table ES-2.

Figure ES-3: Hawaii GHG Emissions Inventory Estimates and Projections (Including Sinks)

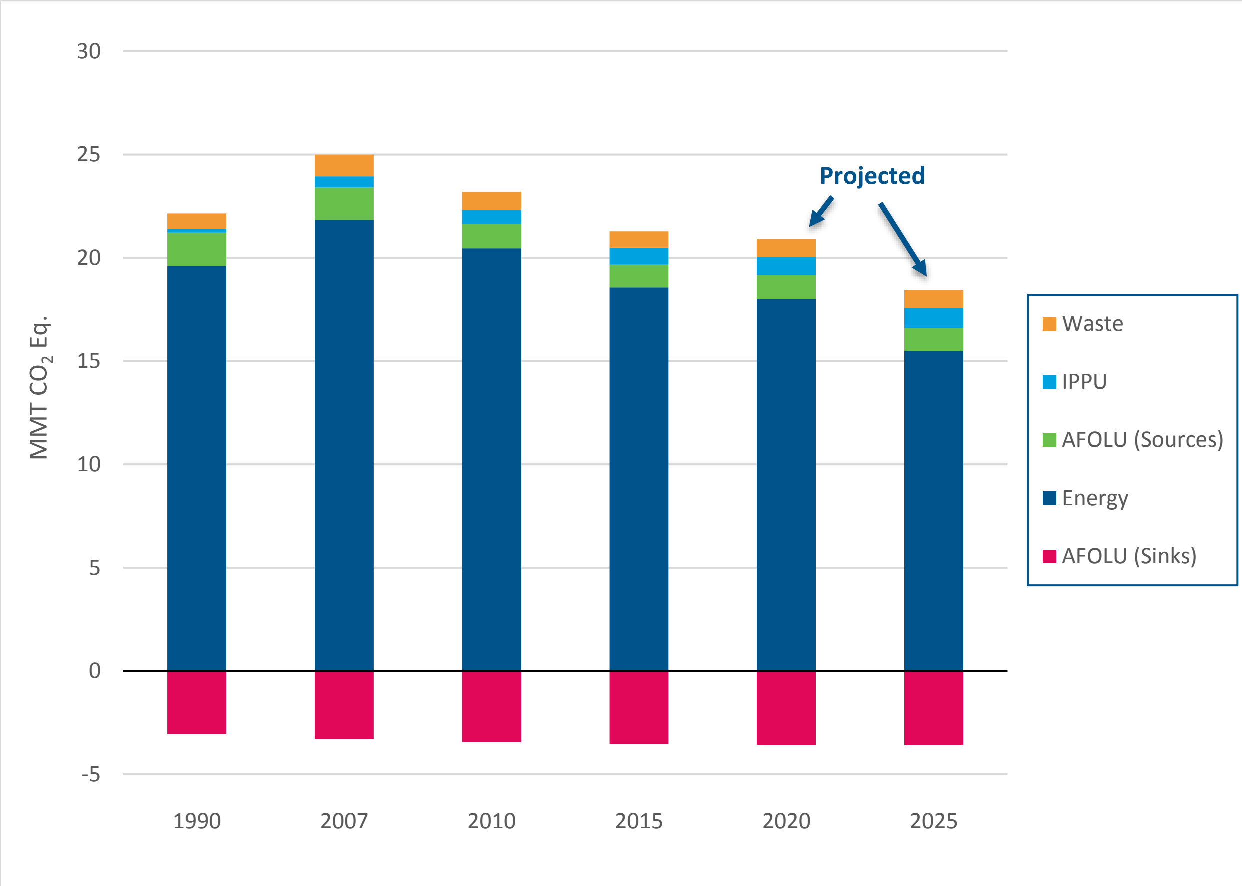


Table ES-2: Hawaii GHG Emission Projections by Sector, 2020 and 2025 (MMT CO_2 Eq.)

Sector	2020	2025
Energy[a]	18.00	15.51
IPPU	0.89	0.95
AFOLU (Sources)	1.18	1.11
AFOLU (Sinks)	(3.57)	(3.60)
Waste	0.84	0.90
Total Emissions (Excluding Sinks)	**20.90**	**18.46**
Net Emissions (Including Sinks)	**17.34**	**14.86**
Domestic Aviation[b]	3.46	3.67
Net Emissions (Including Sinks, Excluding Aviation)[b]	**13.88**	**11.19**

[a] Emissions from International Bunker Fuels are not included in totals, as per IPCC (2006) guidelines.

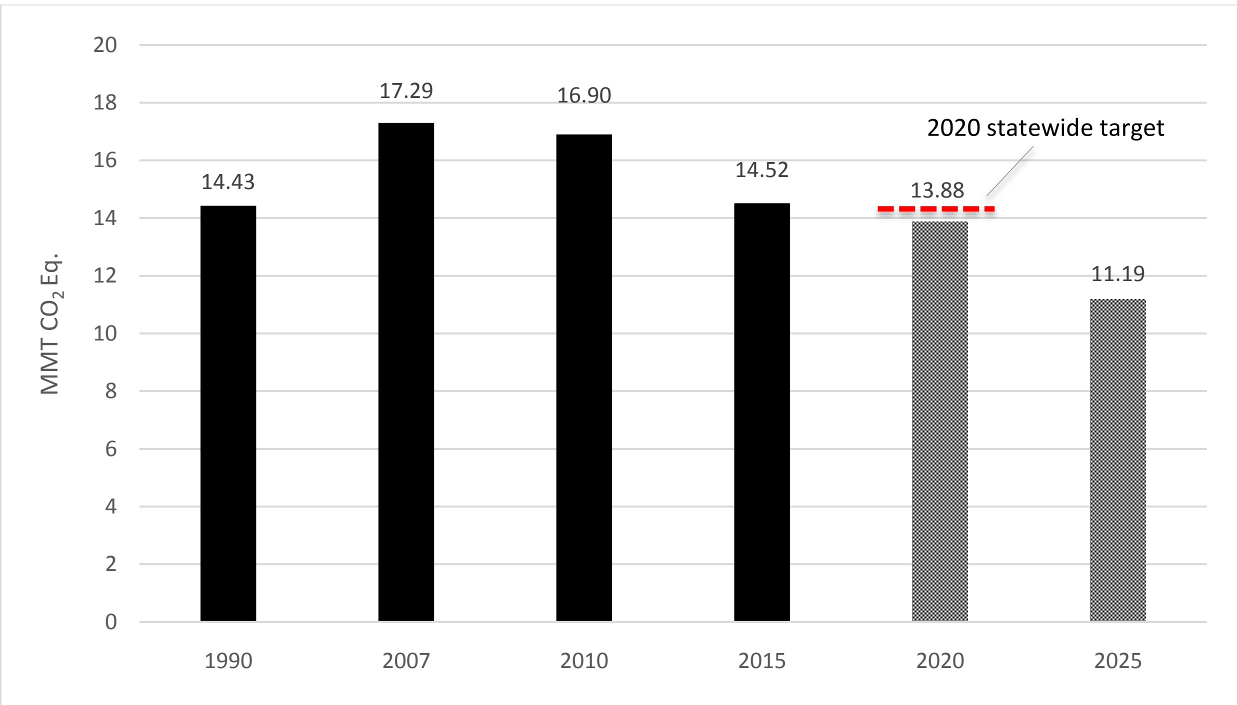
[b] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emission reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Hawaii GHG Goal Progress

Excluding aviation, 1990 statewide emissions were estimated to be 14.43 MMT CO_2 Eq., which represents the 2020 emission target. Figure ES-4 shows net emissions (excluding aviation) in Hawaii for the inventory years presented in this report as well as emission projections for 2020 and 2025. Net GHG emissions in 2015 (excluding aviation) were less than 1 percent higher than the 2020 statewide goal (1990 levels). As net emissions excluding aviation are projected to be 13.88 MMT CO_2 Eq. in 2020, this report finds that Hawaii is currently on track to meet its 2020 statewide emissions target. While the results of this analysis indicate that Hawaii is currently on track to meet the 2020 statewide goal, there is some degree of uncertainty in both the historic and projected emission estimates (described in detail within this report). The development of future inventory reports, which will include the review and update to the estimates presented in this report as well as a quantitative assessment of uncertainties, will further inform the likelihood of Hawaii meeting its 2020 statewide target.

Figure ES-4: Hawaii GHG Emissions Inventory Estimates and Projections (Including Sinks, Excluding Aviation)



Note: 2020 and 2025 represent emissions projections.

1. Introduction

The State of Hawaii is committed to reducing its contribution to global climate change and has taken efforts to measure and reduce statewide greenhouse gas (GHG) emissions. In 2007, the State of Hawaii passed Act 234 to establish the state's policy framework and requirements to address GHG emissions. The law aims to achieve emission levels at or below Hawaii's 1990 GHG emissions by January 1, 2020 (excluding emissions from airplanes). In 2008, the State of Hawaii developed statewide GHG emission inventories for 1990 and 2007. To help Hawaii meet their emissions target, Hawaii Administrative Rules, Chapter 11-60.1 was amended in 2014 to establish a facility-level GHG emissions cap for large existing stationary sources with potential GHG emissions at or above 100,000 tons per year. In an effort to track progress toward achieving the state's 2020 GHG reduction goal, this report presents updated 1990 and 2007 emission estimates;[4] inventory estimates for 2010 and 2015; and emission projections for 2020 and 2025.

This information will be used by the state to evaluate whether current and planned actions are sufficient to achieve the statewide GHG emissions target. Based on the analysis presented in this report, net GHG emissions in 2020 (excluding aviation) are projected to be slightly lower than net GHG emissions 1990. These estimates and projections will be reviewed and updated, and presented along with GHG estimates for 2016 and 2017 in forthcoming inventory and projection reports. Therefore, while this report finds that Hawaii is currently on track to meet the 2020 target, this finding will be reassessed in the forthcoming reports.

1.1. Background

GHGs are gases that trap heat in the atmosphere by absorbing infrared radiation and thereby warming the planet. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). While some of these gases occur naturally in the environment, human activities have significantly changed their atmospheric concentrations. Scientists agree that it is extremely likely that most of the observed temperature increase since 1950 is due to anthropogenic or human-caused increases in GHGs in the atmosphere (IPCC 2014).

The amount of warming caused by each GHG depends on how effectively the gas traps heat and how long it stays in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) developed the Global Warming Potential (GWP) concept to compare the ability of each GHG to trap heat in the atmosphere relative to the reference gas, CO_2 (IPCC 2014). Throughout this report the relative contribution of each gas is shown in million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). The

[4] It is best practice to review GHG emission estimates for prior years and revise these estimates as necessary to take into account updated activity data and improved methodologies or emission factors that reflect advances in the field of GHG accounting.

GWP values used in this report are from the *IPCC Fourth Assessment Report* (IPCC 2007), assuming a 100-year time horizon, as summarized in Table 1-1.

The persistence of excess GHGs in the atmosphere has had, and continues to have, significant impacts across the globe. Global climate is being altered, with a net warming effect of the atmosphere and ocean that is causing glaciers and sea ice levels to decrease, global mean sea levels to rise, and an increase in extreme weather events (IPCC 2014). In an effort to better understand the sources and drivers of GHG emissions and to mitigate their global impact, communities and organizations at all levels—including federal governments, state and local jurisdictions, multinational firms, and local enterprises—develop GHG inventories. A GHG inventory quantifies emissions and sinks for a given jurisdictional or organizational boundary. The results of these inventories are then used to inform strategies and policies for emission reductions, and to track the progress of actions over time.

Table 1-1: Global Warming Potentials (GWPs) used in this Report

Gas	GWP
CO_2	1
CH_4	25
N_2O	298
HFC-23	14,800
HFC-32	675
HFC-125	3,500
HFC-134a	1,430
HFC-143a	4,470
HFC-152a	124
HFC-227ea	3,220
HFC-236fa	9,810
HFC-4310mee	1,640
CF_4	7,390
C_2F_6	12,200
C_4F_{10}	8,860
C_6F_{14}	9,300
SF_6	22,800

Note: This inventory, as most inventories do, uses GWPs with a 100-year time horizon.
Source: *IPCC Fourth Assessment Report* (2007).

1.2. Inventory Scope

The GHG emission estimates presented in this report include anthropogenic GHG emissions and sinks for the state of Hawaii for 1990, 2007, 2010, and 2015 from the following four sectors:

- **Energy**, including emissions from stationary combustion, transportation, incineration of waste, and oil and natural gas systems.
- **Industrial Processes and Product Use (IPPU)**, including emissions from cement production, electrical transmission and distribution, and substitution of ozone depleting substances.
- **Agriculture, Forestry, and Other Land Use (AFOLU)**, including emissions from agricultural activities, land use, changes in land use, and land management practices. Specifically, this includes enteric fermentation, manure management, agricultural soil management, field burning of agricultural residues, and urea application as well as agricultural soil carbon, forest fires, landfilled yard trimmings and food scraps, urban trees, and forest carbon.
- **Waste**, including emissions from waste management and treatment activities such as landfills, composting, and wastewater treatment.

This inventory was developed in accordance with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[5] to ensure completeness and allow for comparability of results with other inventories. Emission results are presented by source and sink category and gas. Appendix A provides a summary of all IPCC source and sink categories as well as the reason for any exclusions from this analysis.

As it is best practice to review GHG emission estimates for prior years, this report includes revised estimates for 1990 and 2007, and newly developed estimates for 2010 and 2015. The 1990 and 2007 estimates were updated to account for updated activity data and methods, and to ensure time-series consistency across all inventory years. Key changes include updates to emission factors and the GWP values (previously taken from the *IPCC Second Assessment Report)* to reflect values from the *IPCC Fourth Assessment Report.*[6] Appendix B summarizes changes in emission estimates relative to the previous inventory report.

Emissions by County

The development of emission estimates by county for the state of Hawaii were not part of this inventory effort and, therefore, are not presented in this report. A breakout of emissions by county may be included in future inventory reports to support county-level efforts to track and reduce GHG emissions.

1.3. Methodologies and Data Sources

ICF relied on the best available activity data, emissions factors, and methodologies to develop emission estimates presented in this report. Activity data varies for each source or sink category; examples of activity data used include fuel consumption, vehicle-miles traveled, raw material processed, animal populations, crop production, land area, and waste landfilled. Emission factors relate quantities of emissions to an activity (EPA 2017a).

Key guidance and resources included the *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP), the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* (hereafter referred to as the U.S. Inventory), and EPA's State Inventory Tool (SIT).

The *2006 IPCC Guidelines* highlight the standard methodological approaches adopted by the United States and all other Annex 1 (developed) countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC). As appropriate and feasible, emissions and removals from source and sink categories included in this report were estimated using methodologies that are consistent with the *2006 IPCC Guidelines*. The methodologies used to estimate emissions align with the IPCC "Tier" approach, which is a useful framework for addressing the combined challenges of data availability and resources, while maintaining transparency and consistency. For most source and sink categories, the *2006 IPCC Guidelines* suggest three tiers: Tier 1 is the most basic; Tier 2 provides an intermediate approach; and Tier 3 is the most resource-intensive (requiring highly specific activity data

[5] The *2006 IPCC Guidelines* are the most recent inventory guidelines from the IPCC. These guidelines are still widely in use, as they largely reflect the most up-to-date scientific information for estimating emissions.

[6] Key changes to the GWP values, assuming a 100-year time horizon, include the value for CH_4 increasing from 21 to 25 and the value for N_2O decreasing from 310 to 298.

inputs). Specific data sources and methodologies used to develop estimates are discussed for each source and sink category in the subsequent sections of this report.

1.4. Quality Assurance and Quality Control (QA/QC)

A number of quality assurance and quality control measures were implemented during the process of developing this inventory to ensure inventory accuracy as well as to improve the quality of the inventory over time. This includes the evaluation of the quality and relevance of data inputs; proper management, incorporation, and aggregation of data in a series of Excel workbooks; review of the numbers and estimates; and clear documentation of the results and methods.

Evaluation of Data Inputs. As described in the section above, the best available data and methodologies were used to develop the emission estimates presented in this report.

Data Management. A series of Excel workbooks were used to compile and analyze the inventory results. These spreadsheets are clearly labeled and linked, as appropriate, to make them easy to navigate. The calculations are transparent to support error-checking and updating. Automated error checks are also incorporated into the spreadsheets to facilitate QA/QC.

Review of Estimates. ICF reviewed the results of this work against other available data sets and emission estimates. For example, the fuel consumption data used to develop estimates for the Energy sector were compared against other available data sets. The Energy chapter and Appendix F discuss the results of this cross-walk in more detail. ICF also ran EPA's State Inventory and Projection Tool for Hawaii using default values and compared the output against the 2015 inventory and the inventory projections for 2020 and 2025. The results of this comparison are presented and discussed in Appendix J. In addition, the results were reviewed by representatives from the Department of Health (DOH) as well as a group of other government entities.[7] Comments and feedback provided by the review team were then incorporated into this report.

Documentation of Results. As documented in this report, all assumptions, methodologies, and data sources used to develop the emission estimates are clearly described. This transparency allows for replication and assessment of these results.

1.5. Uncertainty of Emission Estimates

Some degree of uncertainty in GHG estimates is associated with all emission inventories. This uncertainty can be attributed to a number of factors such as incomplete data, uncertainty in the activity data collected, the use of average or default emission factors that may not reflect the specific nature of how emissions are generated from certain sources, the use of national data where state-specific data were unavailable, and uncertainty in scientific understanding of emission pathways. For some sources (e.g., CO_2 emissions from fuel combustion), emissions are relatively well understood and uncertainty is

[7] The review team included representatives from the Department of Business, Economic Development and Tourism (DBEDT), the Division of Consumer Advocacy (DCA), the Department of Land and Natural Resources (DLNR), Hawaii County, and the City and County of Honolulu.

expected to be low and largely dependent on the accuracy of activity data. For other sources (e.g., CH_4 and N_2O emissions from wastewater), emission estimates have greater uncertainty. Overall, it is important to recognize that some level of uncertainty exists with all GHG estimates, and these uncertainties vary between sector, source, and gas.

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015* estimated the range of uncertainty for total U.S. emission estimates to be -1 to +5 percent (EPA 2017a). Considerable resources are expended at the national level to develop these estimates of uncertainty, which have been incrementally developed and improved over time. Quantitative estimates of uncertainty have not yet been developed for Hawaii; however, a quantitative uncertainty analysis will be conducted on statewide GHG estimates in forthcoming inventory reports in order to help identify areas for improvement and prioritize future actions to improve GHG emission estimates for Hawaii. As fuel combustion in Hawaii accounts for about 85 percent of total emissions, uncertainty around this source (which is typically lower than other sources) drives the uncertainty around the inventory totals.

1.6. Organization of Report

The remainder of this report is organized as follows:

- **Chapter 2: Emission Results** – Summarizes 2015 inventory results for the state of Hawaii as well as trends in GHG emissions and sinks across the inventory years since 1990.
- **Chapter 3: Energy** – Presents GHG emissions that occur from stationary and mobile energy combustion activities. Describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement.
- **Chapter 4: Industrial Processes and Product Use (IPPU)** – Presents GHG emissions that occur from industrial processes and product use. Describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement.
- **Chapter 5: Agriculture, Forestry and Other Land Uses (AFOLU)** – Presents GHG emissions from agricultural activities, land use, changes in land use, and land management practices. Describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement.
- **Chapter 6: Waste** – Presents GHG emissions from waste management and treatment activities. Describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement.
- **Chapter 7: Emission Projections** – Presents projections for statewide GHG emissions and sinks for 2020 and 2025.
- **Chapter 8: GHG Reduction Goal Progress** – Provides an assessment of statewide progress relative to the statewide GHG emissions limit based on the emission estimates developed.

Appendices

- **Appendix A: IPCC Source and Sink Categories** – Provides a summary of all IPCC source and sink categories as well as the reason for any exclusions from this analysis.
- **Appendix B: Summary of Updates to Emission Estimates since the Previous Inventory Report** – Summarizes changes to the emission estimates relative to the 2008 inventory report.
- **Appendix C: Hawaii Administrative Rule (HAR) Facility Data** – Summarizes annual GHG emissions from HAR affected facilities for 2010 to 2015 and projections for 2020 and 2025.
- **Appendix D: Activity Data** – Summarizes by sector the activity data used to develop the inventory presented in this report.
- **Appendix E: Emission Factors** – Summarizes by sector the emission factors used to develop the inventory presented in this report.
- **Appendix G: ODS Emissions** – Summarizes for informational purposes estimated emissions from ozone depleting substances (ODS) for the state of Hawaii.
- **Appendix H: Emission Projections Methodology** – Summarizes the methodology used to project emissions for 2020 and 2025 by source and sink category, and includes a discussion of key uncertainties and areas for improvement.
- **Appendix I: Emission Scenarios for Electricity Generation by HECO** – Summarizes alternative scenarios for capital investments towards power generation by Hawaii Energy Companies (HECO) and their impact on the electric sector emissions forecast for 2020 and 2025.
- **Appendix J: Comparison of Results with the State Inventory Tool and Projection Tool** – Compares emission estimates for Hawaii generated by EPA's State Inventory and Projections Tool against the results of the 2015 inventory and the emission projections for 2020 and 2025.

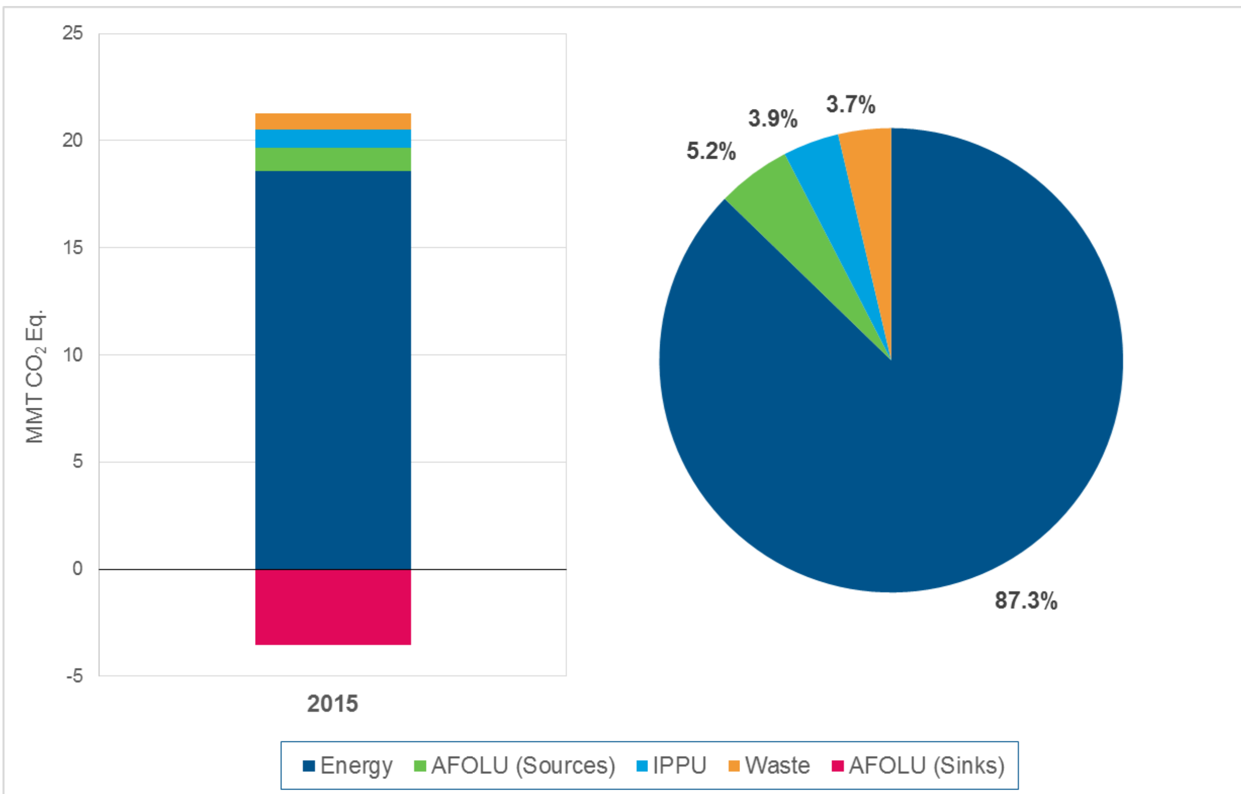
2. Emission Results

This section summarizes 2015 inventory results for the state of Hawaii as well as trends in GHG emissions and sinks across the inventory years since 1990.

2.1. Overview of 2015 Emissions

In 2015, total GHG emissions in Hawaii were 21.28 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 17.75 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (87 percent) of total emissions in Hawaii, followed by the AFOLU sector (5 percent), the IPPU sector (4 percent), and the Waste sector (4 percent). Figure 2-1 shows emissions for 2015 by sector.

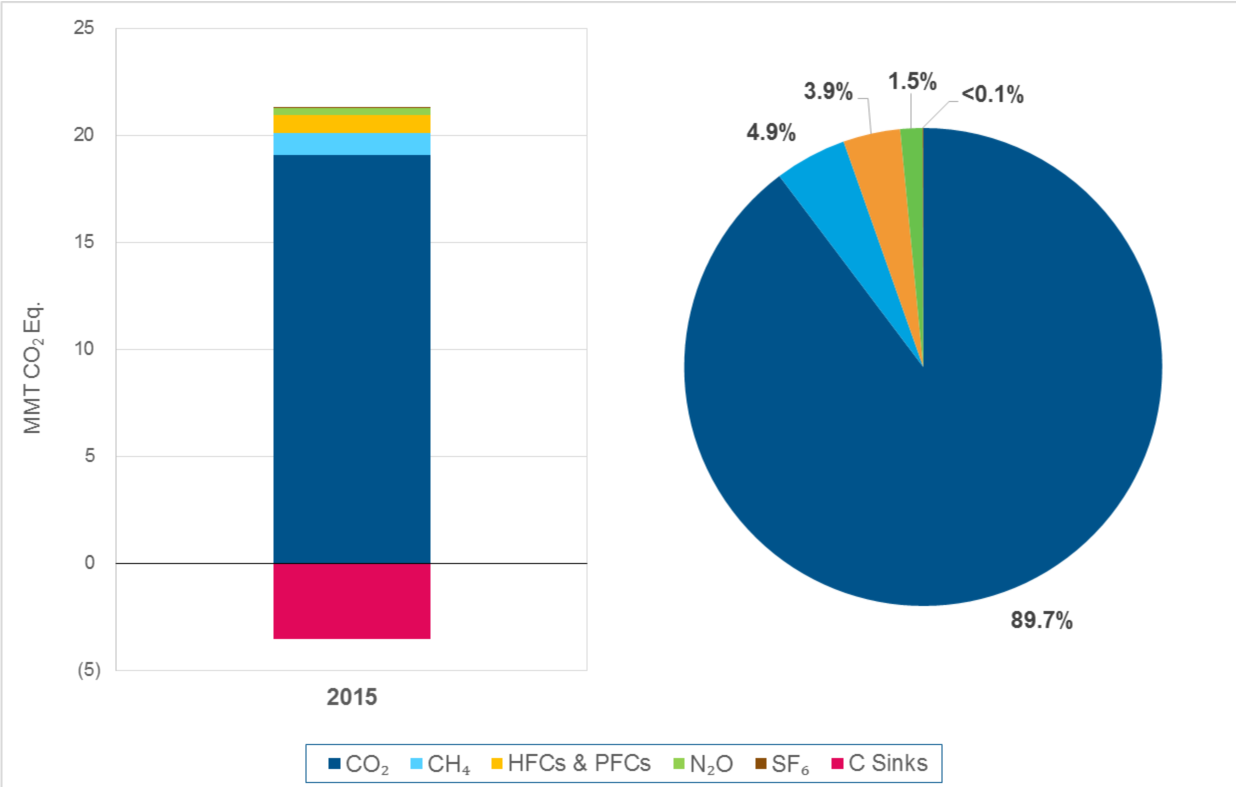
Figure 2-1: Hawaii 2015 GHG Emissions by Sector



Note: Percentages represent the percent of total emissions excluding sinks.

Carbon dioxide was the largest single contributor to statewide GHG emissions in 2015, accounting for roughly 90 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). Methane is the second largest contributor (5 percent), followed closely by hydrofluorocarbons and perfluorocarbons (4 percent), nitrous oxide (2 percent), and sulfur hexafluoride (less than 0.1 percent). Figure 2-2 shows emissions for 2015 by gas.

Figure 2-2: Hawaii 2015 GHG Emissions by Gas

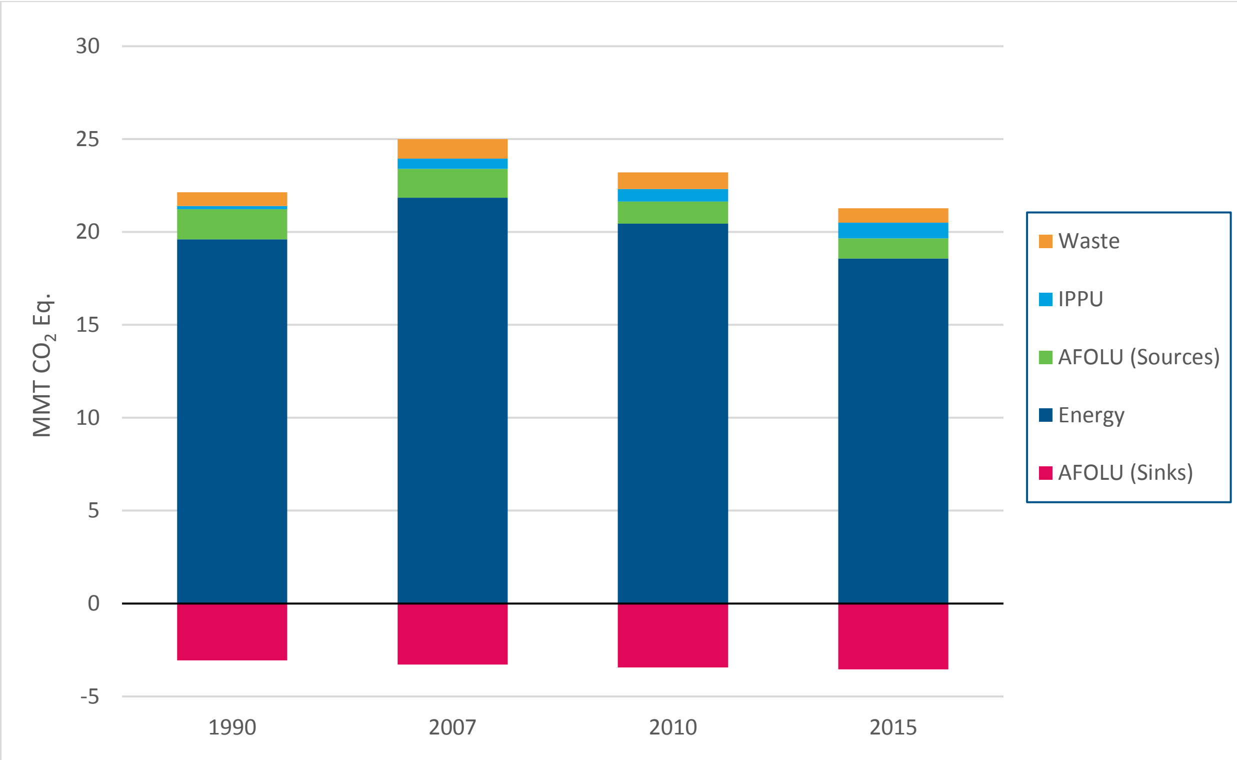


Note: Percentages represent the percent of total emissions excluding sinks.

2.2. Emission Trends

Total GHG emissions in Hawaii grew by 13 percent between 1990 and 2007 before falling 7 percent between 2007 and 2010 and another 8 percent between 2010 and 2015. Total emissions in 2015 were roughly 4 percent lower than 1990 levels. Net emissions were lower by roughly 7 percent in 2015 relative to 1990. In all inventory years since 1990, emissions from the Energy sector accounted for the largest portion (more than 85 percent) of total emissions in Hawaii. Figure 2-3 below shows emissions for each inventory year by sector. Emission by source and year are also summarized in Table 2-1.

Figure 2-3: Hawaii GHG Emissions by Sector (1990, 2007, 2010 and 2015)



As the largest source of emissions in Hawaii, the Energy sector is a major driver of the overall emissions trends, accounting for 78 percent of the emissions increase from 1990 to 2007 and 88 percent of reductions between 2007 and 2015. Relative to 1990, emissions from the Energy sector in 2015 were lower by roughly 5 percent. Transportation emissions, which increased between 1990 and 2007 and decreased between 2007 and 2015, accounted for the largest share of Energy sector emissions in all inventory years. Stationary combustion emissions is the second largest share, and increased between 1990 and 2010 and decreased between 2010 and 2015, largely driven by emissions from energy industries (electric power plants and petroleum refineries).

Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2015, falling by about 30 percent and 25 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 53 percent from 2007 to 2015. Relative to 1990, emissions from the IPPU sector in 2015 were almost four times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances. Carbon removals from AFOLU sinks have also grown since 1990, increasing by roughly 15 percent between 1990 and 2015.

Table 2-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010 and 2015 (MMT CO_2 Eq.)

Sector/Category	1990	2007	2010	2015
Energy	**19.61**	**21.84**	**20.46**	**18.57**
Stationary Combustion	7.91	9.26	9.91	8.38
Transportation	11.26	12.19	10.16	9.79
Incineration of Waste[a]	0.18	0.15	0.19	0.20
Oil and Natural Gas Systems	0.27	0.24	0.20	0.19
International Bunker Fuels[b]	*2.95*	*1.54*	*1.38*	*1.61*
CO_2 from Wood Biomass and Biofuel Consumption[b]	*NE*	*0.16*	*1.22*	*1.45*
IPPU	**0.17**	**0.54**	**0.67**	**0.83**
Cement Production	0.10	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01
Substitution of Ozone Depleting Substances	+	0.53	0.66	0.82
AFOLU (Sources)	**1.61**	**1.56**	**1.18**	**1.10**
Enteric Fermentation	0.32	0.29	0.27	0.24
Manure Management	0.15	0.05	0.04	0.04
Agricultural Soil Management	0.17	0.16	0.15	0.14
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01
Urea Application	+	+	+	+
Agricultural Soil Carbon	0.57	0.48	0.53	0.56
Forest Fires	0.38	0.57	0.19	0.11
AFOLU (Sinks)	**(3.06)**	**(3.28)**	**(3.44)**	**(3.54)**
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)
Urban Trees	(0.28)	(0.37)	(0.38)	(0.40)
Forest Carbon	(2.66)	(2.87)	(3.01)	(3.08)
Waste	**0.75**	**1.05**	**0.89**	**0.78**
Landfills	0.65	0.92	0.84	0.72
Composting	+	0.02	0.01	0.02
Wastewater Treatment	0.10	0.12	0.04	0.05
Total Emissions (Excluding Sinks)	**22.15**	**25.00**	**23.21**	**21.28**
Net Emissions (Including Sinks)	**19.08**	**21.71**	**19.77**	**17.75**
Domestic Aviation[c]	4.66	4.42	2.87	3.23
Net Emissions (Including Sinks, Excluding Aviation)[c]	**14.43**	**17.29**	**16.90**	**14.52**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).

[a] Emissions from the incineration of waste are reported under the Energy sector, consistent with the U.S. Inventory, since the incineration of waste generally occurs at facilities where energy is recovered.

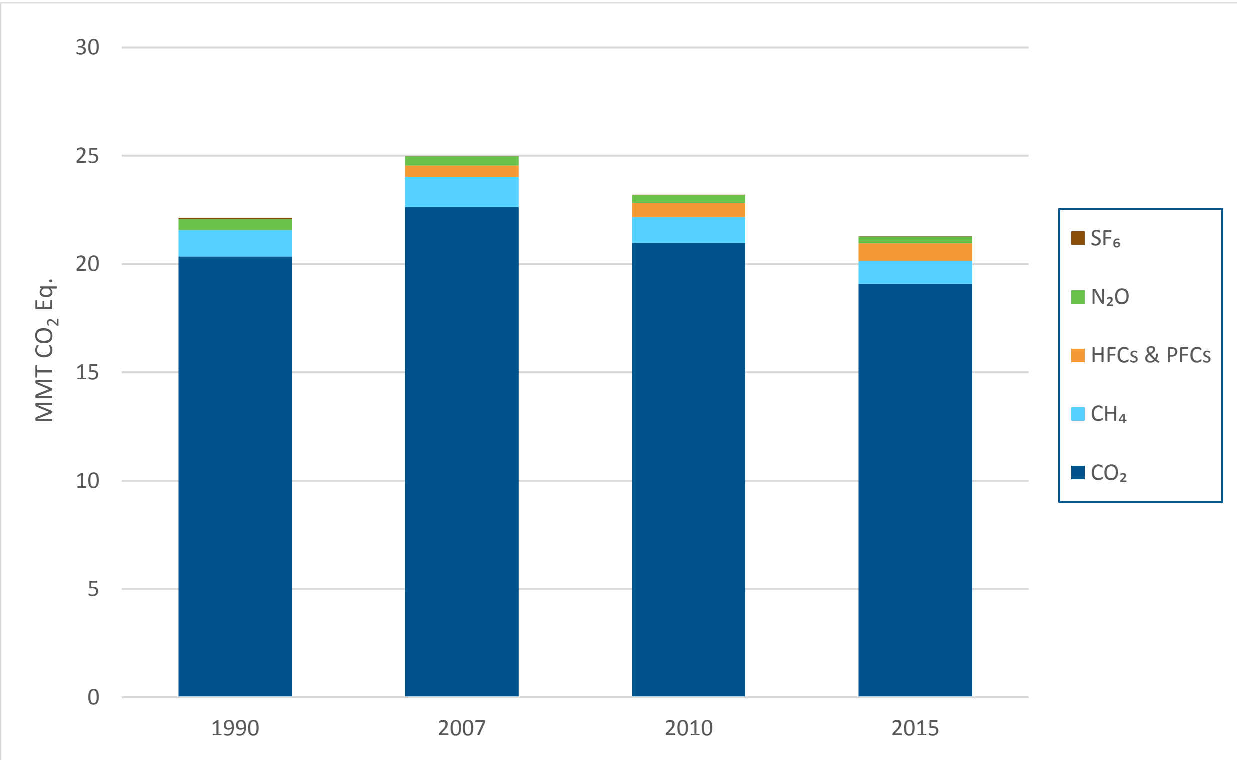
[b] Emissions from International Bunker Fuels and CO_2 from Wood Biomass and Biofuel Consumption are estimated as part of this inventory report but are not included in emission totals, as per IPCC (2006) guidelines.

[c] Domestic aviation emissions, which are reported under the transportation source category under the Energy sector, are excluded from Hawaii's GHG emissions reduction goal established in Act 234.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

In all inventory years, CO_2 made up the vast majority of emissions. As CO_2 is the primary gas emitted from fuel consumption for energy production, trends in CO_2 emissions are consistent with Energy sector emission trends, increasing between 1990 and 2007 and decreasing between 2007 and 2015. Methane emissions also increased between 1990 and 2007 and decreased between 2007 and 2015. Emissions of HFCs and PFCs grew substantially from 1990 to 2015, while N_2O and SF_6 emissions both decreased over the same period. Figure 2-4 shows emissions for each inventory year by gas.

Figure 2-4: Hawaii GHG Emissions by Gas (1990, 2007, 2010 and 2015)

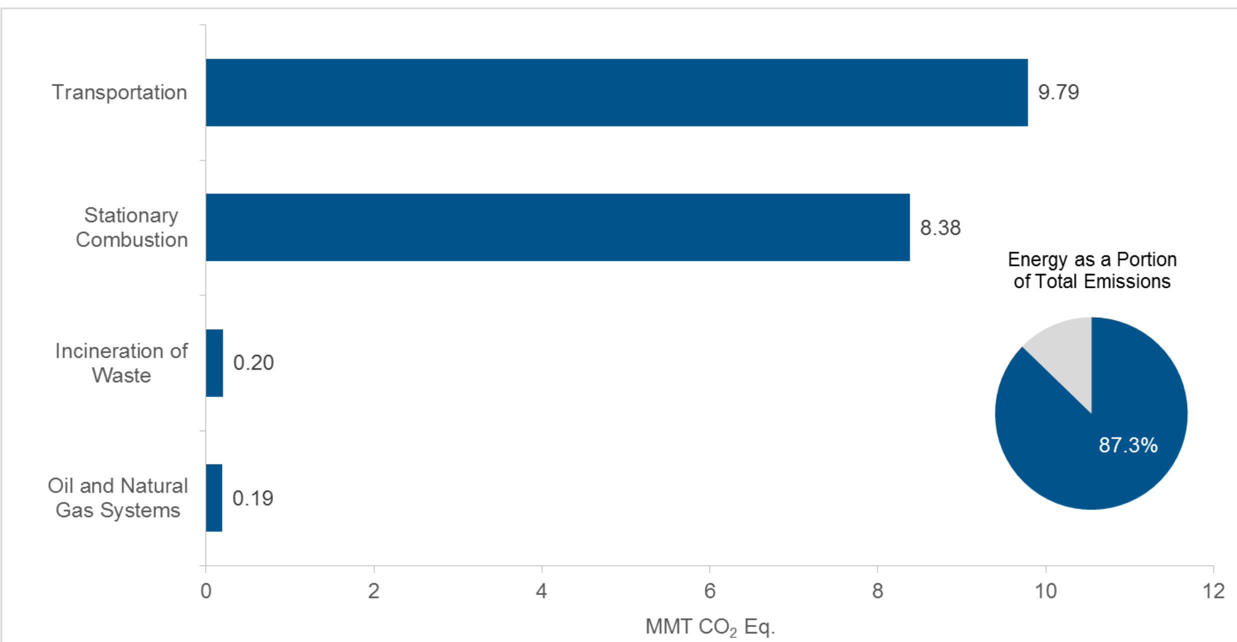


3. Energy

This chapter presents GHG emissions that result from energy-related activities, primarily fuel combustion for transportation and generation of electricity. For the state of Hawaii, energy sector emissions are estimated from the following sources: stationary combustion (IPCC Source Categories 1A1, 1A2, 1A4, 1A5), transportation (IPCC Source Category 1A3), incineration of waste (IPCC Source Category 1A1a), and oil and natural gas systems (IPCC Source Category 1B2).[8] Emissions from international bunker fuels (IPCC Source Category 1: Memo Items) and CO_2 emissions from wood biomass and biofuel consumption (IPCC Source Categories 1A) are also estimated as part of this analysis; however, these emissions are not included in the totals, consistent with IPCC (2006) guidelines.

In 2015, emissions from the Energy sector were 18.57 MMT CO_2 Eq., accounting for 87 percent of total Hawaii emissions. Emissions from transportation activities accounted for the largest share of Energy sector emissions (53 percent), followed closely by stationary combustion (45 percent). Emissions from waste incineration and oil and natural gas systems comprised a relatively small portion of Energy sector emissions (2 percent). Figure 3-1 and Figure 3-2 show emissions from the Energy sector by source for 2015.

Figure 3-1: 2015 Energy Emissions by Source



Note: Totals may not sum due to independent rounding.

[8] IPCC Source Categories for which emissions were not estimated for the state of Hawaii include: Fugitive emissions from Solid Fuels (1B1) and CO_2 Transport and Storage (1C). Appendix A provides information on why emissions were not estimated for these IPCC Source Categories.

Relative to 1990, emissions from the Energy sector in 2015 were lower by roughly 5 percent. Figure 3-3 below shows Energy sector emissions by source category for each inventory year. In all inventory years transportation accounted for the largest share of emissions, followed closely by stationary combustion. The trend in transportation emissions, which increased from 1990 to 2007 and then decreased from 2007 to 2015, is largely driven by a decrease in domestic marine, domestic aviation, and military emissions, which more than offset an increase in ground transportation emissions. The trend in stationary combustion emissions, which increased from 1990 to 2010 and then decreased from 2010 to 2015, is largely driven by emissions from energy industries (electric power plants and petroleum refineries). Emissions by source and year are also summarized in Table 3-1.

Figure 3-2: 2015 Energy Emissions by Source

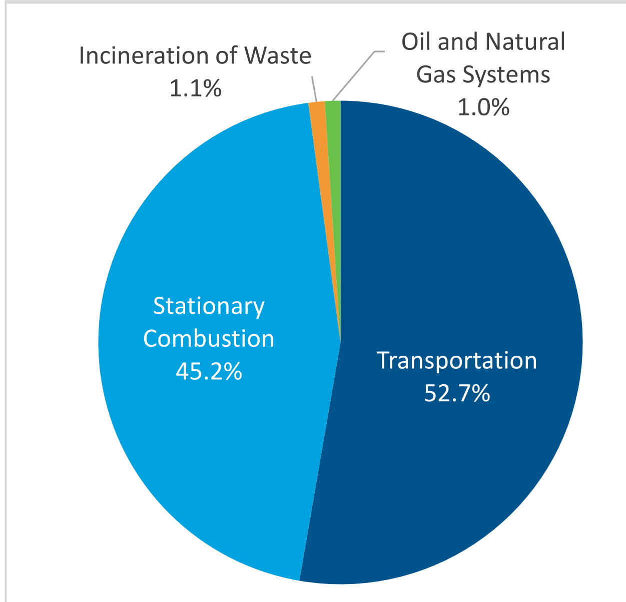


Figure 3-3: Energy Sector Emissions by Source and Year

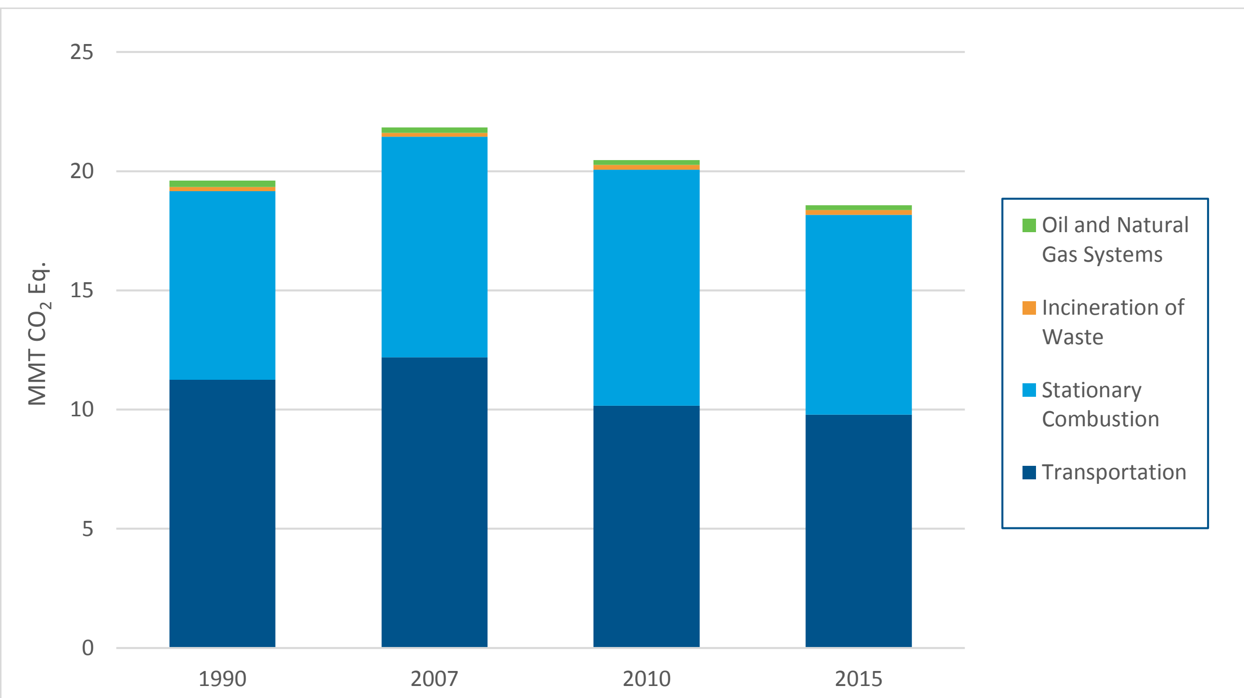


Table 3-1: GHG Emissions from the Energy Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015
Stationary Combustion[a]	**7.91**	**9.26**	**9.91**	**8.38**
Energy Industries[b]	6.80	8.78	8.48	7.06
Residential	0.03	0.04	0.08	0.08
Commercial	0.38	0.24	0.51	0.84
Industrial	0.70	0.19	0.84	0.40
Transportation[a]	**11.26**	**12.19**	**10.16**	**9.79**
Ground	3.40	4.97	5.28	5.64
Domestic Marine	1.82	1.79	0.91	0.39
Domestic Aviation	4.66	4.42	2.87	3.23
Military	1.38	1.02	1.10	0.53
Incineration of Waste	**0.18**	**0.15**	**0.19**	**0.20**
Oil and Natural Gas Systems	**0.27**	**0.24**	**0.20**	**0.19**
International Bunker Fuels[c]	*2.95*	*1.54*	*1.38*	*1.61*
CO_2 from Wood Biomass and Biofuel Consumption[c]	*NE*	*0.16*	*1.22*	*1.45*
Total	**19.61**	**21.84**	**20.46**	**18.57**

+ Does not exceed 0.005 MMT CO_2 Eq.; NE (emissions are Not Estimated)

[a] Includes CH_4 and N_2O emissions from Wood Biomass and Biofuel Consumption.

[b] Includes fuel combustion emissions from electric power plants and petroleum refineries.

[c] Emissions from International Bunker Fuels and CO_2 emissions from Wood Biomass and Biofuel Consumption are estimated as part of this inventory report but are not included in emission totals, as per IPCC (2006) guidelines.

Notes: Totals may not sum due to independent rounding.

The remainder of this chapter describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement. Activity data and emission factors used in the analysis are summarized in Appendix D and Appendix E, respectively.

3.1. Stationary Combustion (IPCC Source Categories 1A1, 1A2, 1A4, 1A5)

Fossil fuels are burned to generate energy from a variety of stationary sources, including electric power plants, industrial facilities, commercial businesses, and homes. When fossil fuels are combusted, they release CO_2, CH_4, and N_2O emissions. Stationary combustion emissions can be broken out by economic sector (i.e., energy industries, residential, commercial, and industrial), based on where the fuel is combusted. In 2015, emissions from stationary combustion in Hawaii were 8.38 MMT CO_2 Eq., accounting for 45 percent of Energy sector emissions. The vast majority of these emissions are from energy industries (84 percent), which includes both electric power plants and petroleum refineries. The commercial sector accounted for the next largest portion of stationary combustion emissions (10 percent), followed by the industrial (5 percent) and residential sectors (1 percent). Figure 3-4 shows the breakout of stationary combustion emissions by economic sector for 2015.

Relative to 1990, emissions from stationary combustion in 2015 were higher by roughly 6 percent, down from 25 percent above 1990 levels in 2010. This trend is largely driven by emissions from energy industries, which increased from 1990 to 2007 and then decreased from 2007 to 2015. Emissions from the residential sector consistently increased from 1990 to 2015, while emissions from the commercial sector decreased from 1990 to 2007 and then increased from 2007 to 2015. Emissions from the industrial sector also followed an inconsistent trend, decreasing from 1990 to 2007, increasing from 2007 to 2010, and then decreasing again from 2010 to 2015. Figure 3-5 presents emissions from stationary combustion in Hawaii by economic sector for 1990, 2007, 2010 and 2015. Table 3-2 summarizes emissions from stationary combustion in Hawaii by economic sector and gas for 1990, 2007, 2010 and 2015.

Figure 3-4: 2015 Stationary Combustion Emissions by Economic Sector

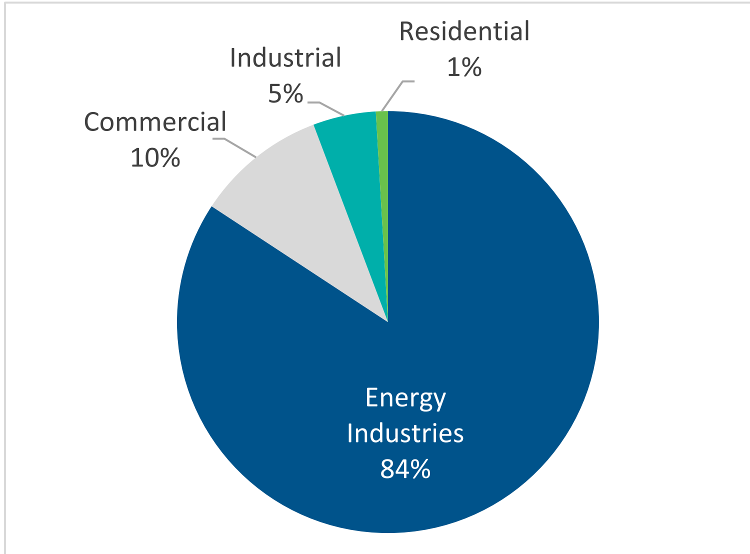


Figure 3-5: GHG Emissions from Stationary Combustion by Economic Sector and Year (MMT CO_2 Eq.)

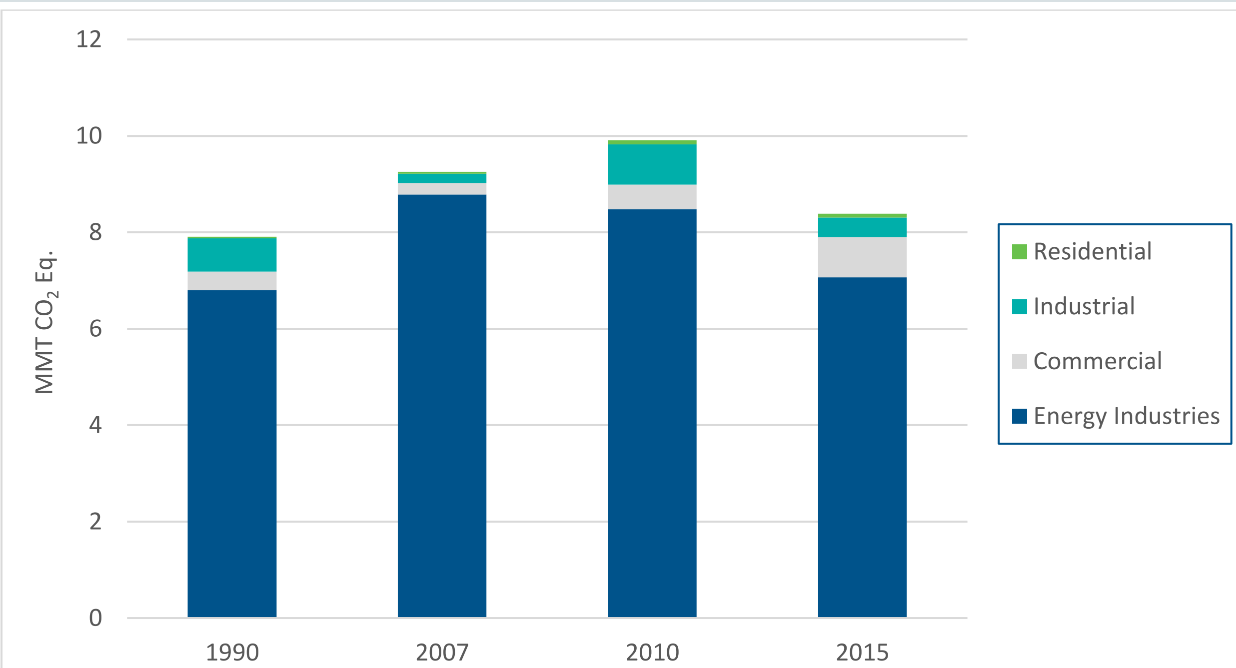


Table 3-2: GHG Emissions from Stationary Combustion by Economic Sector and Gas (MMT CO_2 Eq.)

Economic Sector/Gas	1990	2007	2010	2015
Energy Industries	**6.80**	**8.78**	**8.48**	**7.06**
CO_2	6.78	8.75	8.45	7.04
CH_4	0.01	0.01	0.01	0.01
N_2O	0.02	0.02	0.02	0.02
Residential	**0.03**	**0.04**	**0.08**	**0.08**
CO_2	0.03	0.04	0.08	0.08
CH_4	+	+	+	+
N_2O	+	+	+	+
Commercial	**0.38**	**0.24**	**0.51**	**0.84**
CO_2	0.38	0.24	0.51	0.83
CH_4	+	+	+	+
N_2O	+	+	+	+
Industrial	**0.70**	**0.19**	**0.84**	**0.40**
CO_2	0.69	0.19	0.83	0.40
CH_4	+	+	+	+
N_2O	+	+	0.01	0.01
Total	**7.91**	**9.26**	**9.91**	**8.38**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

With the exception of emission estimates obtained directly from EPA's Greenhouse Gas Reporting Program (GHGRP), CO_2 emissions from stationary combustion were calculated using an IPCC (2006) Tier 2 methodology. Emissions were calculated using the following equation:

$$CO_2\ Emissions\ =\ Fuel\ Consumption \times C_{fuel} \times \frac{44}{12}$$

where,

Fuel Consumption	= total amount of fuel combusted (Billion British Thermal Units or Bbtu)
C_{fuel}	= fuel specific Carbon Content Coefficient (lbs C/Bbtu)
44/12	= conversion of carbon to CO_2

Methane and N_2O emissions were calculated using an IPCC (2006) Tier 1 methodology. Emissions were calculated using the following equation:

$$CH_4\ and\ N_2O\ Emissions\ =\ Fuel\ Consumption \times EF_{fuel}$$

where,

Fuel Consumption	= total amount of fuel combusted (terajoule or TJ)
EF_{fuel}	= emission factor of CH_4 and N_2O by fuel type (kilogram or kg gas/TJ)

Carbon content coefficients for estimating CO_2 emissions, which are specific to each fuel type, were taken from the U.S. Inventory (EPA 2017a). Methane and N_2O emission factors were obtained from the *2006 IPCC Guidelines* (IPCC 2006) for fossil fuels and ethanol, and the U.S. Inventory (EPA 2017a) for biodiesel.

2010 and 2015

Fuel consumption data for 2010 and 2015 were obtained from the following three data sources:

- **Hawaii Department of Business, Economic Development, and Tourism (DBEDT):** Fuel consumption data for fossil fuels and liquid biofuels (i.e., ethanol and biodiesel consumption for non-transportation activities) by fuel type were provided by DBEDT (2018a), who collects the data from various fuel refiners and distributors.[9,10] Data were provided at an aggregate level to preserve the confidentiality of the information, in accordance with HRS Chapter 486J. Several assumptions were made to disaggregate the data into economic sectors.[11] For example, the Energy Information Administration's (EIA) State Energy Data System (SEDS) (EIA 2017a) and historic DBEDT (2008a) data were used to allocate fuel consumption by economic sector.
- **EIA State Energy Data System (SEDS):** Diesel fuel consumption in the energy industries sector and residual fuel consumption in all sectors for 2015 were obtained from SEDS (EIA 2017a). This data source was chosen after a comparative analysis of various top-down and bottom-up data sources, which showed SEDS data to be a closer match to these sources than the data collected by DBEDT.[12] DBEDT did not provide data on coal consumption; coal consumption in the industrial and energy industries sector for 2010 and 2015 was obtained from SEDS (EIA 2017a).
- **EPA Greenhouse Gas Reporting Program (GHGRP):** Carbon dioxide, CH_4, and N_2O emissions from naphtha consumption at refineries were obtained directly from EPA's GHGRP (EPA 2017b). Methane and N_2O emissions from solid biomass consumption at the Hawaiian Commercial and Sugar Company, the Hawaiian Electric Company (HECO), and the Maui Electric Company (MECO) were obtained directly from EPA's GHGRP (EPA 2017b).[13,14]

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[9] DBEDT collected and provided consumption data on ethanol-blended motor gasoline. Consumption totals for ethanol and pure motor gasoline were calculated using the percent of ethanol contained in the ethanol-blended motor gasoline (i.e., E10 motor gasoline contains 10 percent ethanol and 90 percent motor gasoline).

[10] As DBEDT is the conduit of this data but not the source of this data, DBEDT cannot ascertain the data's accuracy. Use of this data was at the discretion of the authors of this report.

[11] In some cases, fuel types were also disaggregated into more specific fuel types to quantify GHG emissions.

[12] Sources used in this comparison include EPA's GHGRP; DBEDT's Monthly Energy Data; Hawaii Energy Facts & Figures Report; EIA-923 Electric Power Data; and Hawaii's State and Local Emissions Inventory System (SLEIS). Appendix F provides additional information on the results of this comparison.

[13] Carbon dioxide emissions from Wood Biomass and Biofuels Consumption are reported in Section 3.6.

[14] Stationary biomass fuel types include: agricultural byproducts; biodiesel (100%); and wood and wood residuals.

1990 and 2007

Fuel consumption data by fuel type for 1990 and 2007 were obtained from DBEDT collected data (2008a). DBEDT categorized the data into economic sectors (i.e., residential, commercial, industrial, and energy industries) based on the consumption activity of each fuel type.

Uncertainties and Areas for Improvement

Uncertainties associated with stationary consumption estimates include the following:

- The consumption data for diesel and residual fuel are based on information compiled from multiple data sources rather than a single data source. The decision to use multiple sources of data was based on a comparative analysis of the DBEDT collected data with other available fuel consumption data, which showed the DBEDT collected data to be inconsistent with the other data sources. The results of this comparative analysis is discussed further in Appendix F. Further review of the data collected by DBEDT is recommended to better understand the observed differences, and to ensure use of the best estimates of fuel consumption available.
- There is uncertainty associated with the disaggregation of the DBEDT collected data by fuel type and economic sector. To protect the confidentiality of the data, in accordance with HRS Chapter 486J, the 2010 and 2015 fuel consumption data collected and provided by DBEDT was aggregated across fuel categories and end-use sectors. Further review of the DBEDT collected data over time and against other data sources is needed to ensure the trends by sector and magnitudes of emissions are accurate.
- Data on solid biomass and biodiesel consumption were not available for 1990 and 2007. As a result, CH_4 and N_2O emissions from these fuels for 1990 and 2007 are not reflected in this analysis. If data becomes available, these emissions will be incorporated into the totals for this source category.
- DBEDT collected and provided information on fossil fuel feedstocks (i.e., asphalt, synthetic natural gas feedstock, etc.) for 2010 and 2015. This information was not provided for 1990 and 2007. To ensure time series consistency, consumption of these feedstocks for non-combustion uses are not currently incorporated into the inventory calculations. Furthermore, emissions from these sources are expected to be very small (less than 0.005 MMT CO_2 Eq.). Future analyses should investigate potential emissions that could occur from the consumption of these feedstocks for non-energy uses (NEU).

3.2. Transportation (IPCC Source Category 1A3)

Emissions from transportation result from the combustion of fuel for ground, domestic marine, domestic aviation, and military transportation. Ground transportation includes passenger cars, light trucks, motorcycles, and heavy-duty vehicles (i.e., trucks and buses). In 2015, emissions from transportation activities in Hawaii were 9.79 MMT CO_2 Eq., accounting for 53 percent of Energy sector emissions. Ground transportation accounted for the largest portion of transportation emissions (58 percent) followed by domestic aviation (33 percent), military (5 percent), and domestic marine (4 percent). Figure 3-6 shows the breakout of transportation emissions by end-use sector for 2015.

Relative to 1990, emissions from transportation in 2015 were lower by roughly 13 percent. While emissions from ground transportation increased between 1990 and 2015, emissions from domestic aviation, domestic marine, and military transportation decreased during the same time period. Domestic aviation emissions, which saw the largest decrease in magnitude, were 4.66 MMT CO_2 Eq. in 1990 and 3.23 MMT CO_2 Eq. in 2015. Figure 3-7 presents emissions from transportation in Hawaii by end-use sector for 1990, 2007, 2010 and 2015. Table 3-3 summarizes emissions from transportation in Hawaii by end-use sector and gas for 1990, 2007, 2010 and 2015.

Figure 3-6: 2015 Transportation Emissions by End-Use Sector

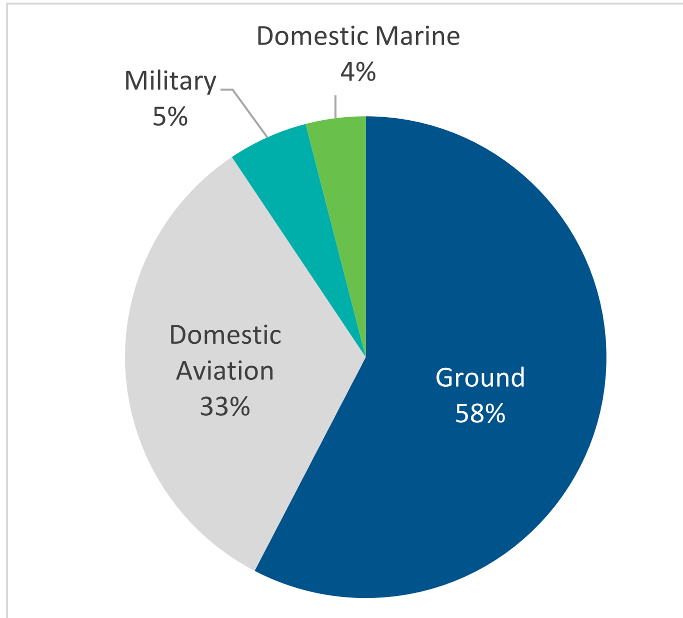

Figure 3-7: Transportation Emissions by End-Use Sector and Year (MMT CO_2 Eq.)

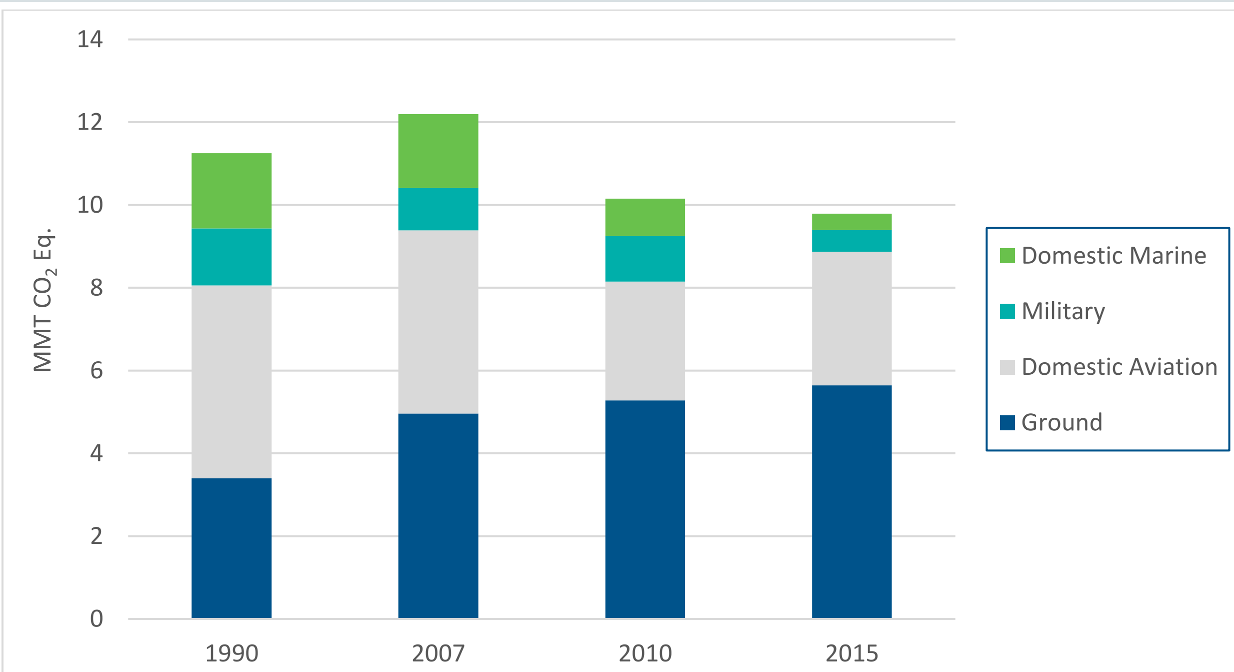

Table 3-3: GHG Emissions from Transportation by End-Use Sector and Gas (MMT CO_2 Eq.)

End-Use Sector/Gas	1990	2007	2010	2015
Ground	**3.40**	**4.97**	**5.28**	**5.64**
CO_2	3.23	4.86	5.21	5.60
CH_4	0.02	0.01	0.01	0.01
N_2O	0.15	0.10	0.07	0.04
Domestic Marine	**1.82**	**1.79**	**0.91**	**0.39**
CO_2	1.81	1.77	0.90	0.39
CH_4	+	+	+	+
N_2O	0.01	0.01	0.01	+
Domestic Aviation	**4.66**	**4.42**	**2.87**	**3.23**
CO_2	4.61	4.38	2.84	3.20
CH_4	+	+	+	+
N_2O	0.04	0.04	0.03	0.03
Military	**1.38**	**1.02**	**1.10**	**0.53**
CO_2	1.37	1.01	1.09	0.52
CH_4	+	+	+	+
N_2O	0.01	0.01	0.01	+
Total	**11.26**	**12.19**	**10.16**	**9.79**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Domestic vs. International Aviation and Marine

Consistent with IPCC (2006), the following approach is used to determine emissions from the transportation sector:

- **Included in Hawaii Inventory Totals:** All transportation activities that occur within Hawaii (e.g., flights from Oahu to Maui) and domestic interstate activities originating in Hawaii (e.g., flights from Honolulu to Los Angeles).
- **Estimated but Excluded from Hawaii Inventory Totals:** Any fuel combustion used for international flights and marine voyages that originate in Hawaii (e.g., flights from Honolulu to Hong Kong).
- **Not Estimated:** All transportation activities that originate outside Hawaii (e.g., travel from Los Angeles to Honolulu, travel from Tokyo to Honolulu).

Methodology

Calculating CO_2 emissions from all transportation sources

Carbon dioxide emissions were estimated using the following equation, consistent with IPCC (2006):

$$CO_2\ Emissions\ =\ [Fuel\ Consumption\ -\ IBF\ Consumption\ ] \times C_{fuel}\ \times \frac{44}{12}$$

where,

Fuel Consumption	= total energy consumption by fuel type (Bbtu)
IBF Consumption	= total consumption of International Bunker Fuels by fuel type (Bbtu)
C_{fuel}	= total mass of carbon per unit of energy in each fuel (lbs C/Bbtu)
44/12	= conversion of carbon to CO_2

Fuel consumption data by fuel type and source for were collected and provided by DBEDT (2008a and 2018a).[15] For 1990 and 2007, DBEDT categorized the data into ground, aviation, marine, and military transportation end-uses based on the consumption activity of each fuel type. For 2010 and 2015, data were provided at an aggregate level to preserve the confidentiality of the information. Several assumptions were made to disaggregate these data into individual fuel types and end-uses. This included the use of SEDS (EIA 2017a) and historic DBEDT (2008a) collected data to allocate fuel consumption to individual sectors. For all years, aviation and marine fuel consumption were categorized as either domestic or international consumption, which is discussed in Section 3.5.

Calculating CH_4 and N_2O emissions from highway vehicles

Methane and N_2O emissions from highway vehicles are dependent on numerous factors, such as engine type and emissions control technology. Consistent with the IPCC (2006) Tier 2 methodology, the following equation was used to calculate CH_4 and N_2O emissions from highway vehicles:

$$CH_4\ and\ N_2O\ Emissions\ =\ VMT \times EF_t$$

where,

VMT	= Vehicle Miles traveled by vehicle, fuel, model year and control technology (mi)
EF_t	= Control Technology Emission Factor (kg CH_4 or N_2O/mi)

For 2010 and 2015, vehicle miles traveled (VMT) estimates by functional class (e.g., interstate, local, other freeways and expressways, other principal arterial, minor arterial, etc.) for the state of Hawaii were obtained from the Federal Highway Administration's (FHWA) Annual Highway Statistics (FHWA 2010 and 2015). The distribution of annual VMT by vehicle type for each functional class for the state of Hawaii, which was also obtained from FHWA (2010 and 2015), was then used to calculate VMT by vehicle type. For 1990 and 2007, VMT estimates by vehicle type were provided by the Hawaii Department of Transportation (DOT) (Hawaii DOT 2008). Vehicle age distribution by model year, as well

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[15] For 2010 and 2015, DBEDT collected and provided consumption data on ethanol-blended motor gasoline. Consumption totals for ethanol and pure motor gasoline were calculated using the percent of ethanol contained in the ethanol-blended motor gasoline (i.e., gasoline (E10) contains 10 percent ethanol and 90 percent motor gasoline).

as control technologies and emission factors by vehicle type for all years, were obtained from the U.S. Inventory (EPA 2017a).

Calculating CH_4 and N_2O emissions from non-highway vehicles

Methane and N_2O emissions from non-highway vehicles[16] were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:

$$CH_4 \text{ and } N_2O \text{ Emissions} = [\, C_{Non\ Highway} - C_{IBF}] \times EF$$

where,

$C_{Non\ Highway}$	= total amount of fuel combusted by non-highway vehicles by fuel type (Bbtu)
C_{IBF}	= total amount of International Bunker Fuels combusted by fuel type (Bbtu)
EF	= emission factor for non-highway vehicles (kg CH_4 or N_2O/Bbtu)

Default emission factors for estimating emissions from off-road vehicles were obtained from the *1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). This source was used because the *2006 IPCC Guidelines* does not include updated emission factors for off-road vehicles.

Uncertainties and Areas for Improvement

Uncertainties associated with transportation estimates include the following:

- There is uncertainty associated with the disaggregation of the DBEDT collected data by fuel type and end-use sector. To protect the confidentiality of the data, in accordance with HRS Chapter 486J, the 2010 and 2015 fuel consumption data collected and provided by DBEDT was aggregated across fuel categories and end-use sectors. Further review of the DBEDT collected data over time and against other data sources is needed to ensure the trends by sector and magnitudes of emissions are accurate.
- Discrepancies were identified when comparing the data collected by DBEDT with other data sources. For example, diesel fuel consumption for transportation provided by DBEDT is more than double the amount reported in SEDS for 2015, as shown in Appendix F. Further review of the data collected by DBEDT is recommended to better understand the reason for the observed differences.
- In addition, there is some uncertainty associated with the emission factors used for estimating emissions from off-road vehicles, which were obtained from the 1996 IPCC Guidelines (IPCC/UNEP/OECD/IEA 1997). The U.S. Inventory (EPA 2017a) uses non-road emission factors developed based on the *2006 IPCC Guidelines* (IPCC 2006) Tier 3 guidance and EPA's

[16] Non-highway vehicles are defined as any vehicle or equipment not used on the traditional road system, excluding aircraft, rail, and watercraft. This category includes snowmobiles, golf carts, riding lawn mowers, agricultural equipment, and trucks used for off-road purposes, among others.

MOVES2014 model. The use of these updated emission factors for off-road vehicles should be considered for future analyses.

3.3. Incineration of Waste (IPCC Source Category 1A1a)

Municipal solid waste (MSW) releases CO_2, CH_4, and N_2O emissions when combusted. In 2015, emissions from the incineration of waste in Hawaii were 0.20 MMT CO_2 Eq., accounting for 1 percent of Energy sector emissions.[17] In 1990, MSW was combusted in Hawaii at two facilities: the H-POWER plant and the Waipahu Incinerator. The Waipahu Incinerator ceased operations in the early 1990s. As a result, emissions from the incineration of waste in Hawaii decreased between 1990 and 2007. Between 2007 and 2015 emissions increased due to expansions in H-POWER's processing capacity. Table 3-4 summarizes emissions from the incineration of waste in Hawaii by gas for 1990, 2007, 2010 and 2015.

Table 3-4: Emissions from Incineration of Waste by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	0.17	0.15	0.18	0.19
CH_4	+	+	+	+
N_2O	+	+	0.01	0.01
Total	**0.18**	**0.15**	**0.19**	**0.20**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

2010 and 2015

Emissions for the H-POWER plant for 2010 and 2015 were obtained directly from EPA's GHGRP (EPA 2017b). This includes non-biogenic CO_2, CH_4, and N_2O emissions and biogenic CH_4 and N_2O emissions.

1990 and 2007

Waipahu Incinerator: For the Waipahu Incinerator, CO_2, CH_4, and N_2O emissions were calculated using the IPCC (2006) Tier 1 methodology. For CO_2 emissions, this approach uses waste composition data (i.e., the percent of plastics and synthetic materials) and their respective carbon content to determine emissions from the combustion of these materials, as described in the following equation:

$$CO_2\ Emissions = MSW\ x \sum_i (WF_i\ x\ dm_i\ x\ CF_i\ x\ FCF_i\ x\ OF_i)$$

where,

CO_2 Emissions = CO_2 emissions in the inventory year

[17] Consistent with the U.S. Inventory (EPA 2017a), emissions from waste incineration are reported under the Energy sector because the waste is used to produce energy.

MSW	= total amount of MSW incinerated
WF_i	= fraction of waste type/material of component i in the MSW
dm_i	= dry matter content in the waste incinerated
CF_i	= fraction of carbon in the dry matter (total carbon content)
FCF_i	= fraction of fossil carbon in the total carbon
OF_i	= oxidation factor
i	= type of waste incinerated

For CH_4 emissions, this Tier 1 approach uses the waste input to the incinerator and a default emission factor, as described in the following equation:

$$CH_4\ Emissions = IW\ x\ EF$$

where,

CH_4 Emissions	= CH_4 emissions in the inventory year
IW	= amount of incinerated waste
EF	= CH_4 emission factor

For N_2O emissions, this Tier 1 approach uses the waste input to the incinerator and a default emission factor, as described in the following equation:

$$N_2O\ Emissions = IW\ x\ EF$$

where,

N_2O Emissions	= N_2O emissions in the inventory year
IW	= amount of incinerated waste
EF	= N_2O emission factor

Data on the quantity of waste combusted at the Waipahu Incinerator was provided by Steve Serikaku, Honolulu County Refuse Division (Serikaku 2008). Emission factors and the proportion of plastics, synthetic rubber, and synthetic fibers in the waste stream were taken from the U.S. EPA's State Inventory Tools – Solid Waste Module (EPA 2017c).

H-POWER plant: For the H-POWER plant, emissions were calculated using a Tier 3 methodology consistent with California Air Resources Board (CARB) guidance for Mandatory GHG Emissions Reporting (Hahn 2008) for the years 1990 and 2007. This methodology is believed to be more accurate than the IPCC methodology and attributes a specific ratio of carbon emissions to account for biogenic and anthropogenic sources based on carbon isotope measurements at the facility. This approach utilizes facility-specific steam output data from HPOWER to estimate CO_2, CH_4, and N_2O emissions from the combustion of refuse-derived fuel which is processed from MSW, as described in the following equation:

$$Emissions = \sum_i Heat\ x\ EF_i$$

where,

Emissions	= GHG emissions in the inventory year
Heat	= heat output at a given facility
EF_i	= default emission factor for GHG i
i	= type of GHG emitted (CO_2, CH_4, and N_2O)

Facility-specific information for the H-POWER plant for 1990 and 2007 was obtained directly from Convanta Energy, which operated the H-POWER facility. This data included steam generation, refuse-derived fuel (RDF) composition, biogenic carbon ratios, fuel consumption data, and CO_2 and N_2O emissions (Hahn 2008).

Uncertainties and Areas for Improvement

No major uncertainties or areas for improvement were identified for this source category.

3.4. Oil and Natural Gas Systems (IPCC Source Category 1B2)

Refinery activities release CO_2, CH_4, and N_2O to the atmosphere as fugitive emissions, vented emissions, and emissions from operational upsets. Two refineries, Island Energy Services and Par Hawaii,[18] operate in Hawaii that contribute to these emissions (EIA 2017b). In 2015, emissions from oil and natural gas systems in Hawaii were 0.19 MMT CO_2 Eq., accounting for 1 percent of Energy sector emissions. Relative to 1990, emissions from oil and natural gas systems in 2015 were lower by roughly 28 percent. This decrease is attributed to a reduction in crude oil throughput over this time period. Table 3-5 summarizes emissions from oil and natural gas systems in Hawaii by gas for 1990, 2007, 2010 and 2015.[19]

Table 3-5: Emissions from Oil and Natural Gas Systems by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	0.27	0.24	0.20	0.19
CH_4	+	+	+	+
N_2O	+	+	+	+
Total	**0.27**	**0.24**	**0.20**	**0.19**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

[18] The Island Energy Services Refinery was previously known as the Chevron Products Company Hawaii Refinery; the Par Hawaii Refinery was previously known as the Hawaii Independent Energy Petroleum Refinery.

[19] Emissions from fuels combusted at refineries are included in under the Stationary Combustion source category.

Methodology

2010 and 2015

Emissions from oil and gas systems for 2010 and 2015 were taken directly from EPA's GHGRP (U.S. EPA 2017b). This includes non-biogenic CO_2, CH_4, and N_2O fugitive emissions from petroleum refining and hydrogen production for Hawaii's two refineries.

1990 and 2007

Emissions from oil and gas systems for 1990 and 2007 were estimated by scaling 2010 emissions data from EPA's GHGRP (EPA 2017b) based on the ratio of crude oil refined (i.e., throughput) each year for the two refineries relative to 2010. Data on the amount of crude oil refined was obtained from reports collected by DBEDT as well as direct correspondence with the refinery owners (DBEDT 2008b; Island Energy Services 2017; Par Petroleum 2017).

Uncertainties and Areas for Improvement

Fugitive emissions from petroleum refining for 1990 and 2007 were not available from EPA's GHGRP. These emissions were instead estimated based on annual throughput for each refinery. For well-controlled systems the primary source of emissions are fugitive equipment leaks, which are independent of system throughputs (IPCC 2000). As a result, there is uncertainty associated with using throughput as a proxy for emissions. Additionally, annual throughput for the Chevron refinery (now Island Energy Services) was not available for 1990; for the purposes of this analysis, it was assumed that 1990 throughput was consistent with 2007 levels.

Emissions from hydrogen production also occur at refineries in Hawaii. This process uses carbon based feedstock inputs (e.g., methane from natural gas) as a source of hydrogen and emits the carbon as CO_2. While these emissions occur at refineries, they do not result from the combustion of fuels and therefore are not captured under the Energy sector. Instead, emissions from hydrogen production are captured under the IPPU sector (IPCC Source Category 2B). These emissions, which totaled 0.1 MMT CO_2 Eq. in 2015 (EPA 2017b), are not currently captured in this inventory. These emissions should be incorporated into future inventory analyses.

3.5. International Bunker Fuels (IPCC Source Category 1: Memo Items)

International bunker fuels are defined as marine and aviation travel originating in Hawaii and ending in a foreign country. According to IPCC (2006), emissions from the combustion of fuels used for international transport activities, or international bunker fuels, should not be included in emission totals, but instead should be reported separately. International bunker fuel combustion produces CO_2, CH_4, and N_2O emissions from both marine and aviation fuels. In 2015, emissions from international bunker fuels in Hawaii were 1.61 MMT CO_2 Eq., which is 45 percent lower than 1990 levels. Table 3-6 summarizes emissions from international bunker fuels in Hawaii for 1990, 2007, 2010 and 2015.

Table 3-6: Emissions from International Bunker Fuels by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	2.92	1.53	1.37	1.59
CH_4	+	+	+	+
N_2O	0.03	0.01	0.01	0.01
Total	**2.95**	**1.54**	**1.38**	**1.61**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Aviation Bunker Fuel: Aviation bunker fuel emissions were calculated based on the estimated amount of jet fuel used for international trips in each year. The portion of jet fuel used for international trips was estimated using the ratio of international flight mileage to the total flight mileage originating in Hawaii, which was calculated using data obtained from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database (U.S. DOT 2017). That ratio was multiplied by total jet fuel consumption in Hawaii, as obtained from DBEDT (2008a and 2018a) collected data, to calculate aviation international bunker fuel consumption. The aviation bunker fuel consumption was then multiplied by CO_2, CH_4, and N_2O emission factors to calculate GHG emissions. Carbon dioxide emission factors were obtained from the U.S. Inventory (EPA 2017a), while CH_4 and N_2O emission factors were obtained from IPCC (2006).

Marine Bunker Fuel: Marine bunker fuel emissions were calculated by multiplying diesel and residual fuel consumption for international trips by their respective emission factors as obtained from the U.S. Inventory (EPA 2017a) and IPCC (2006). For all inventory years except 1990, marine bunker fuel consumption for Hawaii was obtained from the Census Bureau (DOC 2008 and 2017). For 1990, marine bunker fuel consumption was estimated by assuming Hawaii represented the same proportion of the total U.S. consumption in 1990 as in 2006 (the earliest available year for Hawaii marine bunker fuel). National marine bunker fuel consumption was obtained from the U.S. Inventory (EPA 2017a).

Uncertainties and Areas for Improvement

Uncertainties associated with international bunker fuel estimates include the following:

- There is some uncertainty associated with estimating jet fuel consumption for international trips based on the international flight to total flight mileage ratio. This approach was used because data on jet fuel consumption for international trips originating in Hawaii were not available.
- There is some uncertainty with estimating marine bunker fuel consumption in 1990 due to a lack of available data and use of the 2006 ratio of Hawaii consumption to total U.S. consumption.
- Uncertainties exist with the reliability of Census Bureau (DOC 2008 and 2017) data on marine vessel fuel consumption reported at U.S. customs stations due to the significant degree of inter-annual variation, as discussed further in the U.S. Inventory (EPA 2017a).
- For this analysis, emissions from aviation bunker fuels were estimated using aggregate jet fuel consumption data. The *2006 IPCC Guidelines* (IPCC 2006) recommend estimating CH_4 and N_2O

emissions from aviation bunker fuels using data by specific aircraft type, number of individual flights, and movement data in order to differentiate between domestic and international aviation and incorporate the effects of technology changes.

3.6. CO_2 from Wood Biomass and Biofuel Consumption (IPCC Source Category 1A)

Ethanol, biodiesel, and other types of biomass release CO_2 emissions when combusted.[20,21] According to IPCC (2006), since these emissions are biogenic, CO_2 emissions from biomass combustion should be estimated separately from fossil fuel CO_2 emissions and should not be included in emission totals. This is to avoid double-counting of biogenic CO_2 emissions from the AFOLU sector. In 2015, CO_2 emissions from wood biomass and biofuel consumption in Hawaii were 1.45 MMT CO_2 Eq. Table 3-7 summarizes CO_2 emissions from wood biomass and biofuel consumption in Hawaii for 1990, 2007, 2010 and 2015.

Table 3-7: Emissions from Wood Biomass and Biofuel Consumption by Gas (MMT CO_2 Eq.)

Gas	1990[a]	2007[a]	2010	2015
CO_2	NE	0.16	1.22	1.45

+ Does not exceed 0.005 MMT CO_2 Eq; NE (emissions are Not Estimated).

[a] Emissions from biodiesel and solid biomass were not estimated for 1990 and 2007 due to a lack of available data. Emissions reported for 2007 reflect emissions from ethanol consumption only.

Methodology

Carbon dioxide emissions from biofuel combustion were calculated using the following equation:

$$CO_2\ Emissions = Biofuel\ Consumption \times HHV_{biofuel} \times EF_{biofuel}$$

where,

Biofuel Consumption	= total volume of ethanol and biodiesel combusted (gal)
$HHV_{biofuel}$	= Default high heat value of ethanol and biodiesel (Million Btu or MMBtu/gal)
$EF_{biofuel}$	= Ethanol- and biodiesel-specific default CO_2 emission factor (kg CO_2/MMBtu)

[20] Ethanol is blended with motor gasoline at oil refineries. Hawaii began blending ethanol into its motor gasoline supply in 2006.

[21] In addition to CO_2, small amounts of CH_4 and N_2O are also emitted from biomass sources. Unlike CO_2 emissions from biomass, these CH_4 and N_2O emissions are not accounted for in a separate process, and thus are included in the stationary combustion and transportation source categories and are counted towards total emissions.

2010 and 2015

Liquid biofuel consumption (i.e., ethanol-blended motor gasoline and biodiesel) were obtained from DBEDT (2018a) collected data. Ethanol consumption was then calculated using the percent of ethanol contained in the ethanol-blended motor gasoline (i.e., E10 gasoline contains 10 percent ethanol). Liquid biofuel CO_2 combustion emission factors were obtained from the EIA's *Monthly Energy Review* (EIA 2017d).

Carbon dioxide emissions from solid biomass consumption at the Hawaiian Commercial and Sugar Company, the Hawaiian Electric Company (HECO), and the Maui Electric Company (MECO) were obtained directly from EPA's GHGRP (EPA 2017b).[22]

1990 and 2007

Ethanol consumption data, in barrels, were obtained from DBEDT (2017a) collected data. Ethanol consumption data were converted to energy units using the lower heating value obtained from the U.S. Department of Energy (DOE) (2014). Ethanol CO_2 combustion emission factors were obtained from EIA's *Monthly Energy Review* (EIA 2017d).

Uncertainties and Areas for Improvement

Data on solid biomass and biodiesel consumption were not available for 1990 and 2007. As a result, emissions from these fuels for 1990 and 2007 are not reflected in this analysis. In addition, emissions from solid biomass for 2010 and 2015 that were obtained from EPA's GHGRP (EPA 2017b) do not include emissions from facilities that are below the reporting threshold of 25,000 MT CO_2 Eq. per year. If data becomes available, these emissions should be incorporated into the totals for this source category.

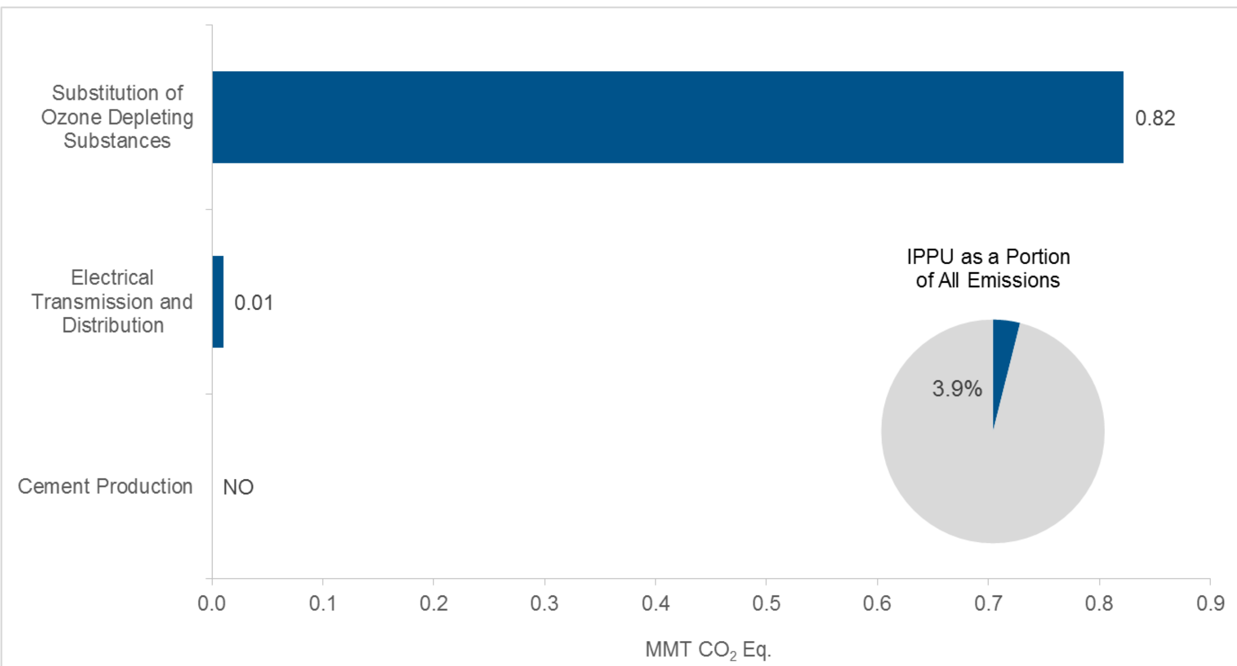
[22] Stationary biomass fuel types include: agricultural byproducts; biodiesel (100%); and wood and wood residuals.

4. Industrial Processes and Product Use (IPPU)

This chapter presents GHG emissions that occur from industrial processes and product use (IPPU). For the state of Hawaii, IPPU sector emissions are estimated from the following sources: Cement Production (IPCC Source Category 2A1), Electrical Transmission and Distribution (IPCC Source Category 2G1), and Substitution of Ozone Depleting Substances (IPCC Source Category 2F).[23]

In 2015, emissions from the IPPU sector were 0.83 MMT CO_2 Eq., accounting 4 percent of total Hawaii emissions. Emissions from the substitution of ozone depleting substances accounted for the majority of emissions from the IPPU sector, representing 99 percent of total emissions. The remaining 1 percent of emissions are from electrical transmission and distribution. Clinker production in Hawaii ceased in 1996 and, as a result, emissions from cement production in 2015 were zero. Figure 4-1 and Figure 4-2 show emissions from the IPPU sector by source for 2015.

Figure 4-1: 2015 IPPU Emissions by Source (MMT CO_2 Eq.)



NO (emissions are <u>N</u>ot <u>O</u>ccurring).

[23] IPCC Source Categories for which emissions were not estimated for the state of Hawaii include: Lime Production (2A2), Glass Production (2A3), Other Process Uses of Carbonates (2A4), Chemical Industry (2B), Metal Industry (2C), Non-Energy Products from Fuels and Solvent Use (2D), Electronics Industry (2E), SF_6 and PFCs from Other Product Uses (2G2), and N_2O from Product Uses (2G3). Appendix A provides information on why emissions were not estimated for these IPCC Source Categories.

Relative to 1990, emissions from the IPPU sector in 2015 were almost four times higher. The increase is due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances, which has grown steadily in line with national emissions as ozone depleting substances are phased out under the Montreal Protocol (EPA 2017a). Sulfur hexafluoride emissions from electrical transmission and distribution decreased by 85 percent over the same time period, also consistent with national emissions. This decrease is attributed to increasing SF_6 prices and industry efforts to reduce emissions (EPA 2017a). Figure 4-3 below shows IPPU sector emissions by source category for each inventory year. Emissions by source and year are also summarized in Table 4-1.

Figure 4-2: 2015 IPPU Emissions by Source

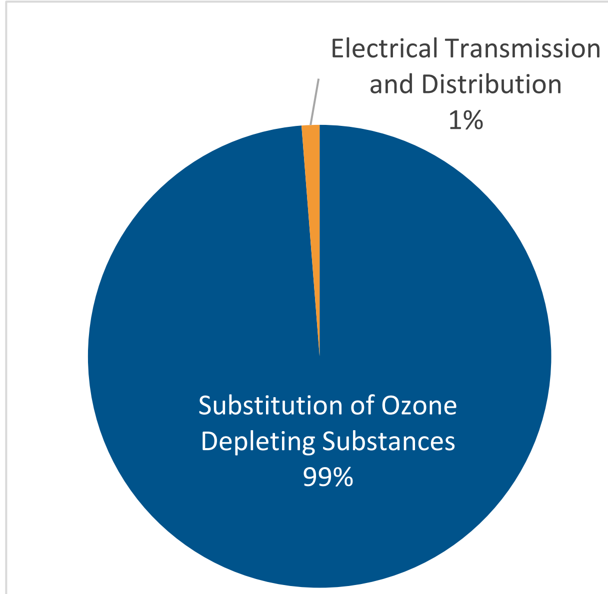


Figure 4-3: IPPU Emissions by Source and Year

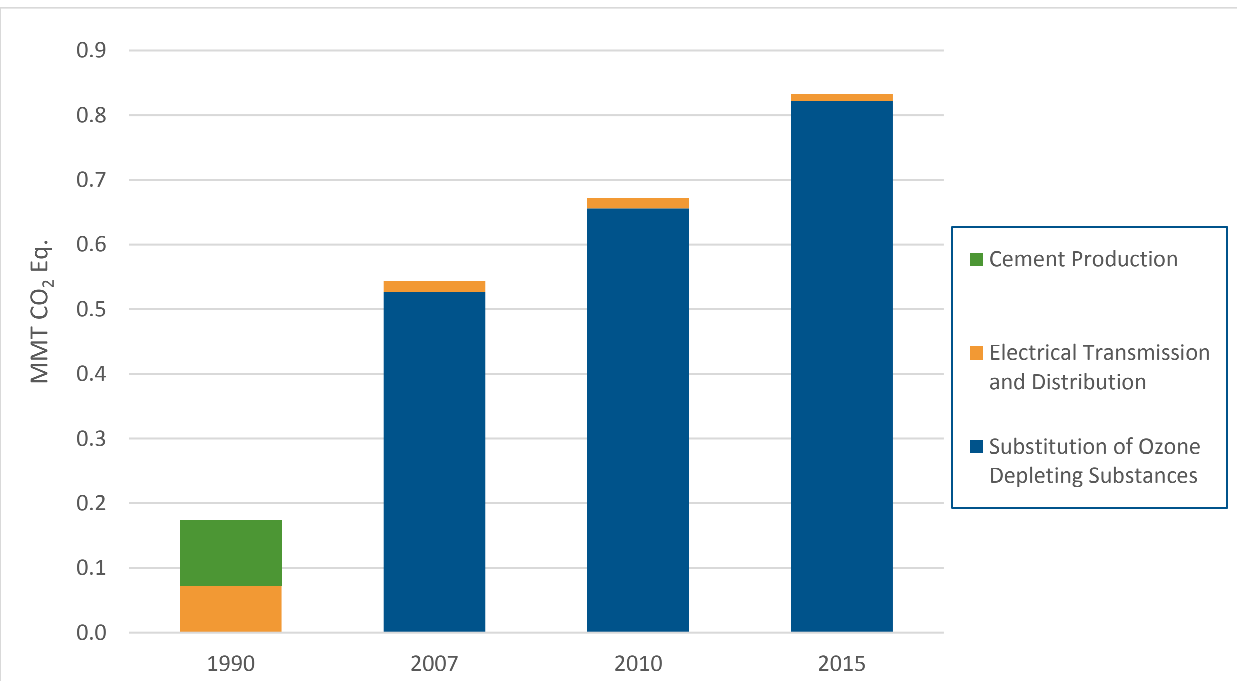


Table 4-1: GHG Emissions from the IPPU Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015
Cement Production	0.10	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01
Substitution of Ozone Depleting Substances	+	0.53	0.66	0.82
Total	**0.17**	**0.54**	**0.67**	**0.83**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).

Note: Totals may not sum due to independent rounding.

The remainder of this chapter describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement. Activity data and emission factors used in the analysis are summarized in Appendix D and Appendix E, respectively.

4.1. Cement Production (IPCC Source Category 2A1)

Carbon dioxide emissions are released as a by-product of the clinker production process, an intermediate product used primarily to make portland cement. In Hawaii, clinker was produced on-site in Oahu until production ceased in 1996, after which clinker was imported (Wurlitzer 2008). Portland cement production ended in Hawaii in 2001 (Wurlitzer 2008). As a result, in 2015, emissions from cement production in Hawaii were zero. Table 4-2 summarizes emissions from cement production in Hawaii for 1990, 2007, 2010 and 2015.

Table 4-2: Emissions from Cement Production by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	0.10	NO	NO	NO

NO (emissions are Not Occurring).

Methodology

Process-related CO_2 emissions from cement production were estimated using IPCC (2006) Tier 2 methodology, plant-specific clinker production provided by Hawaiian Cement (Wurlitzer 2008), and default factors for calcium oxide content and cement kiln dust from the *2006 IPCC Guidelines* (IPCC 2006). Emissions were calculated using the following equation:

$$CO_2 \text{ Emissions} = M_{clinker} \times EF_{clinker} \times CF_{cement\ kiln\ dust}$$

where:

$M_{clinker}$ = weight (mass) of clinker produced, tonnes
$EF_{clinker}$ = emission factor for clinker
$CF_{cement\ kiln\ dust}$ = emissions correction factor for cement kiln dust

Uncertainties and Areas for Improvement

No major uncertainties or areas for improvement were identified for this source category.

4.2. Electrical Transmission and Distribution (IPCC Source Category 2G1)

Sulfur hexafluoride (SF_6) emissions from electrical transmission and distribution systems result from leaks in transmission equipment. In 2015, emissions from electrical transmission and distribution systems in Hawaii were 0.01 MMT CO_2 Eq., accounting for 1 percent of IPPU sector emissions. Relative to 1990, emissions from electrical transmission and distribution systems in 2015 were lower by 85 percent. Nationally, these emissions have decreased over time due to a sharp increase in the price of SF_6 during the 1990s and a growing awareness of the environmental impact of SF_6 emissions (EPA 2017a). Table 4-3 summarizes emissions from electrical transmission and distribution systems in Hawaii for 1990, 2007, 2010 and 2015.

Table 4-3: Emissions from Electrical Transmission and Distribution by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
SF_6	0.07	0.02	0.02	0.01

Methodology

Emissions were calculated by apportioning U.S. emissions from this source to Hawaii based on the ratio of Hawaii electricity sales to U.S. electricity sales. Estimates of national SF_6 emissions data were taken from the U.S. Inventory (EPA 2017a). National electricity sales data come from the U.S. Department of Energy, Energy Information Administration (EIA 2016). Hawaii electricity sales data come from the State of Hawaii Data Book (DBEDT 2017b).

Uncertainties and Areas for Improvement

The apportionment method was used to estimate emissions from electrical transmission and distribution systems in Hawaii instead of the IPCC methodology because data on SF_6 purchases and emissions for Hawaiian utilities were not available. The apportionment method does not account for state-specific circumstances that may deviate from national trends (e.g., efforts taken by the state, or utilities within the state, to reduce SF_6 emissions from electrical transmission and distribution systems beyond the average rate of national emissions reductions). If data on SF_6 purchases for Hawaiian utilities were made available, the methodology could be revised to incorporate these data into future inventory analyses.

4.3. Substitution of Ozone Depleting Substances (IPCC Source Category 2F)

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are used as alternatives to ozone depleting substances (ODS) that are being phased out under the Montreal Protocol and the Clean Air Act Amendments of 1990. These chemicals are most commonly used in refrigeration and air conditioning equipment, solvent cleaning, foam production, fire extinguishing, and aerosols. In 2015, emissions from ODS substitutes in Hawaii were 0.82 MMT CO_2 Eq., accounting for 99 percent of IPPU sector emissions. Nationally, emissions from ODS substitutes have risen dramatically since 1990, and now represent one of the largest sources of GHG emissions from the IPPU sector. Table 4-4 summarizes emissions from HFCs and PFCs that are used as substitutes of ODS in Hawaii for 1990, 2007, 2010 and 2015. While not included in the inventory totals, estimated emissions from ODS in Hawaii are presented in Appendix G.[24]

Table 4-4: Emissions from Substitutes of ODS by Gas (MMT CO_2 Eq.)

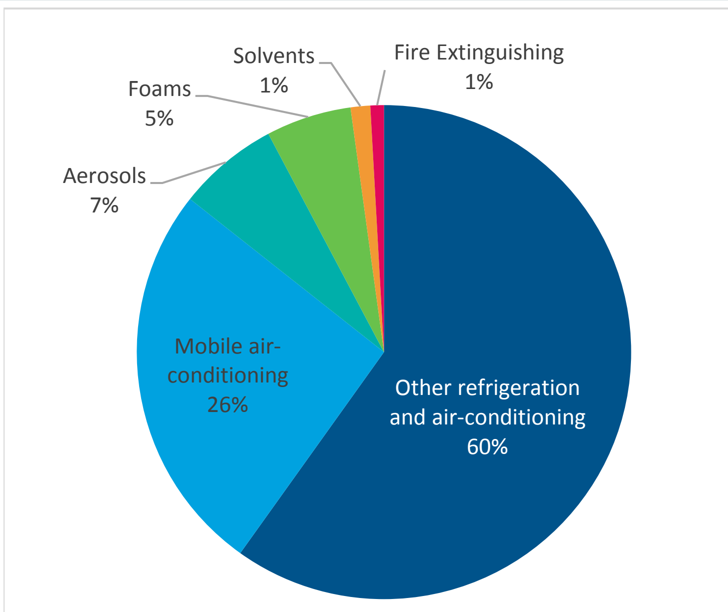
Gas	1990	2007	2010	2015
HFC/PFC	+	0.53	0.66	0.82

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

In contrast to source categories in which emissions are calculated based on production data or are directly monitored at a small number of point sources, emissions of HFCs and PFCs can occur from thousands of types of equipment from millions of sources, including refrigeration and air-conditioning units, aerosols, and solvents. Emissions by sub-category are shown in Figure 4-4.

Figure 4-4: 2015 Emissions from ODS Substitutes by Sub-Category



At the national level, these emissions are estimated using EPA's Vintaging Model, which tracks the use characteristics of equipment currently in use for more than 50 different end-use categories, and applies HFC and

[24] Per IPCC (2006) guidelines, emissions of ODS, which are also GHGs, are not included in this inventory. For informational purposes, ODS emissions were estimated for the state of Hawaii and are presented in Appendix G.

PFC leak rates to estimate annual emissions. In the U.S. Inventory (EPA 2017a), emissions are presented for the following sub-categories:

- Mobile air-conditioning
- Other refrigeration and air-conditioning
- Aerosols
- Foams
- Solvents
- Fire extinguishing

Hawaii emissions from mobile air-conditioning systems were estimated by apportioning national emissions from the U.S. Inventory (EPA 2017a) to Hawaii based on the ratio of Hawaii vehicle registrations from the State of Hawaii Data Book (DBEDT 2017b) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2016). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2017a) were apportioned to Hawaii based on the ratio of Hawaii population from DBEDT (2017b) to U.S. population from the U.S. Census Bureau (2016).

Uncertainties and Areas for Improvement

The apportionment method was used instead of the IPCC methodology due to the complexity of the source category and lack of sufficient data. This approach is consistent with the approach used in EPA's State Inventory Tool (EPA 2017d). Because emissions from substitutes of ODS are closely tied to the prevalence of the products in which they are used, in the absence of state-specific policies that control the use and management of these chemicals, emissions from this source closely correlate with vehicles registered and population. However, further research may be done to identify other metrics that could be taken into account to disaggregate national emissions, particularly for the air conditioning sub-category, which is also impacted by the local climate. For example, information on the percentage of households with central or room air conditioning, if available, could be incorporated into future inventory analyses.

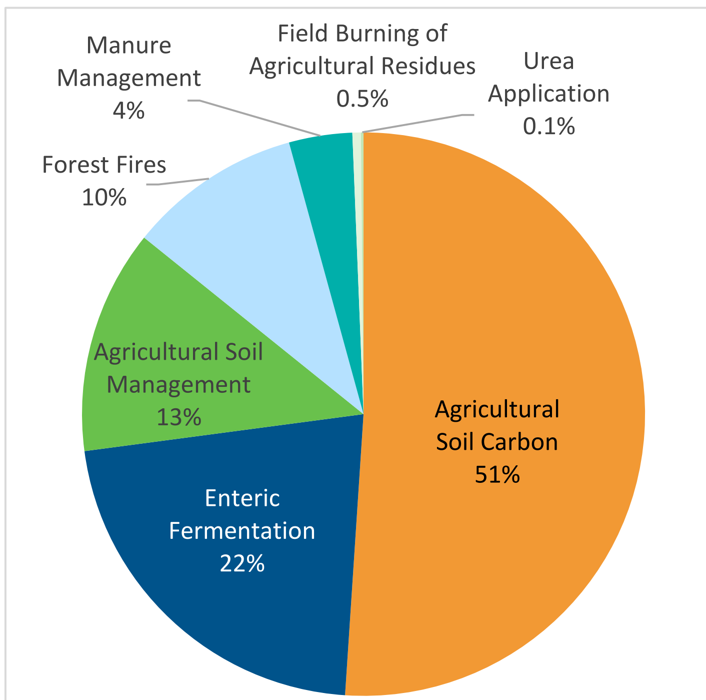
5. Agriculture, Forestry and Other Land Uses (AFOLU)

This chapter presents GHG emissions from sources and GHG removals from sinks from agricultural activities, land use, changes in land use, and land management practices. Agricultural activities are typically GHG "sources," which emit GHGs into the atmosphere. Land use, changes in land use, and land management practices may either be "sources" of GHGs or "sinks" of GHGs (sinks remove CO_2 from the atmosphere).

For the state of Hawaii, emissions and removals from agriculture, forestry, and other land uses (AFOLU) are estimated from the following source and sink categories:[25] Enteric Fermentation (IPCC Source Category 3A1); Manure Management (IPCC Source Category 3A2 and 3C6); Agricultural Soil Management (IPCC Source Categories 3C4 and 3C5); Field Burning of Agricultural Residues (IPCC Source Category 3C1b); Urea Application (IPCC Source Category 3C3); Agricultural Soil Carbon (IPCC Source Categories 3B2 and 3B3); Forest Fires (IPCC Source Category 3C1a); Landfilled Yard Trimmings and Food Scraps (IPCC Source Category 3B5a); Urban Trees (IPCC Source Category 3B5a); and Forest Carbon (IPCC Source Category 3B1a). In Hawaii, landfilled yard trimmings and food scraps, urban trees, and forest carbon are CO_2 sinks. The remaining AFOLU categories presented in this chapter are sources of GHGs.

In 2015, total emissions (excluding sinks) from the AFOLU sector were 1.10 MMT CO_2 Eq., accounting for 5 percent of total Hawaii emissions. Agricultural soil carbon accounted for the largest share of AFOLU emissions, followed by enteric fermentation, forest fires, agricultural soil management, manure management, field burning of agricultural residues, and urea application. Figure 5-1 and Figure 5-2 show emissions from the AFOLU sector by source for 2015.

Figure 5-1: 2015 AFOLU Emissions by Source



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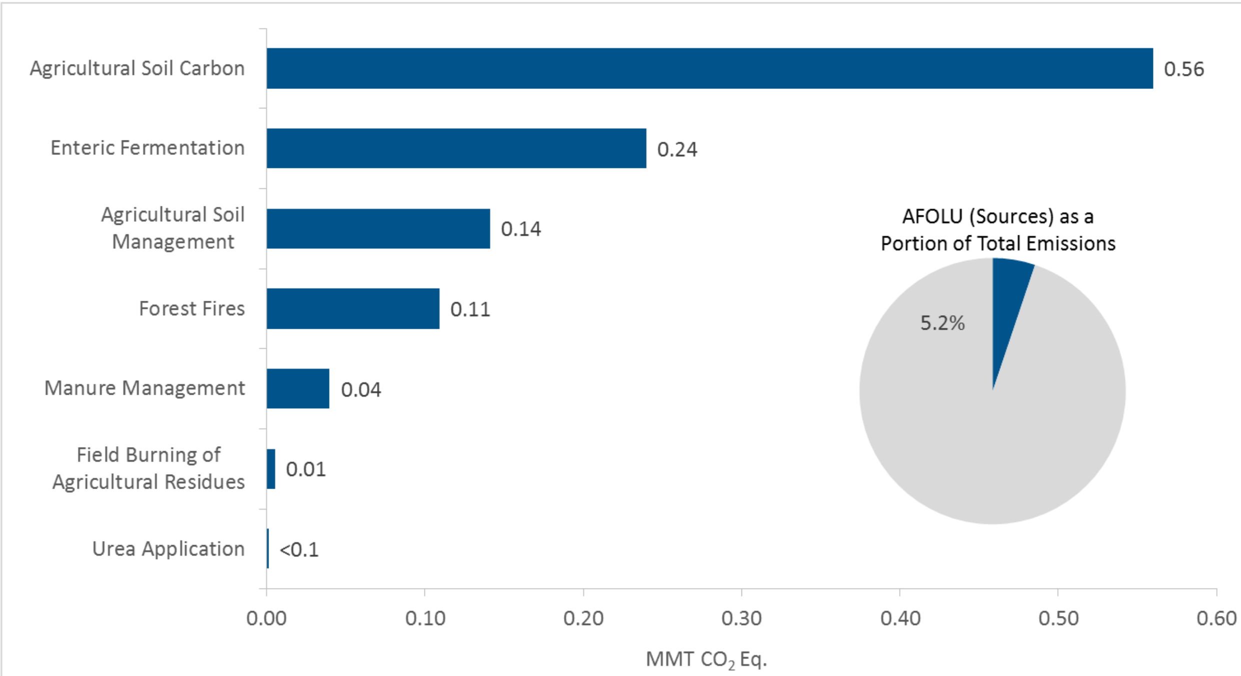
[25] IPCC Source and Sink Categories for which emissions were not estimated for the state of Hawaii include: Land Converted to Forest Land (3B1b), Wetlands (3B4), Land Converted to Settlements (3B5b), Other Land (3B6), Biomass Burning in Grassland (3C1c), Biomass Burning in All Other Land (3C1d), Liming (3C2), Rice Cultivation (3C7), and Harvested Wood Products (3D1). Appendix A provides information on why emissions were not estimated for these IPCC source categories.

Figure 5-2: 2015 AFOLU Emissions by Source (MMT CO_2 Eq.)



Note: Totals may not sum due to independent rounding.

Carbon sinks were 3.54 MMT CO_2 Eq. in 2015. Therefore, the AFOLU sector resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 2.44 MMT CO_2 Eq. in 2015. Forest carbon accounted for the largest carbon sink, followed by urban trees and landfilled yard trimmings and food scraps. Figure 5-3 shows removals by the AFOLU sector by carbon sink for 2015.

Relative to 1990, emissions from AFOLU sources in 2015 were lower by roughly 32 percent. Carbon removals from AFOLU sinks in 2015 were higher by roughly 15 percent relative to 1990 sinks. As a result, net removals from AFOLU increased by 68 percent in 2015 compared to 1990 (i.e., this sector "removes" slightly more carbon than it did in 1990). Figure 5-4 presents AFOLU emissions and removals by source and sink category in Hawaii for each inventory year. Emission sources and sinks by category and year are also summarized in Table 5-1.

Figure 5-3: 2015 AFOLU Removals by Carbon Sink

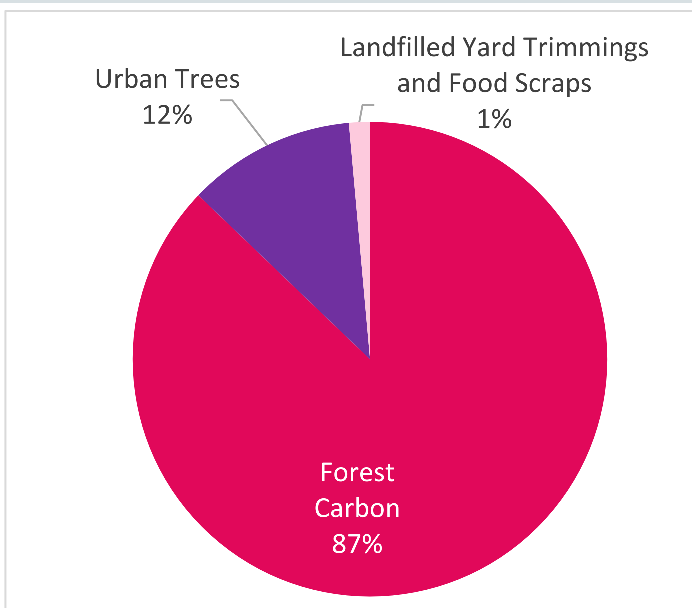


Figure 5-4: AFOLU Emissions and Removals by Source and Sink Category and Year

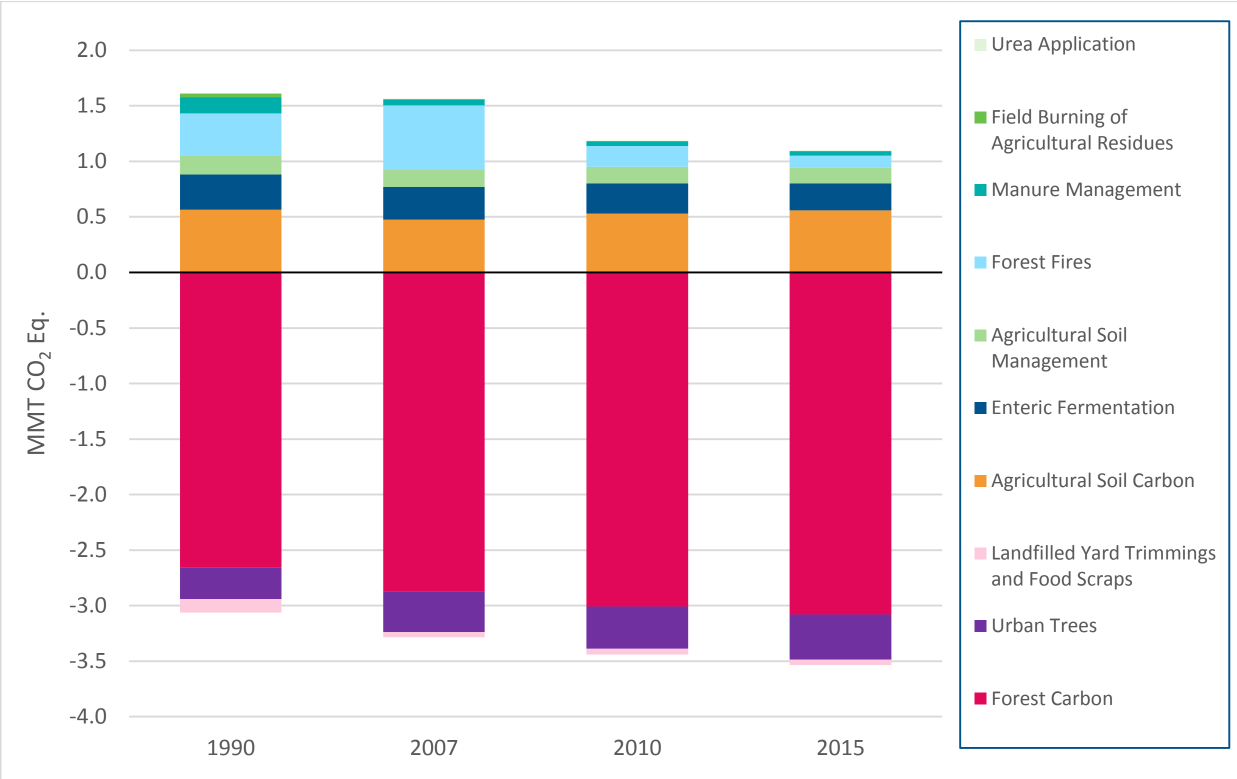


Table 5-1: GHG Emissions from the AFOLU Sector by Category (MMT CO_2 Eq.)

Category	1990	2007	2010	2015
Agriculture	**0.66**	**0.51**	**0.47**	**0.43**
Enteric Fermentation	0.32	0.29	0.27	0.24
Manure Management	0.15	0.05	0.04	0.04
Agricultural Soil Management	0.17	0.16	0.15	0.14
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01
Urea Application	+	+	+	+
Land Use, Land-Use Change, and Forestry	**(2.11)**	**(2.23)**	**(2.73)**	**(2.87)**
Agricultural Soil Carbon	0.57	0.48	0.53	0.56
Forest Fires	0.38	0.57	0.19	0.11
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)
Urban Trees	(0.28)	(0.37)	(0.38)	(0.40)
Forest Carbon	(2.66)	(2.87)	(3.01)	(3.08)
Total (Sources)	**1.61**	**1.56**	**1.18**	**1.10**
Total (Sinks)	**(3.06)**	**(3.28)**	**(3.44)**	**(3.54)**
Total Net Emissions	**(1.45)**	**(1.72)**	**(2.26)**	**(2.44)**

+ Does not exceed 0.005 MMT CO_2 Eq.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

The remainder of this chapter describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement. Activity data and emission factors used in the analysis are summarized in Appendix D and Appendix E, respectively.

5.1. Enteric Fermentation (IPCC Source Category 3A1)

Methane is produced as part of the digestive processes in animals, a microbial fermentation process referred to as enteric fermentation. The amount of CH_4 emitted by an animal depends upon the animal's digestive system, and the amount and type of feed it consumes (EPA 2017a). This source includes CH_4 emissions from dairy and beef cattle, sheep, goats, swine, and horses. In 2015, CH_4 emissions from enteric fermentation were 0.24 MMT CO_2 Eq., accounting for 22 percent of AFOLU sector emissions. Table 5-2 summarizes emissions from enteric fermentation in Hawaii for 1990, 2007, 2010, and 2015.

Table 5-2: Emissions from Enteric Fermentation by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CH_4	0.32	0.29	0.27	0.24

Methodology

The IPCC (2006) Tier 1 methodology was used to estimate emissions of CH_4 from enteric fermentation. Emissions were calculated using the following equation:

$$CH_4\ Emissions = \sum for\ each\ animal\ type\ (\mathrm{P} \times EF_{enteric})$$

where,

P = animal population (head)

$EF_{enteric}$ = animal-specific emission factor for CH_4 from cattle, sheep, goats, swine and horses (kg CH_4 per head per year)

Population data for cattle and swine were obtained directly from the U.S. Department of Agriculture's (USDA) National Agriculture Statistics Service (NASS) (USDA 2017a and 2017b). Population data for sheep, goats, and horses were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999, 2004, 2009, and 2014), which is compiled every five years. Specifically, population data for 2007 were obtained directly from USDA (2009) while population estimates for 1990, 2010, and 2015 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012 data.

Yearly emission factors for all cattle types available for the state of Hawaii for all years were obtained from the U.S. Inventory (EPA 2017a).[26] Constant emission factors for sheep, goats, horses, and swine were also obtained from the U.S. Inventory (EPA 2017a).

Uncertainties and Areas for Improvement

Uncertainties associated with enteric fermentation estimates include the following:

- There is uncertainty associated with animal population data. Population data for sheep, goats, and horses are reported every five years in the USDA Census of Agriculture, with the latest data available in 2012. As a result, population data for these animals were interpolated between years and extrapolated to obtain estimates for 1990, 2010, and 2015. Further research into the accuracy of interpolated and extrapolated data may be considered in future analyses.
- Population data for other dairy heifers and other beef heifers are not available from USDA NASS and therefore are apportioned based on total other heifers and the ratio of dairy cows to beef cows (USDA 2017a). Due to different animal groupings in the U.S. Inventory and this inventory, emission factors for other dairy heifers are proxied to those for dairy replacement heifers. Similarly, because there are more animal sub-types (by class and weight) in the U.S. Inventory than in this inventory, for certain animal types, emission factors are either proxied or averages of emission factors of multiple animal types. Further research into aligning animal groupings with those used in the U.S. Inventory may be considered in future analyses.
- There is some uncertainty associated with the enteric fermentation emission factors. Specifically, there is uncertainty associated with the emission factor for beef cattle, as obtained from the U.S. Inventory (EPA 2017a), due to the difficulty in estimating the diet characteristics for grazing members of this animal group (EPA 2017a). In addition, the emission factors for non-cattle animal types, also obtained from the U.S. Inventory (EPA 2017a), are not specific to Hawaii. Updated and/or Hawaii-specific emission factors should be incorporated into future analyses if data becomes available.

5.2. Manure Management (IPCC Source Categories 3A2 and 3C6)

The main GHGs emitted by the treatment, storage, and transportation of livestock manure are CH_4 and N_2O. Methane is produced by the anaerobic decomposition of manure. Direct N_2O emissions are produced through the nitrification and denitrification of the organic nitrogen (N) in livestock dung and urine. Indirect N_2O emissions result from the volatilization of N in manure and the runoff and leaching of N from manure into water (EPA 2017a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. In 2015, emissions from manure management were 0.04 MMT CO_2 Eq., accounting for 4 percent of AFOLU sector emissions. Table 5-3 summarizes emissions from manure management in Hawaii for 1990, 2007, 2010, and 2015.

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[26] The U.S. Inventory includes annually variable emission factors for the following cattle types: dairy cows, beef cows, dairy replacement heifers, beef replacement heifers, other beef heifers, steers, and calves.

Table 5-3: Emissions from Manure Management by Gas (MMT CO2 Eq.)

Gas	1990	2007	2010	2015
CH_4	0.12	0.04	0.03	0.03
N_2O	0.03	0.01	0.01	0.01
Total	**0.15**	**0.05**	**0.04**	**0.04**

Note: Totals may not sum due to independent rounding.

Methodology

The IPCC (2006) Tier 2 method was employed to estimate emissions of both CH_4 and N_2O using the following equations:

$$CH_4\ Emissions = P \times TAM \times VS \times B_O \times wMCF \times 0.67$$

where,

P	= animal population (head)
TAM	= typical animal mass (kg per head per year)
VS	= volatile solids excretion per kilogram animal mass (kg VS/1000 kg animal mass/day)
B_O	= maximum methane producing capacity for animal waste (m^3 CH_4 / kg VS)
wMCF	= weighted methane conversion factor (%)
0.67	= conversion factor of m^3 CH_4 to kg CH_4

$$N_2O\ Emission = P \times \sum for\ each\ WMS\ [TAM \times Nex \times 365 \times (1 - V) \times WMS\ VS \times EF_{WMS} \times \frac{44}{28}]$$

where,

WMS	= waste management system
P	= animal population (head)
TAM	= typical animal mass (kg per head per year)
Nex	= nitrogen excretion rate (kg N/kg animal mass per day)
V	= volatilization percent (%)
WMS VS	= fraction volatile solids distribution by animal type and waste management system (%)
EF_{WMS}	= emission factor for waste management system (kg N_2O-N/kg N)
44/28	= conversion from N_2O-N to N_2O

Animal population data for cattle, swine, and chickens for all years were obtained directly from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c), with the exception of chicken population data for 2015, which was estimated by extrapolating data available for 1990 through 2010. Population data for sheep, goats, and horses were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999, 2004, 2009, and 2014), which is compiled every five years. Specifically, population data for 2007 were obtained directly from USDA (2009) while population estimates for 1990, 2010, and 2015 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012 data.

To develop CH_4 emissions from manure management, typical animal mass and maximum potential emissions by animal for all animal types were obtained from the U.S. Inventory (EPA 2017a). Weighted methane conversion factors (MCFs) for all cattle types, sheep, goats and horses were obtained from the U.S. Inventory (EPA 2017a), while swine and chicken MCFs were taken from the EPA's State Inventory Tool (EPA 2017e). Volatile solids (VS) excretion rates were obtained from the U.S. Inventory (EPA 2017a), with the exception of VS rates for horses, which were taken from EPA's State Inventory Tool (EPA 2017e).

To develop N_2O emissions from manure management, nitrogen excretion (Nex) rates for all cattle types were obtained from the U.S. Inventory (EPA 2017a), while non-cattle Nex rates were obtained from EPA's State Inventory Tool (EPA 2017e). The distributions of waste by animal in different waste management systems (WMS) were obtained from the U.S. Inventory (EPA 2017a). Weighted MCFs take into account the percent of manure for each animal type managed in different WMS. Emission factors for the different WMS were obtained from the *2006 IPCC Guidelines* (IPCC 2006).

Uncertainties and Areas for Improvement

Uncertainties associated with manure management estimates include the following:

- There is uncertainty associated with animal population data. Population data for sheep, goats, and horses are reported every five years in the USDA Census of Agriculture, with the latest data available in 2012. As a result, population data for these animals were interpolated between years and extrapolated to obtain estimates for 1990, 2010, and 2015. Similarly, chicken population data, which are only available through 2010, were extrapolated to obtain an estimate for 2015. Further research into the accuracy of interpolated and extrapolated data may be considered in future analyses.
- Population data for other dairy heifers and other beef heifers are not available from USDA NASS and therefore are apportioned based on total other heifers and the ratio of dairy cows to beef cows (USDA 2017a). Due to different animal groupings in the U.S. Inventory and this inventory, emission factors for other dairy heifers are proxied to those for dairy replacement heifers. Similarly, because there are more animal sub-types (by class and weight) in the U.S. Inventory than in this inventory, for certain animal types, emission factors are either proxied or averages of emission factors of multiple animal types. Further research into the availability of animal population data that are disaggregated by weight and into aligning animal groupings with the U.S. Inventory may be considered in future analyses.
- There is some uncertainty associated with the manure management emission factors. Specifically, the static emission factors for non-cattle animal types do not reflect potential changes in animal management practices that may influence emission factors. In addition, certain emission factors (i.e., Nex rates for calves and TAM) that were obtained from the U.S. Inventory are not specific to Hawaii. Finally, according to the U.S. Inventory, B_O data used to estimate emissions from manure management are dated (EPA 2017a). If updated data becomes

available, updated and/or Hawaii-specific emission factors should be incorporated into future analyses.

5.3. Agricultural Soil Management (IPCC Source Categories 3C4 and 3C5)

Nitrous oxide is produced naturally in soils through the nitrogen (N) cycle. Many agricultural activities, such as the application of N fertilizers, increase the availability of mineral N in soils that lead to direct N_2O emissions from nitrification and denitrification (EPA 2017a). This category includes N_2O emissions from synthetic fertilizer, organic fertilizer, manure N, as well as crop residue inputs from sugarcane, pineapples, sweet potatoes, ginger root, taro and corn for grain. In 2015, emissions from agricultural soil management were 0.14 MMT CO_2 Eq., accounting for 13 percent of AFOLU sector emissions. Table 5-4 summarizes emissions from agricultural soil management in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-4: Emissions from Agricultural Soil Management by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
N_2O	0.17	0.16	0.15	0.14

Methodology

The IPCC (2006) Tier 1 approach was used to calculate N_2O emissions from agricultural soil management. The overall equation for calculating emissions is as follows:

$$N_2O\ Emissions = Direct\ N_2O\ Emissions + Indirect\ N_2O\ Emissions$$

The following equations were used to calculate direct emissions:

$$Direct\ N_2O\ Emissions = [(N_F \times EF_F) + (N_O \times EF_F) + (N_{CR} \times EF_{CR}) + (N_{PRP1} \times EF_{PRP1}) + (N_{PRP2} \times EF_{PRP2})] \times \frac{44}{28}$$

where,

$$N_{CR} = AG_{DM} \times A \times (N_{AG} + R_{BGBIO} \times N_{BG})$$

$$AG_{DM} = Yield \times DRY \times slope + intercept$$

where,

N_F	= N inputs to agricultural soils from synthetic fertilizers
N_O	= N inputs to agricultural soils from organic fertilizers
N_{CR}	= N inputs to agricultural soils from crop residues
N_{PRP1}	= N inputs to agricultural soils from pasture, range, and paddock manure from cattle, swine, and poultry

N_{PRP2} = N inputs to agricultural soils from pasture, range, and paddock manure from sheep, goats, and horses
EF_F = emission factor for direct N_2O emissions from synthetic and organic fertilizers and crop residues (kg N_2O-N/kg N input)
EF_{CR} = emission factor for direct N_2O emissions from crop residues (kg N_2O-N/kg N input)
EF_{PRP1} = emission factor for direct N_2O emissions from pasture, range, and paddock manure from cattle, swine, and poultry (kg N_2O-N/kg N input)
EF_{PRP2} = emission factor for direct N_2O emissions from pasture, range, and paddock manure from sheep, goats, and horses (kg N_2O-N/kg N input)
AG_{DM} = above-ground residue dry matter (Mg/hectares)
A = crop area (hectares)
N_{AG} = N content of above-ground residue (kg N/dry matter)
N_{BG} = N content of below-ground residues (kg N/dry matter)
R_{BG-BIO} = Ratio of below-ground residues to harvested yield for crop
Yield = fresh weight yield (kg fresh weight harvested/hectares)
DRY = dry matter fraction of harvested product
Slope = default slope value for AG_{DM} for each crop type
Intercept = default intercept value for AG_{DM} for each crop type
44/28 = conversion from N_2O-N to N_2O

The following equations were used to calculate indirect emissions:

$$Indirect\ N_2O\ Emissions = Indirect\ Emissions\ from\ Volatilization + Indirect\ Emissions\ from\ Leaching/runoff$$

where,

$$Indirect\ Emissions\ from\ Volatilization = [(N_F \times L_{vol-F}) + (N_O \times L_{vol-O}) + (N_{PRP} \times L_{vol-O})] \times EF_{vol} \times \frac{44}{28}$$

$$Indirect\ Emissions\ from\ Leaching/Runoff = (N_F + N_O + N_{CR} + N_{PRP}) \times L_{leach} \times EF_{leach} \times \frac{44}{28}$$

where,

N_F = N inputs to agricultural soils from synthetic fertilizers
N_O = N inputs to agricultural soils from organic fertilizers
N_{CR} = N inputs to agricultural soils from crop residues
N_{PRP} = N inputs to agricultural soils from pasture, range, and paddock manure from all animals
L_{vol-F} = fraction N lost through volatilization from synthetic fertilizer inputs
L_{vol-O} = fraction N lost through volatilization from organic fertilizer and manure inputs
L_{leach} = fraction N lost through leaching/runoff from all N inputs

EF_{vol}	= emission factor for indirect N_2O emissions from N volatilization (kg N_2O-N / kg NH_3–N + NO_x–N volatilized)
EF_{leach}	= emission factor for N_2O emissions from pasture, range, and paddock manure from cattle, swine, and poultry (kg N_2O-N / kg N leached/runoff)
44/28	= conversion from N_2O-N to N_2O

Annual sugarcane area and production estimates used to estimate emissions from crop residue N additions were obtained directly from USDA NASS (USDA 2017d). For other crops (i.e., pineapples, sweet potatoes, ginger root, taro, and corn for grain), data were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999, 2004, 2009, and 2014), which is compiled every five years. Specifically, data for 2007 were obtained directly from USDA (2009) while production estimates for 1990, 2010, and 2015 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012. Pineapple crop production and crop acreage were not available for 2007 or 2012, so pineapple data for 2010 and 2015 were estimated by extrapolating data for 1997 and 2002 (USDA 2004). Sweet potato production was not available for 2012, so sweet potato production data for 2010 and 2015 were estimated based on sweet potato acreage for 2007 and 2012 (USDA 2014). Percent distribution of waste to various animal waste management systems, used to estimate manure N additions to pasture, range, and paddock soils, were obtained from the U.S. Inventory (EPA 2017a).

Synthetic and organic fertilizer N application data were obtained from the annual *Commercial Fertilizers* publication by the Association of American Plant Food Control Officials (AAPFCO 1995-2017, TVA 1991-1994). Synthetic fertilizer N application data were not available after 2014, so 2015 data were extrapolated based on 2014 data. According to these data sources, commercial organic fertilizer is not applied in Hawaii.

Crop residue factors for corn were obtained from the *2006 IPCC Guidelines* (IPCC 2006). Crop residue factors for tubers were used for sweet potatoes, ginger root, and taro. No residue factors nor adequate proxy factors were available for pineapples or sugarcane, so crop residue N inputs from these crops were not included. However, as nearly 100 percent of aboveground sugarcane residues are burned in Hawaii, there is little crop residue N input from sugarcane. All emission and other factors are IPCC (2006) defaults.

Animal population data are used to calculate the N inputs to agricultural soils from pasture, range, and paddock manure from all animals. Animal population data for cattle, swine, and chickens for all years were obtained directly from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c), with the exception of chicken population data for 2015, which was estimated by extrapolating data available for 1990 through 2010. Population data for sheep, goats, and horses were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999, 2004, 2009, and 2014), which is compiled every five years. Specifically, population data for 2007 were obtained directly from USDA (2009) while population estimates for 1990, 2010, and 2015 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012 data.

Uncertainties and Areas for Improvement

Uncertainties associated with agricultural soil management estimates include the following:

- There is uncertainty associated with animal population data. Population data for other dairy heifers and other beef heifers are not available from USDA NASS and therefore are apportioned based on total other heifers and the ratio of dairy cows to beef cows (USDA 2017a). Population data for sheep, goats, and horses are reported every five years in the USDA Census of Agriculture, with the latest data available in 2012. As a result, population data for these animals were interpolated between years and extrapolated through 2015. Similarly, chicken population data, which are only available through 2010, were extrapolated to obtain an estimate for 2015.
- There is also some uncertainty associated with crop area and crop production data. Crop area and production data from the USDA Census of Agriculture are not reported every year. As a result, data were interpolated between years. In particular, pineapple production and crop acreage data were not available in the 2007 Census of Agriculture or 2012 Census of Agriculture, so data through 2015 were extrapolated using 1997 and 2002 data.
- There is uncertainty associated with the extrapolation of synthetic fertilizer N application data to 2015 as well as the apportioning of fertilizer sales from the fertilizer year (i.e., July previous year to June current year) to the inventory calendar year (e.g., January to December). Further research into the accuracy of interpolated and extrapolated data as well as calendar year fertilizer consumption patterns may be considered in future analyses.
- Crop residue factors were obtained from sources published over 10 years ago and may not accurately reflect current practices. As factors are updated and/or better data become available, future analyses should update the factors accordingly.
- Emissions from seed production, including emissions from fertilizer consumption for seed production, are not fully captured in total emissions from agricultural soil management, because acres harvested for seed crops are reported in aggregate with other crop acreage data in USDA Census of Agriculture reports. It is also unclear whether seed producers report fertilizer consumption to AAPFCO. Conducting further research to identify seed production activity data may be considered to estimate emissions from seed production in future analyses.

5.4. Field Burning of Agricultural Residues (IPCC Source Category 3C1b)

Field burning is a method that farmers use to manage the vast amounts of agricultural crop residues that can be created during crop production. Crop residue burning is a net source of CH_4 and N_2O, which are released during combustion (EPA 2017a).[27] This source includes CH_4 and N_2O emissions from

[27] Carbon dioxide is also released during the combustion of crop residue. These emissions are not included in the inventory totals for field burning of agricultural residues because CO_2 from agricultural biomass is not considered a net source of emissions. This is because the carbon released to the atmosphere as CO_2 from the combustion of agricultural biomass is assumed to have been absorbed during the previous or a recent growing season (IPCC 2006).

sugarcane burning, which is the only major crop in Hawaii whose residues are regularly burned (Hudson 2008). In 2015, emissions from field burning of agricultural residues were 0.01 MMT CO_2 Eq., accounting for less than 1 percent of AFOLU sector emissions. Table 5-5 summarizes emissions from field burning of agricultural residues in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-5: Emissions from Field Burning of Agricultural Residues Emissions by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CH_4	0.03	0.01	+	+
N_2O	+	+	+	+
Total	**0.03**	**0.01**	**0.01**	**0.01**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

The IPCC/UNEP/OECD/IEA (1997) Tier 1 approach was used to calculate CH_4 and N_2O emissions from field burning of agricultural residues. The IPCC/UNEP/OECD/IEA (1997) method was used instead of the IPCC (2006) approach because it is more flexible for incorporating country-specific data and therefore is considered more appropriate for conditions in the United States (EPA 2017a). Emissions were calculated using the following equation:

$$CH_4\ and\ N_2O\ Emissions = Crop \times R_{RC} \times DMF \times Frac_{BURN} \times BE \times CE \times \\ C\ or\ N\ content\ of\ residue \times R_{emissions} \times F_{conversion}$$

where,

Crop	= crop production; annual weight of crop produced (kg)
R_{RC}	= residue-crop ratio; amount of residue produced per unit of crop production
DMF	= dry matter fraction; amount of dry matter per unit of biomass
$Frac_{BURN}$	= fraction of crop residue burned amount of residue which is burned per unit of total residue
BE	= burning efficiency; the proportion of pre-fire fuel biomass consumed
CE	= combustion efficiency; the proportion of C or N released with respect to the total amount of C or N available in the burned material
C or N content of residue	= amount of C or N per unit of dry matter
$R_{emissions}$	= emissions ratio; g CH_4-C/g C released or g N_2O-N/g N release (0.0055 and 0.0077, respectively)
$F_{conversion}$	= conversion factor; conversion of CH_4-C to C or N_2O-N to N (16/12 and 44/28, respectively)

Annual sugarcane area and production estimates were obtained directly from USDA NASS (USDA 2017d). The residue/crop ratio and burning efficiency were taken from Kinoshita (1988). Dry matter fraction, fraction of C and N, and combustion efficiency were taken from Turn et al. (1997). Fraction of residue burned was taken from Ashman (2008).

Uncertainties and Areas for Improvement

This analysis assumes that sugarcane is the only major crop in Hawaii whose residues are regularly burned (Hudson 2008); therefore, emissions from the field burning of crop residues for other major crops is assumed to be zero. If information on the field burning of crop residues from other crops becomes available, this information should be incorporated into future inventory analyses.

Crop residue factors were obtained from sources published over 10 years ago and may not accurately reflect current practices. As factors are updated and/or better data become available, future analyses should update the factors accordingly.

5.5. Urea Application (IPCC Source Category 3C3)

Urea ($CO(NH_2)_2$) is a nitrogen fertilizer that is often applied to agricultural soils. When urea is added to soils, bicarbonate forms and evolves into CO_2 and water (IPCC 2006). In 2015, emissions from urea application were 0.002 MMT CO_2 Eq., accounting for less than 1 percent of AFOLU sector emissions. Table 5-6 summarizes emissions from urea application in Hawaii for 1990, 2007, 2010, and 2015.

Table 5-6: Emissions from Urea Application by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	+	+	+	+

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

The IPCC (2006) Tier 1 methodology was used to estimate emissions from urea application. Emissions were calculated using the following equation:

$$CO_2\ Emissions = M \times EF_{urea} \times \frac{44}{12}$$

where:

M = annual amount of urea fertilization, metric tons
EF_{urea} = emission factor, metric tons C/ton urea
44/12 = conversion of carbon to CO_2

Fertilizer sales data were obtained from the annual *Commercial Fertilizers* publication by the Association of American Plant Food Control Officials (AAPFCO 1995-2017, TVA 1991-1994). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[28] Historical usage patterns were used to apportion these sales to the inventory calendar years (January through December). Urea fertilizer application data were not available after 2014, so 2015 data were estimated based on 2014 data.

The *2006 IPCC Guidelines* default emission factor was used to estimate the carbon emissions, in the form of CO_2, that result from urea application.

Uncertainties and Areas for Improvement

There is uncertainty associated with the extrapolation of urea fertilizer application data to 2015 as well as the apportioning of fertilizer sales from the fertilizer year (i.e., July previous year to June current year) to the inventory calendar year (e.g., January to December). Further research into the accuracy of extrapolated data as well as calendar year fertilizer consumption patterns may be considered in future analyses. Additionally, if more recent urea fertilizer application data become available, it should be incorporated into future inventory analyses.

5.6. Agricultural Soil Carbon (IPCC Source Categories 3B2, 3B3)

Agricultural soil carbon refers to the change in carbon stock in agricultural soils—either in cropland or grasslands—that have been converted from other land uses. Agricultural soils can be categorized into organic soils, which contain more than 12 to 20 percent organic carbon by weight, and mineral soils, which typically contain 1 to 6 percent organic carbon by weight (EPA 2017a). Organic soils that are actively farmed tend to be sources of carbon emissions as soil carbon is lost to the atmosphere due to drainage and management activities. Mineral soils can be sources of carbon emissions after conversion, but fertilization, flooding, and management practices can result in the soil being either a net source or net sink of carbon. Nationwide, sequestration of carbon by agricultural soils is largely due to enrollment in the Conservation Reserve Program, conservation tillage practices, increased hay production, and intensified crop production. In 2015, emissions from agricultural soils were 0.56 MMT CO_2 Eq., accounting for 51 percent of AFOLU sector emissions. Table 5-7 summarizes emissions from agricultural soils in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-7: Emissions from Agricultural Soil Carbon by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	0.57	0.48	0.53	0.56

+ Does not exceed 0.005 MMT CO_2 Eq.

[28] Fertilizer sales are reported by fertilizer year, corresponding to the growing season. The 2010 fertilizer year, for example, runs from July 2009 to June 2010.

Methodology

Emission estimates from Hawaii's agricultural soils were taken directly from the U.S. Inventory (EPA 2017a).[29] These estimates were developed by EPA using a Tier 2 IPCC methodology. This Tier 2 methodology incorporates country-specific carbon storage factors and activity data from the USDA National Resources Inventory, among other sources (EPA 2017a).

Uncertainties and Areas for Improvement

Efforts to initialize agricultural greenhouse gas accounting tools, specifically the DAYCENT biogeochemical simulation model and COMET-Farm tool, for Hawaii are currently being explored.[30] The DAYCENT model is used in the U.S. Inventory to estimate emissions from agricultural soils in the lower 48 states using a Tier 3 IPCC methodology. The DAYCENT model simulates daily changes in soil carbon based on land-use transitions, management practices, soil characteristics, crop characteristics, and weather. Key processes simulated by DAYCENT include:

- plant growth;
- organic matter formation and decomposition;
- soil water and temperature regimes by layer;
- nitrification and denitrification processes; and
- methanogenesis (biological formation of methane) (EPA 2017a).

Future improvements may include using the DAYCENT model and COMET-Farm tool to estimate changes in agricultural soil carbon for Hawaii.

5.7. Forest Fires (IPCC Source Category 3C1a)

Forest and shrubland fires (herein referred to as forest fires) emit CO_2, CH_4, and N_2O as biomass is combusted. This source includes emissions from forest fires caused by lightning, campfire, smoking, debris burning, arson, equipment, railroads, children, and other miscellaneous activities reported by the Hawaii Department of Land and Natural Resources (DLNR). In 2015, emissions from forest fires were 0.11 MMT CO_2 Eq., accounting for 10 percent of AFOLU sector emissions. Table 5-8 summarizes emissions from forest fires in Hawaii for 1990, 2007, 2010 and 2015.

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[29] State-level estimates from the U.S. Inventory do not include emissions from federal agricultural land, land enrolled in the Conservation Reserve Program after 2012, or the application of sewage sludge to soils, which were only estimated at the national scale (EPA 2017a).
[30] More information on the DAYCENT model and COMET-Farm tool can be found at: https://www2.nrel.colostate.edu/projects/daycent/ and http://cometfarm.nrel.colostate.edu/.

Table 5-8: Emissions from Forest Fires by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	0.34	0.51	0.17	0.10
CH_4	0.03	0.04	0.01	0.01
N_2O	0.02	0.03	0.01	+
Total	**0.38**	**0.57**	**0.19**	**0.11**

+ Does not exceed 0.005 MMT CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Methodology

The IPCC (2006) Tier 1 methodology was used to calculate GHG emissions from forest fires according to the following equation:

$$Emissions = \mathrm{A} \times M_B \times C_f \times \mathrm{G}_{ef} \times 10^{-3}$$

where,

A = forest/shrubland area burnt, hectares (ha)
M_B = mass of fuel available for combustion, tonnes/ha
C_f = combustion factor, dimensionless, 0.36 (forestland) and 0.72 (shrubland)
G_{ef} = emission factor, g/kg dry matter burnt
10^{-3} = conversion of kg to tonnes

Forest/shrubland area burned was derived by multiplying wildland area burned by a ratio of forestland area to wildland area. Wildland area burned for years 1994, 2007, 2010, and 2015 was obtained from the DLNR *Annual Wildfire Summary Report,* published by the Fire Management Program of the DLNR (and also found in DBEDT's Hawaii Data Book) (DLNR 1994-2008, 2011, 2016). 1994 data were used as a proxy for 1990.

The ratio of total forestland area to wildland area was developed based on data from the National Association of State Foresters, DLNR, and the State of Hawaii Data Book (DBEDT 2017b). The estimate of wildland area was obtained, in million acres, for years 1998 and 2002 from the National Association of State Foresters (1998, 2002) and 2010 and 2015 from the DLNR (2011, 2016). 1998 data were used as a proxy for 1990 and 2002 data were used as a proxy for 2007.

Managed forestland area data were obtained from the State of Hawaii Data Book (DBEDT 2017b). Area estimates of private forestland in the conservation district were summed with reserve forestland in the conservation district, forested natural areas, and wooded farmland in order to generate total managed forested land area in Hawaii for 1990, 2007, 2010 and 2015. Unmanaged forests are not included in this analysis per IPCC guidelines because the majority of anthropogenic GHG emissions occurs on managed land (IPCC 2006).

The annual carbon density for the lower 48 states (i.e., the fuel available for combustion) was provided by the U.S. Forest Service (USFS 2014).[31] The annual carbon density for the lower 48 states was not available after 2013, so carbon density in 2013 was used as a proxy for 2015.

Since Hawaii's forest is comprised of both forest and shrubland, IPCC (2006) default combustion factors for tropical forest and shrubland were weighted using a ratio of Hawaii forest to shrubland area. The ratio of Hawaii forest to shrubland area was developed based on land cover data from the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA-CCAP) Descriptive Summary of the Changes in the Main Eight Hawaiian Islands (2000) and an assessment of Hawaii land cover in 2014 from the United States Geological Survey (USGS) (Selmants et al. 2017).

According to NOAA-CCAP, roughly half of Hawaii's forestland in 2000 was shrub/scrubland, defined as land with vegetation less than 20 feet tall (NOAA-CCAP 2000). In 2014, the share of shrubland in Hawaii forests decreased to approximately 32 percent according to USGS (Selmants et al. 2017). 2000 data on the ratio of forest to shrubland area were used as a proxy for 1990, and 2014 data were used as a proxy for 2015. For 2007 and 2010, the ratio of forest to shrubland area was interpolated using forest and shrubland area in 2000 (NOAA-CCAP) and 2014 (Selmants et al. 2017). Emission factors for CH_4 and N_2O emissions were obtained from IPCC (2006).

Uncertainties and Areas for Improvement

Uncertainties associated with forest fire estimates include the following:

- Wildfire acres burned data and the area of wildland under protection were not available for all inventory years. As a result, estimates for these data were proxied based on the available data. There is significant annual variability in wildfire acres burned data, so 1994 data may not accurately represent wildfire acres burned in 1990. Further investigation into alternative sources for historical wildfire acres burned may be considered in future analyses.
- The ratio of forest and shrubland area is also a source of uncertainty for all inventory years because the ratios are estimated based on land cover data for years 2000 and 2014. Additional land cover data should be incorporated into future analyses if it becomes available.
- The estimate of carbon density in forests and shrubland and their assumed combustion efficiencies are not specific to Hawaii. Further research into the carbon density and combustion efficiencies in Hawaii may be considered in future analyses to further tailor these emission factors for the state of Hawaii.
- In addition to wildfires, prescribed fires are also a source of GHG emissions. Prescribed fires are intentional, controlled burning of forests to prevent wildfires and the spread of invasive forest species. Prescribed fires typically emit less GHG emissions per acre burned compared to wildfires. Emissions from prescribed fires are not included in this analysis due to a lack of data;

[31] Extensive research was conducted to find a Hawaii-specific factor for carbon density. Due to a lack of such a factor, annual carbon density for the lower 48 states was used, as provided by the USFS (2014).

therefore, emission estimates in this analysis may be conservative. Further investigation into data on annual prescribed acres burned in Hawaii may be considered in future analyses.

5.8. Landfilled Yard Trimmings and Food Scraps (IPCC Source Category 3B5a)

Yard trimmings (i.e., grass clippings, leaves, and branches) and food scraps continue to store carbon for long periods of time after they have been discarded in landfills. In 2015, landfilled yard trimmings sequestered 0.05 MMT CO_2 Eq., accounting for 1 percent of carbon sinks. Table 5-9 summarizes changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-9: CO_2 Flux from Landfilled Yard Trimmings (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	(0.12)	(0.05)	(0.05)	(0.05)

Note: Parentheses indicate negative values or sequestration.

Methodology

Estimates of the carbon sequestration in landfilled yard trimmings and food scraps for Hawaii were generated by the EPA's State Inventory Tool (EPA 2017f). The State Inventory Tool calculates carbon stock change from landfilled yard trimmings and food scraps based on IPCC (2003) and IPCC (2006) Tier 2 methodologies using the following equation:

$$LFC_{i,t} = \sum W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e^{-k \times (t-n)}]\}$$

where:

t	= the year for which carbon stocks are being estimated
$LFC_{i,t}$	= the stock of carbon in landfills in year t, for waste i (grass, leaves, branches, and food scraps)
$W_{i,n}$	= the mass of waste i disposed in landfills in year n, in units of wet weight
n	= the year in which the waste was disposed, where 1960 < n < t
MC_i	= moisture content of waste i
CS_i	= the proportion of carbon that is stored permanently in waste i
ICC_i	= the initial carbon content of waste i
e	= the natural logarithm
k	= the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition

The State Inventory Tool uses data on the generation of food scraps and yard trimmings for the entire United States. Additionally, it uses data on the amounts of organic waste composted, incinerated, and landfilled each year to develop an estimate of the yard trimmings and food scraps added to landfills each year nationwide. State and national population data is then used to scale landfilled yard trimmings and food scraps down to the state level. These annual additions of carbon to landfills and an estimated decomposition rate for each year are then used, along with carbon conversion factors, to calculate the carbon pool in landfills for each year.

Default values from the State Inventory Tool (EPA 2017f) for the composition of yard trimmings (i.e., amount of grass, leaves, and branches that are landfilled), food scraps, and their carbon content were used to calculate carbon inputs into landfills. Waste generation data for each year, also obtained from the State Inventory Tool (EPA 2017f), were used to calculate the national-level estimates. Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2017b).

Uncertainties and Areas for Improvement

The methodology used to estimate carbon sequestration in landfilled yard trimmings and food scraps is based on the assumption that the portion of yard trimmings or food scraps in landfilled waste in Hawaii is consistent with national estimates. The methodology does not consider Hawaii-specific trends in composting yard trimmings and food scraps. For example, the City and County of Honolulu prohibits commercial and government entities from disposing yard trimmings in landfills (City & County of Honolulu's Department of Environmental Services 2005).

In addition, there are uncertainties associated with scaling U.S. sequestration to Hawaii based on population only. Sequestration in landfilled yard trimmings and food scraps may vary by climate and composition of yard trimmings (e.g., branches, grass) for a particular region in addition to waste generation, which is assumed to increase with population. Further research into Hawaii trends in diverting yard trimmings and food scraps from landfills may be considered in future analyses.

5.9. Urban Trees (IPCC Source Category 3B5a)

Trees in urban areas (i.e., urban forests) sequester carbon from the atmosphere. Urban areas in Hawaii represented approximately 5 percent of Hawaii's total area in 1990 and 6 percent of Hawaii's total area in 2010 (U.S. Census Bureau 1990a and 2012; DBEDT 2017b). In 2015, urban trees sequestered 0.40 MMT CO_2 Eq., accounting for 11 percent of carbon sinks. Table 5-10 summarizes carbon flux from urban trees in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-10: CO_2 Flux from Urban Trees (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	(0.28)	(0.37)	(0.38)	(0.40)

Notes: Parentheses indicate negative values or sequestration.

Methodology

Carbon flux from urban trees was calculated using a methodology consistent with the U.S. Inventory (EPA 2017a) and the IPCC (2006) default Gain-Loss methodology. Carbon flux estimates from urban trees were calculated using the following equation.

$$CO_2\ Flux = A \times T_{Percent} \times S_c \times \frac{44}{12}$$

where:

A	= total urban area (including clusters), km^2
$T_{percent}$	= percent of urban area covered by trees, dimensionless
S_c	= C sequestration rates of urban trees, metric tons C/km^2
44/12	= conversion of carbon to CO_2

The City and County of Honolulu's *Municipal Forest Resource Analysis* (Vargas et al. 2007) provides data on Honolulu's carbon sequestration rates for urban trees. Using this Honolulu-specific data, a rate of annual carbon sequestration per square kilometer of tree canopy (MT C/km^2 tree cover) was calculated.

Census-defined urbanized area and cluster values were used to calculate urbanized area in Hawaii.[32] State-level urban area estimates were adapted from the U.S. Census (1990) to be consistent with the definition of urban area and clusters provided in the 2000 U.S. Census (Nowak et al. 2005). Urban area and cluster data for 2000 and 2010 were provided directly from the U.S. Census (2002, 2012). A linear trend was fitted to the 2000 and 2010 data to establish a time series from 2000 to 2007. A linear trend was applied to the 2010 data to establish a time series from 2010 to 2015.

Nowak and Greenfield (2012) developed a study to determine percent tree cover by state. According to Nowak (2012), 39.9 percent of urban areas in Hawaii were covered by trees circa 2005. With an estimate of total urban tree cover for Hawaii, the Hawaii-specific sequestration factor (MT C/km^2 tree cover) was applied to this area to calculate total C sequestration by urban trees (MT C/year).

Uncertainties and Areas for Improvement

The estimated sequestration rates in urban trees are based only on trees in Honolulu. Honolulu County accounted for 56 percent of Hawaii's urban area in 2010 (U.S. Census 2012). While Honolulu County has the largest share of urban area, its sequestration rates may not align with urban trees in other counties. Further research into urban tree sequestration rates by county or island may be considered in future analyses.

[32] Definitions for urbanized area changed between 2000 and 2010. According to the U.S. Inventory, "In 2000, the U.S. Census replaced the 'urban places' category with a new category of urban land called an 'urban cluster,' which included areas with more than 500 people per square mile. In 2010, the Census updated its definitions to have 'urban areas' encompassing Census tract delineated cities with 50,000 or more people, and 'urban clusters' containing Census tract delineated locations with between 2,500 and 50,000 people" (EPA 2017a).

In addition, the percent of urban tree coverage in Hawaii is a static estimate based on 2005 data and does not consider changes in the percent tree cover, which may have been impacted by urban planning initiatives since 2005. Further research into alternative sources for annual percent of urban tree cover in Hawaii, urban planning initiatives that involve tree cover, and trends in urbanization may be considered in future analyses.

5.10. Forest Carbon (IPCC Source Category 3B1a)

Hawaii forests and shrubland contain carbon stored in various carbon pools, which are defined as reservoirs with the capacity to accumulate or release carbon (IPCC 2006). This category includes estimates of carbon sequestered in forests and shrubland aboveground biomass, which is defined as living vegetation above the soil, and belowground biomass, which is defined as all biomass below the roots (IPCC 2006). This analysis only considers managed forests and shrubland per IPCC (2006) guidelines because the majority of anthropogenic GHG emissions and sinks occur on managed land.[33] In 2015, forests and shrubland sequestered 3.08 MMT CO_2 Eq., accounting for 87 percent of carbon sinks. Table 5-11 summarizes carbon flux from forests and shrubland in Hawaii for 1990, 2007, 2010 and 2015.

Table 5-11: CO_2 Flux from Forest Carbon (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CO_2	(2.66)	(2.87)	(3.01)	(3.08)

Note: Parentheses indicate negative values or sequestration.

Methodology

The Tier 1 Gain Loss Method as outlined by the *2006 IPCC Guidelines* (IPCC 2006) was used to calculate carbon flux in managed Hawaii forests. Unmanaged forests are not included in this analysis per IPCC guidelines. This method requires forestland acreage data as well as aboveground biomass growth rate, the ratio of below ground biomass to aboveground biomass, and the carbon fraction. The Gain Loss method calculates annual increase in biomass carbon stocks using the following equation:

$$Forest\ CO_2\ Flux = \sum_i \left(A_i \times G_{TOTAL_i} \times CF_i\right) \times \frac{44}{12}$$

where,

A	= forest land area, hectares
G_{TOTAL_i}	= mean annual biomass growth, tonnes of dry matter/hectare
CF_i	= carbon fraction of dry matter, tonnes C/tonne of dry matter
44/12	= conversion of carbon to CO_2

[33] Managed forests, under IPCC (2006) guidelines, are deemed to be a human-influenced GHG sink and, accordingly, are included here. This encompasses any forest that is under any sort of human intervention, alteration, maintenance, or legal protection. Unmanaged forests are not under human influence and thus out of the purview of this inventory.

i = forest type (forest or shrubland in Hawaii)

Managed forestland acreage data were obtained from the State of Hawaii Data Book (DBEDT 2017b). Area estimates of private forestland in the conservation district were summed with reserve forestland in the conservation district, forested natural areas and wooded farmland in order to generate total managed forested land area in Hawaii for 1990, 2007, 2010 and 2015.

Forestland was divided into two sub-categories: forest and shrub/scrubland using the island-specific forestland to shrubland ratios derived from the NOAA-CCAP land cover study in 2000 and the USGS assessment of land cover in 2014 (NOAA-CCAP 2000; Selmants et al. 2017).

According to NOAA-CCAP, roughly half of Hawaii's forestland in 2000 was shrub/scrubland, defined as land with vegetation less than 20 feet tall (NOAA-CCAP 2000). In 2014, the share of shrubland in Hawaii forests decreased to approximately 32 percent according to USGS (Selmants et al. 2017). 2000 data on the ratio of forest to shrubland area were used as a proxy for 1990, and 2014 data were used as a proxy for 2015. For 2007 and 2010, the ratio of forest to shrubland area was interpolated using forest and shrubland area in 2000 (NOAA-CCAP) and 2014 (Selmants et al. 2017).

Mean biomass growth by forest type is derived by multiplying the average annual above-ground biomass growth by the sum of one and the ratio of below ground biomass to above ground biomass. This biomass growth was then multiplied by a carbon fraction factor to determine the net addition of carbon. In obtaining the mean annual biomass growth and carbon fraction factors, the tropical Asia Insular IPCC (2006) default values were used as default factors for forest and shrubland.[34]

Uncertainties and Areas for Improvement

The methodology used to estimate carbon flux from forests and shrubland in Hawaii assumes constant Tier 1 default factors for aboveground and belowground biomass growth rates and carbon fractions for all inventory years. The factors are based on tropical Asia insular land and may not be specific to Hawaii. Alternative sources of biomass growth rates and carbon stored in other carbon pools, such as the U.S. Forest Inventory Analysis program, will be considered in future analyses.

The ratio of forest and shrubland area is also a source of uncertainty for all inventory years because the ratios are estimated based on land cover data for years 2000 and 2014. Additional land cover data should be incorporated into future analyses if it becomes available.

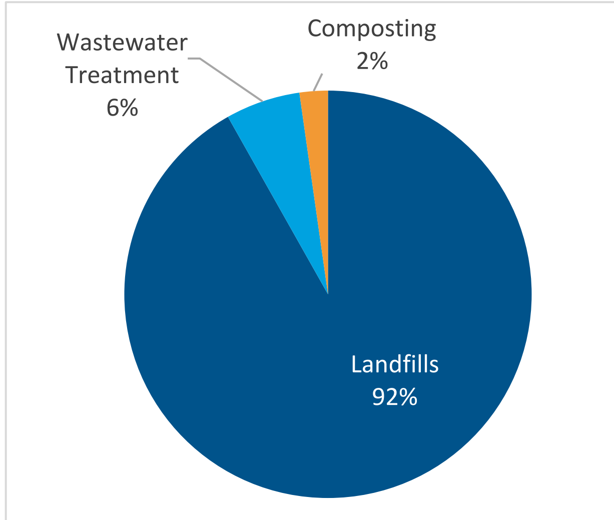
Finally, this methodology does not consider potential changes in sequestration rates due to the age of the forest ecosystem and forest management practices. Further research into the age of Hawaii forests, improved forest management practices, and their emissions reduction potential may be considered in future analyses.

[34] Extensive research was conducted to find Hawaii-specific carbon factors, during the course of which many Hawaii forest experts were contacted (Cole, Giardina, Litton, Bennet, Friday, and Ostertag 2008). However, the results of this research indicated that the IPCC defaults for tropical Asia insular land would be best suited for Hawaii.

6. Waste

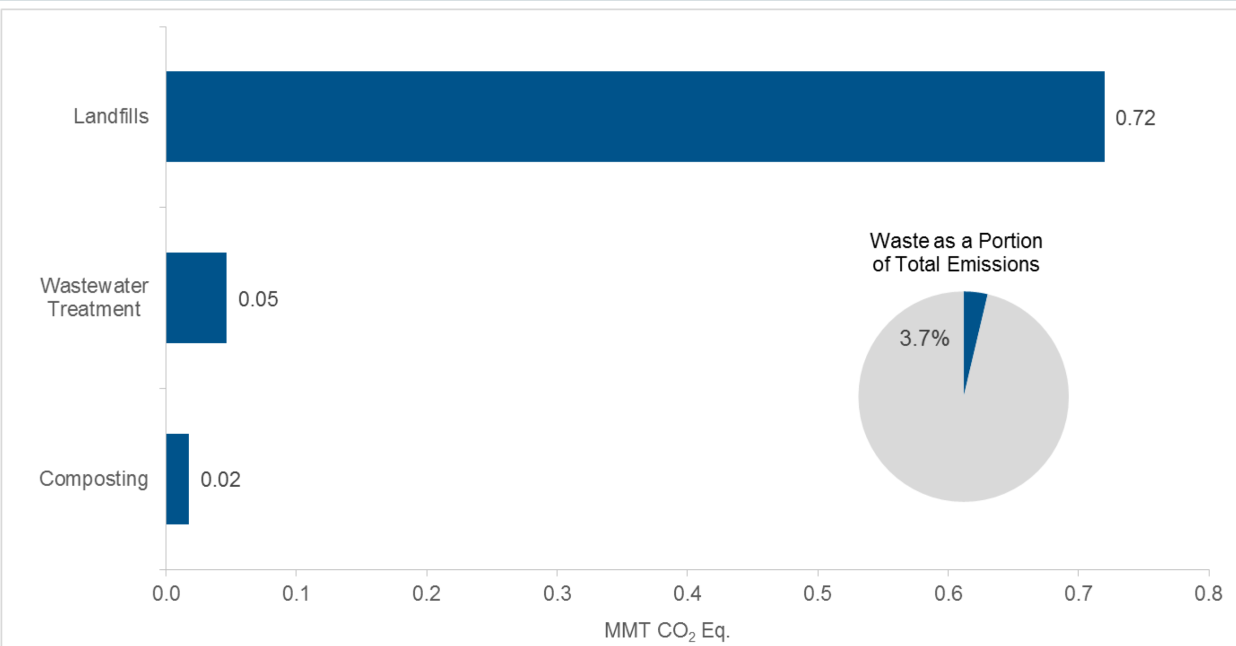
This chapter presents GHG emissions from waste management and treatment activities. For the state of the Hawaii, waste sector emissions are estimated from the following sources: Landfills (IPCC Source Category 4A1), Composting (IPCC Source Category 4B), and Wastewater Treatment (IPCC Source Category 4D).[35]

Figure 6-1: 2015 Waste Emissions by Source



In 2015, emissions from the Waste sector were 0.78 MMT CO_2 Eq., accounting for 4 percent of total Hawaii emissions. Emissions from landfills accounted for the largest share of Waste sector emissions (92 percent), followed by emissions from wastewater treatment (6 percent) and composting (2 percent). Figure 6-1 and Figure 6-2 show emissions from the Waste sector by source for 2015.

Figure 6-2: 2015 Waste Emissions by Source (MMT CO_2 Eq.)



Note: Totals may not sum due to independent rounding.

[35] In Hawaii, incineration of MSW occurs at waste-to-energy facilities and thus emissions from incineration of waste (IPCC Source Category 4C) are accounted for in the Energy sector.

Relative to 1990, emissions from the Waste sector in 2015 were higher by 4 percent, down from 39 percent above 1990 levels in 2007. This trend is driven by emissions from landfills, which accounted for the largest share of emissions from the Waste sector in all inventory years. These emissions decreased between 2007 and 2015 as a result of an increase in the volume of landfill gas recovered for flaring. Figure 6-3 below shows Waste sector emissions by source category for each inventory year. Emissions by source and year are also summarized in Table 6-1.

Figure 6-3: Waste Emissions by Source and Year

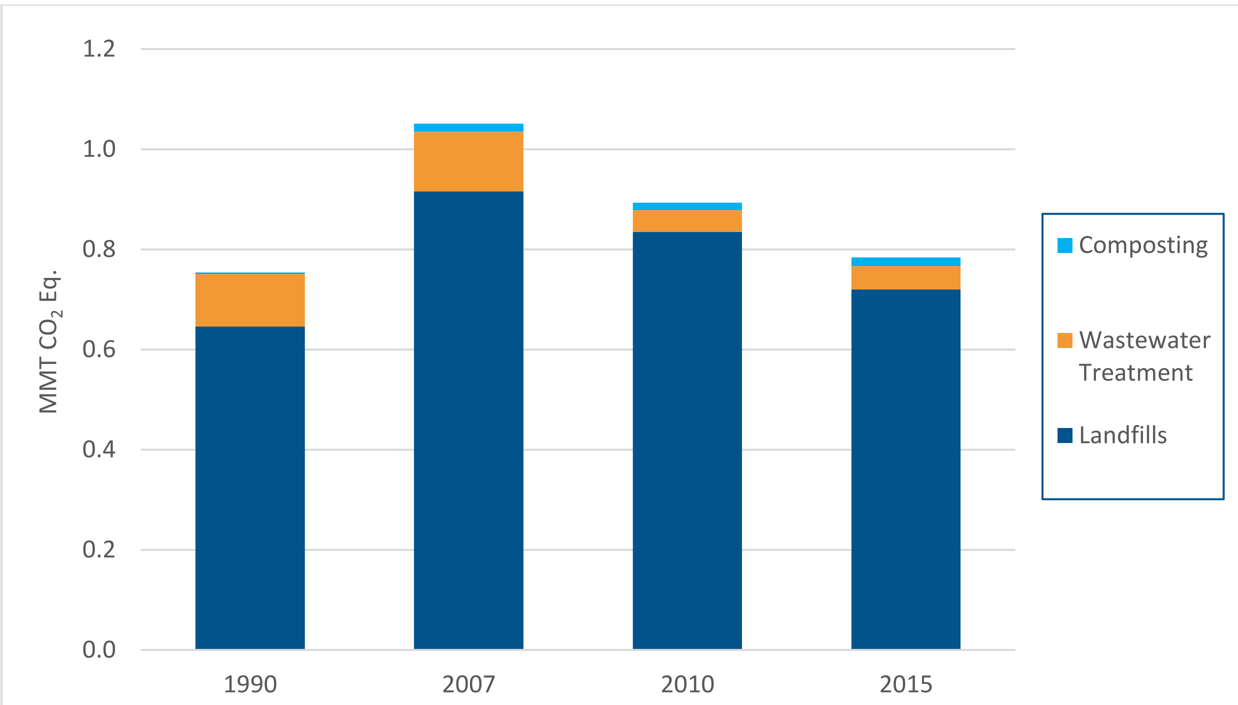


Table 6-1: GHG Emissions from the Waste Sector by Source (MMT CO_2 Eq.)

Source	1990	2007	2010	2015
Landfills	0.65	0.92	0.84	0.72
Composting	+	0.02	0.01	0.02
Wastewater Treatment	0.10	0.12	0.04	0.05
Total	**0.75**	**1.05**	**0.89**	**0.78**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

The remainder of this chapter describes the detailed emission results by source category, including a description of the methodology and data sources used to prepare the inventory, and key uncertainties and areas for improvement. Activity data and emission factors used in the analysis are summarized in Appendix D and Appendix E, respectively.

6.1. Landfills (IPCC Source Category 4A1)

When placed in landfills, organic material in municipal solid waste (MSW) (e.g., paper, food scraps, and wood products) is decomposed by both aerobic and anaerobic bacteria. As a result of these processes, landfills generate biogas consisting of approximately 50 percent biogenic CO_2 and 50 percent CH_4, by volume (EPA 2017a). Consistent with IPCC (2006), biogenic CO_2 from landfills is not reported under the Waste sector. In 2015, CH_4 emissions from landfills in Hawaii were 0.72 MMT CO_2 Eq., accounting for 92 percent of Waste sector emissions. Relative to 1990, emissions from landfills in 2015 were higher by roughly 11 percent, down from 42 percent above 1990 levels in 2007. This trend is attributed to an increase in the volume of landfill gas recovered for flaring in Hawaii between 2007 and 2015. Table 6-2 summarizes CH_4 emissions from landfills in Hawaii for 1990, 2007, 2010, and 2015.

Table 6-2: Emissions from Landfills by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CH_4	0.65	0.92	0.84	0.72

Methodology

Consistent with the methodology used for the U.S. Inventory (EPA 2017a), potential MSW landfill emissions were calculated using a Tier 1 first order decay (FOD) model, which looks at the waste landfilled over the past thirty years. Data on the tons of waste landfilled per year in Hawaii for 1995 through 2015 were provided by the Hawaii Department of Health (DOH), Solid Waste Branch (Hawaii DOH 2017a and 2008a). Historical MSW generation and disposal volumes from 1960 through 1994 were calculated using default waste generation and disposal data for the state of Hawaii from EPA's State Inventory Tool – Municipal Solid Waste Module (EPA 2017c). Potential CH_4 emissions were then calculated using the following equation:

$$Q_{T,x} = A\ x\ k\ x\ R_x\ x\ L_o\ x\ e^{-k(T-y)}$$

where,

$Q_{T,x}$ = amount of CH_4 generated in year T by the waste R_x
T = current year
y = year of waste input
A = normalization factor, $(1-e^{-k})/k$
k = CH_4 generation rate (yr^{-1})
R_x = amount of waste landfilled in year x
L_o = CH_4 generation potential

Using the FOD model, the emissions vary not only by the amount of waste present in the landfill, but also by the CH_4 generation rate (k). Other factors included in the FOD model are the current year (T), the year of waste input (y), normalization factor (A), and the CH_4 generation potential (L_o). The normalization factor, CH_4 generation rate, and CH_4 generation potential were obtained from EPA's State Inventory Tool – Municipal Solid Waste Module (EPA 2017c). The CH_4 generation rate varies according to several factors pertaining to the climate in which the landfill is located. For this analysis, a simplified value for non-arid states of 0.02 was used (i.e., states for which the average annual rainfall is greater than 25 inches).

After calculating the potential CH_4 emissions for each inventory year, the calculations account for the oxidation rate at landfills and subtract any methane recovered for energy or flaring that year, yielding the net CH_4 emissions from landfills, as shown by the equation below:

$$Landfill\ methane\ emissions = Q_{CH4}\ x\ (1 - OR) - Flared - Recovered$$

where,

Q_{CH4}	= potential CH_4 emissions for a given inventory year
OR	= methane oxidation rate
Flared	= amount of methane flared in the inventory year
Recovered	= amount of methane recovered for energy in the inventory year

For 2010 and 2015, volumes of landfill gas recovered for flaring and energy were obtained from EPA's GHGRP (EPA 2017b). For 1990 and 2007, landfill records, including new and historical landfills, landfill operation and gas collection system status, landfill gas flow rates, and landfill design capacity were provided by Lane Otsu of the Hawaii DOH, Clean Air Branch (Otsu 2008), State of Hawaii Data Book (DBEDT 2017b), and Steve Serikaku of the Honolulu County Refuse Division (Serikaku 2008). This information was used to quantify the amount of methane flared and recovered for energy in 1990 and 2007. The oxidation rate for all inventory years was obtained from EPA's State Inventory Tool – Municipal Solid Waste Module (EPA 2017c).

Uncertainties and Areas for Improvement

Due to limitations in data availability, there is some uncertainty associated with historical landfill gas management practices and disposal volumes. Data for landfill disposal was only provided for years 1995 through 2015. Estimates for tons landfilled for 1990 through 1994 were developed using default waste generation and disposal data for the state of Hawaii from EPA's State Inventory Tool – Municipal Solid Waste Module (EPA 2017c). Additionally, limited data are available on volumes of landfill gas recovered for flaring and energy for years prior to 2010. Landfill gas flaring and recovery was included in the emissions estimates only for those landfills that reported data for 1990 and 2007. Finally, data on the composition of landfilled waste are not currently available, resulting in the use of default assumptions on the methane generation rate from EPA's State Inventory Tools – Municipal Solid Waste Module. If additional data on historical waste disposal, historical landfill gas management practices, and the composition of landfilled waste becomes available, this information should be incorporated into future inventory analyses.

6.2. Composting (IPCC Source Category 4B)

Composting involves the aerobic decomposition of organic waste materials, wherein large portions of the degradable organic carbon in the waste materials is converted into CO_2. The remaining solid portion is often recycled as a fertilizer and soil amendment or disposed in a landfill. During the composting process, trace amounts of CH_4 and N_2O can form, depending on how the compost pile is managed (EPA 2017a). In 2015, emissions from composting in Hawaii were 0.01 MMT CO_2 Eq., accounting for 1 percent of Waste sector emissions. There are no known large-scale composting operations currently in place in Hawaii; as such, it is assumed that these emissions result from composting that is performed primarily in backyards for household yard trimmings and food scraps, and in agricultural operations. Emissions from composting in 2015 were more than four times greater than emissions from composting in 1990, which is attributed largely to the growth in population. However, emissions are still relatively small. Table 6-3 summarizes emissions from composting in Hawaii for 1990, 2007, 2010, and 2015.

Table 6-3: Emissions from Composting by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CH_4	+	0.01	0.01	0.01
N_2O	+	0.01	0.01	0.01
Total	**+**	**0.02**	**0.01**	**0.02**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Methane and N_2O emissions from composting were calculated using the IPCC default (Tier 1) methodology, summarized in the equations below (IPCC 2006).

$$CH_4\ Emissions = (M\ x\ EF) - R$$

where,

M = mass of organic waste composted in inventory year
EF = emission factor for composting
R = total amount of CH_4 recovered in inventory year

$$N_2O\ Emissions = M\ x\ EF$$

where,

M = mass of organic waste composted in inventory year
EF = emission factor for composting

Tons of waste composted per year were calculated based on the U.S. national average per capita composting rate for each inventory year in the U.S. Inventory (EPA 2017a). MSW composting volumes for Hawaii were calculated using population data from the State of Hawaii Data Book (DBEDT 2017b). The emission factors for composting were obtained from IPCC (2006). No CH_4 recovery is assumed to occur at composting operations in Hawaii.

Uncertainties and Areas for Improvement

Due to a lack of available Hawaii-specific information, emissions from composting were calculated using the U.S. national average per capita composting rate, which may not reflect the actual composting rate in Hawaii. Hawaii-specific data on composting volumes, if it becomes available, should be incorporated into future inventory analyses.

6.3. Wastewater Treatment (IPCC Source Category 4D)

Wastewater produced from domestic, commercial, and industrial sources is treated either on-site (e.g., in septic systems) or in central treatment systems to remove solids, pathogenic organisms, and chemical contaminants (EPA 2017a). During the wastewater treatment process, CH_4 is generated when microorganisms biodegrade soluble organic material in wastewater under anaerobic conditions. The generation of N_2O occurs during both the nitrification and denitrification of the nitrogen present in wastewater. Over 20 centralized wastewater treatment plants operate in Hawaii in, serving most of the state's population. The remaining wastewater is treated at on-site wastewater systems. In 2015, emissions from wastewater treatment in Hawaii were 0.04 MMT CO_2 Eq., accounting for 6 percent of Waste sector emissions. Relative to 1990, emissions from wastewater treatment in 2015 were lower by 56 percent, down from 14 percent higher than 1990 levels in 2007. Table 6-4 summarizes emissions from wastewater treatment in Hawaii for 1990, 2007, 2010 and 2015.

Table 6-4: Emissions from Wastewater Treatment by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015
CH_4	0.07	0.08	+	+
N_2O	0.04	0.04	0.04	0.05
Total	**0.10**	**0.12**	**0.04**	**0.05**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Wastewater treatment emissions were calculated using a methodology consistent with the methodology used for the U.S. Inventory (EPA 2017a) and EPA's State Inventory Tools – Wastewater Module (EPA 2017g). Wastewater emissions from municipal wastewater treatment, septic tank treatment, and wastewater biosolids were quantified using data on population, septic tank use, biochemical oxygen demand (BOD) production and flow rate at wastewater treatment plans, and biosolids fertilizer use practices.

To calculate CH_4 emissions from municipal wastewater treatment, the total annual 5-day biochemical oxygen demand (BOD_5) production in metric tons was multiplied by the fraction that is treated anaerobically and by the CH_4 produced per metric ton of BOD_5:

$$CH_4\ Emissions = \ BOD_5\ x\ EF\ x\ AD$$

where,

BOD_5	= total annual 5-day biochemical oxygen demand production
EF	= emission factor for municipal wastewater treatment
AD	= Percentage of wastewater BOD_5 treated through anaerobic digestion

Municipal wastewater treatment direct N_2O emissions were calculated by determining total population served by wastewater treatment plants (adjusted for the share of the population on septic) and multiplying by an N_2O emission factor per person per year:

$$Direct\ N_2O\ Emissions = Septic\ x\ EF$$

where,

Septic	= percentage of the population by region not using septic wastewater treatment
EF	= emission factor for municipal wastewater treatment

Municipal wastewater N_2O emissions from biosolids were calculated using the equation below:

$$Biosolids\ N_2O\ Emissions = \left((P\ x\ N_P\ x\ F_N) - N_{Direct}\right) x\ (1 - Biosolids)\ x\ EF$$

where,

P	= total annual protein consumption
N_P	= nitrogen content of protein
F_N	= fraction of nitrogen not consumed
N_{Direct}	= direct N_2O emissions
Biosolids	= percentage of biosolids used as fertilizer
EF	= emission factor for municipal waste treatment

Sewage sludge is often applied to agricultural fields as fertilizer; emissions from this use are accounted for under the AFOLU sector. Therefore, the wastewater calculations exclude the share of sewage sludge applied to agricultural soils so that emissions are not double-counted. For all inventory years, it was assumed that no biosolids were used as fertilizer.

Data on non-National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants, including flow rate and BOD_5, were provided by Hawaii DOH, Wastewater Branch (Pruder 2008 and Hawaii DOH 2017b). Where sufficient data from non-NPDES was available, it was used to characterize BOD_5 for a given island and inventory year. When sufficient data were not available, the Hawaii default BOD_5 value from the 1997 inventory was used (DBEDT and DOH 1997). Population data from the State of Hawaii Data Book (DBEDT 2017b) and U.S. Census Bureau data (1990b, 2007) were used to calculate wastewater treatment volumes and the share of households on septic systems. For 2010 and 2015, data on the number of households on septic systems were unavailable. Therefore, assumptions from 2007 on the share of households using septic systems were applied to 2010 and 2015. Emission factors were obtained from EPA's State Inventory Tools – Wastewater Module (EPA 2017g).

Uncertainties and Areas for Improvement

For all inventory years, it was assumed that biogas generated at wastewater treatment plants in Hawaii was not captured and converted to renewable natural gas. In December 2018, Hawaii Gas opened its first renewable natural gas facility at the Honouliuli Wastewater Treatment Plant. The facility captures biogas at the plant and converts it to renewable natural gas (Hawaii Free Press 2018). Future inventories will account for the volume of CH_4 emissions from wastewater treatment that is captured and combusted for energy.

Data on all non-NPDES wastewater treatment plants was not available for all inventory years, requiring the Hawaii default BOD_5 value from the 1997 inventory to be used for some or all islands across all inventory years (DBEDT and DOH 1997). Due to the lack of Hawaii-specific data, default emission factors from EPA's State Inventory Tools – Wastewater Module were used to calculate emissions. This includes the share of wastewater solids anaerobically digested and the percentage of biosolids used as fertilizer. In addition, data on the share of household septic systems were unavailable for 2010 and 2015. More recent and Hawaii-specific data should be incorporated into future inventory analyses, if it becomes available from the Hawaii DOH, individual wastewater treatment plants in Hawaii, and/or the U.S. Census Bureau.

7. Emission Projections

This section presents projections for statewide GHG emissions and sinks for 2020 and 2025. The detailed methodology used to develop these projections and a discussion of uncertainties by source and sink category is provided in Appendix H.

Methodology Overview

Greenhouse gas emissions are a result of economic activities occurring within Hawaii. They are a reflection of the overall level of economic activities, the types of energy and technologies used, and land use decisions. Estimating future GHG emissions, therefore, relies heavily on projections of economic activities as well as an understanding of policies and programs that impact the intensity of GHG emissions associated with economic activities.

For this analysis, a combination of top-down and bottom-up approaches were used to develop projections of GHG emissions in the year 2020 and 2025. For some sources (i.e., residential energy use, commercial energy use, industrial energy use, domestic aviation, incineration of waste, oil and natural gas systems, IPPU, and waste treatment), the University of Hawaii Economic Research Organization (UHERO) Macroeconomic Forecast was used to project GHG emissions, using the 2015 statewide GHG inventory as a starting point. For other smaller emission sources and sinks (i.e., AFOLU categories), emissions were projected by forecasting activity data using historic trends and published information available on future trends, and applying the same methodology used to estimate 2015 emissions.

UHERO Macroeconomic Forecast

The UHERO Macroeconomic Forecast provides a projection of the changing economic and business environment in the state using statistical methods and empirical data, accounting for the influence of external economies. The UHERO Forecast Project produces quarterly reports, where the year's fourth quarter report provides a review of statewide economic conditions in Hawaii and globally, and a detailed forecast for the state economy. This analysis utilizes the UHERO forecast model presented in the 2017 summary report (UHERO 2017) and adopts the long-range projection for growth in real gross state product (GSP) to the year 2020, as well as an assumption of continuing growth patterns to 2025. Using 2015 as a starting point, the UHERO forecast estimates 7 percent cumulative growth from 2015 to 2020, and 14 percent cumulative growth from 2015 to 2025.

For large GHG emitting sources for which there has been substantial federal and state policy intervention (i.e., energy industries and transportation), the team used a bottom-up approach to project GHG emissions. Due to policy that affects these sources, growth in economic activities alone is only one component of future GHG emissions. Therefore, the team used a more comprehensive sectoral approach for these sources.

Uncertainty of Emission Projections

As with all projections of emissions into the future, uncertainty exists. For this analysis, key areas of uncertainty include the following:

- **Macroeconomy:** There are several highly used sources for macroeconomic forecasting within Hawaii; UHERO's forecast is among them. The other frequently cited forecast comes from the Department of Business, Economic Development and Tourism (DBEDT). Future iterations of this work will assess DBEDT's (2018b) macroeconomic forecast as a point of comparison.[36]
- **Fuel Prices and Fuel Mix:** An important component of any regional economy is the role of fuel prices (Coffman et al. 2007). Major shifts in fossil fuel and renewable energy prices, which are difficult to accurately predict, will impact consumer use of different fuels and resulting GHG emissions. In addition, there is some uncertainty in how changes in relative fuel prices will impact the mix of fuel types used to generate electricity (e.g., the large-scale introduction of natural gas).
- **Policy:** The State of Hawaii has adopted an aggressive Renewable Portfolio Standard (RPS) that mandates electric utilities to reach 30 percent of net electricity sales through renewable sources by the end of 2020, 40 percent by 2030, 70 percent by 2040, and 100 percent by 2045 (DSIRE 2018a). The state has also adopted an Energy Efficiency Portfolio Standard (EEPS) that mandates 4,300 gigawatt-hours of electricity use reduction by 2030 (DSIRE 2018b). In 2017, Hawaii's four county mayors committed to a shared goal of reaching 100 percent "renewable ground transportation" by 2045 (City & County of Honolulu 2018). Because it is not yet clear the set of policy instruments that will be implemented to attain this goal, there is considerable uncertainty in the emissions trajectory within the ground transportation sector. In addition, the impacts of other recently adopted policies such as Act 15, which focuses on increasing GHG sequestration in Hawaii's agricultural and natural environment, and Act 16, which establishes a framework for a carbon offset program—both adopted in 2018—were not directly considered in this analysis.
- **Inventory Estimates:** The projections were developed using the 2015 inventory as a starting point. In cases where 2016 and 2017 data were available, this data was used as a point of comparison for the purposes of determining a trend. Uncertainties related to quality and availability of data used to develop the 2015 inventory estimates similarly apply to the emission projections.

This analysis presents a "baseline" forecast incorporating the best available data that represent current policy. In forthcoming updates to this analysis, the team will develop additional scenarios to help quantitatively identify how uncertainty plays a role in the GHG projections presented in this report. Specifically, additional scenarios that represent alternative policy implementation pathways, as well as fuel prices, will be developed to better assess these sensitivities and for the purposes of comparison.

7.1. Projections Summary

Total GHG emissions are projected to be 20.90 MMT CO_2 Eq. in 2020 and 18.46 MMT CO_2 Eq. in 2025. Net emissions, which take into account carbon sinks, are projected to be 17.34 MMT CO_2 Eq. in 2020 and

[36] DBEDT's macroeconomic forecast extends to the year 2021. DBEDT's long-range forecast out to 2040, which was published in 2012, may also be used for comparison purposes.

14.86 MMT CO_2 Eq. in 2025. Table 7-1 summarizes emission projections of statewide emissions and sinks by sector for 2020 and 2025.

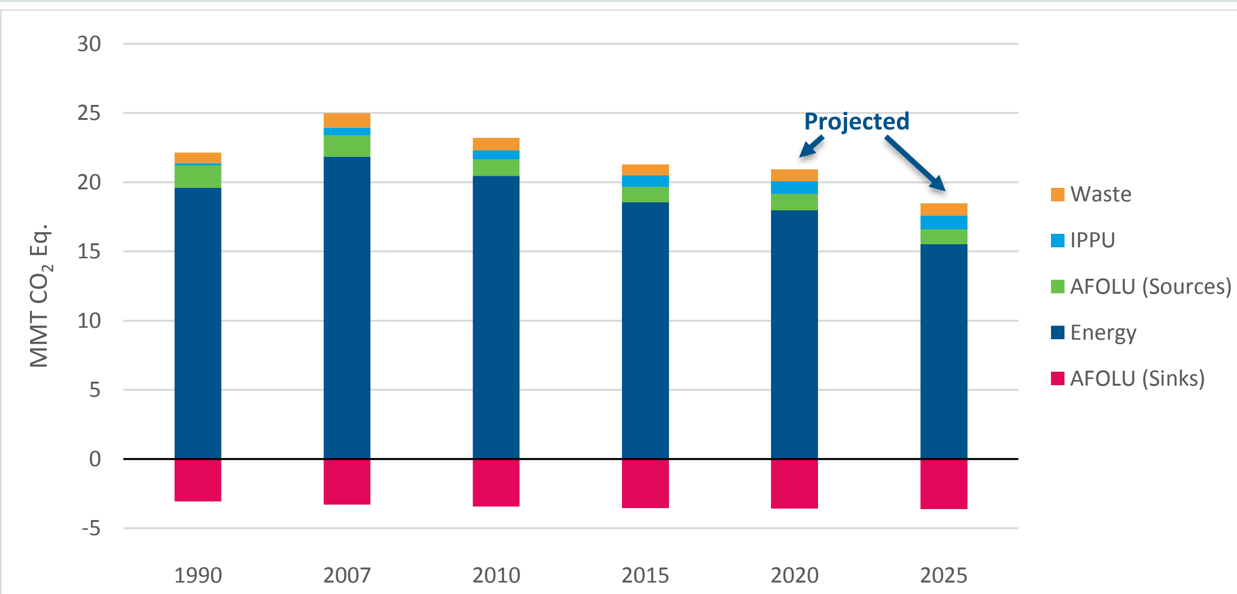
Table 7-1: Hawaii GHG Emission Projections by Sector, 2020 and 2025 (MMT CO_2 Eq.)

Sector	2020	2025
Energy[a]	18.00	15.51
IPPU	0.89	0.95
AFOLU (Sources)	1.18	1.11
AFOLU (Sinks)	(3.57)	(3.60)
Waste	0.84	0.90
Total Emissions (Excluding Sinks)	**20.90**	**18.46**
Net Emissions (Including Sinks)	**17.34**	**14.86**
Domestic Aviation[b]	3.46	3.67
Net Emissions (Including Sinks, Excluding Aviation)[b]	**13.88**	**11.19**

[a] Emissions from International Bunker Fuels are not included in totals, as per IPCC (2006) guidelines.
[b] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emission reduction goal established in Act 234.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Relative to 2015, total emissions are projected to decrease by 2 percent by 2020 and 13 percent by 2025. Over the same period, net emissions are projected to decrease by 2 percent and 16 percent, respectively. This decrease is largely due to a decrease in emissions from energy industries (i.e., electric power plants and petroleum refineries). Figure 7-1 show emissions and sinks for 1990 through 2025 for inventory years by sector.

Figure 7-1: Hawaii GHG Emissions Inventory Estimates and Projections (Including Sinks)



7.2. Energy

Emissions from the Energy sector are projected to be 18.00 MMT CO_2 Eq. in 2020 and 15.51 MMT CO_2 Eq. in 2025, accounting for 86 percent and 84 percent of total projected statewide emissions, respectively. Projected emissions by source for 2020 and 2025 are summarized in Table 7-2.

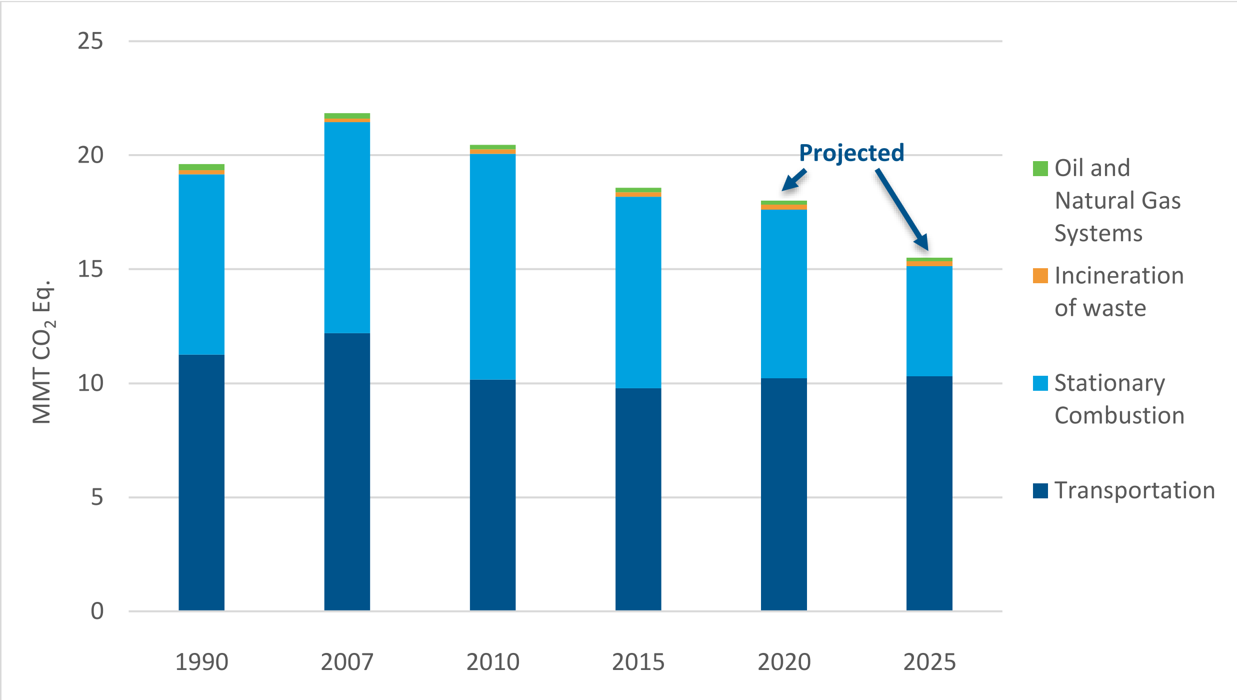
Table 7-2: GHG Emission Projections from the Energy Sector by Source (MMT CO_2 Eq.)

Source[a]	2020	2025
Stationary Combustion	**7.41**	**4.82**
Energy Industries[b]	*5.99*	*3.31*
Residential	*0.08*	*0.09*
Commercial	*0.90*	*0.96*
Industrial	*0.43*	*0.46*
Transportation	**10.22**	**10.32**
Ground	*5.84*	*5.73*
Domestic Marine[c]	*0.39*	*0.39*
Domestic Aviation	*3.46*	*3.67*
Military[d]	*0.53*	*0.53*
Incineration of Waste	**0.20**	**0.22**
Oil and Natural Gas Systems[e]	**0.17**	**0.15**
Total	**18.00**	**15.51**

[a] Emissions from International Bunker Fuels and CO_2 emissions from Wood Biomass and Biofuel Consumption are not projected because they are not included in the inventory total, as per IPCC (2006) guidelines.
[b] Includes fuel combustion emissions from electric power plants and petroleum refineries.
[c] Due to inconsistencies in historical data, future emissions from domestic marine fuel consumption are highly uncertain; these emissions are assumed to remain constant relative to 2015 emission estimates.
[d] Because decisions about military operations are generally external to Hawaii's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2015 emission estimates.
[e] Includes fugitive emissions and emissions from venting and flaring at refineries.
Notes: Totals may not sum due to independent rounding.

Relative to 2015, emissions from the Energy sector are projected to decrease by 2020 and decrease further by 2025. This trend is largely driven by a projected decrease in emissions from energy industries, which is dominated by fuel combustion emissions from electric power plants. The projected emissions reflect planned pathways for the electric sector that meet RPS and EEPS goals (see Appendix H). The emissions from other sources are projected to remain relatively flat. Figure 7-2 shows historical and projected emissions from the Energy sector by source category for inventory years.

Figure 7-2: GHG Emissions and Projections from the Energy Sector



7.3. IPPU

Emissions from the IPPU sector are projected to be 0.89 MMT CO_2 Eq. in 2020 and 0.95 MMT CO_2 Eq. in 2025, accounting for 4 percent and 5 percent of total projected statewide emissions, respectively. Projected emissions by source for 2020 and 2025 are summarized in Table 7-3.

Table 7-3: GHG Emission Projections from the IPPU Sector by Source (MMT CO_2 Eq.)

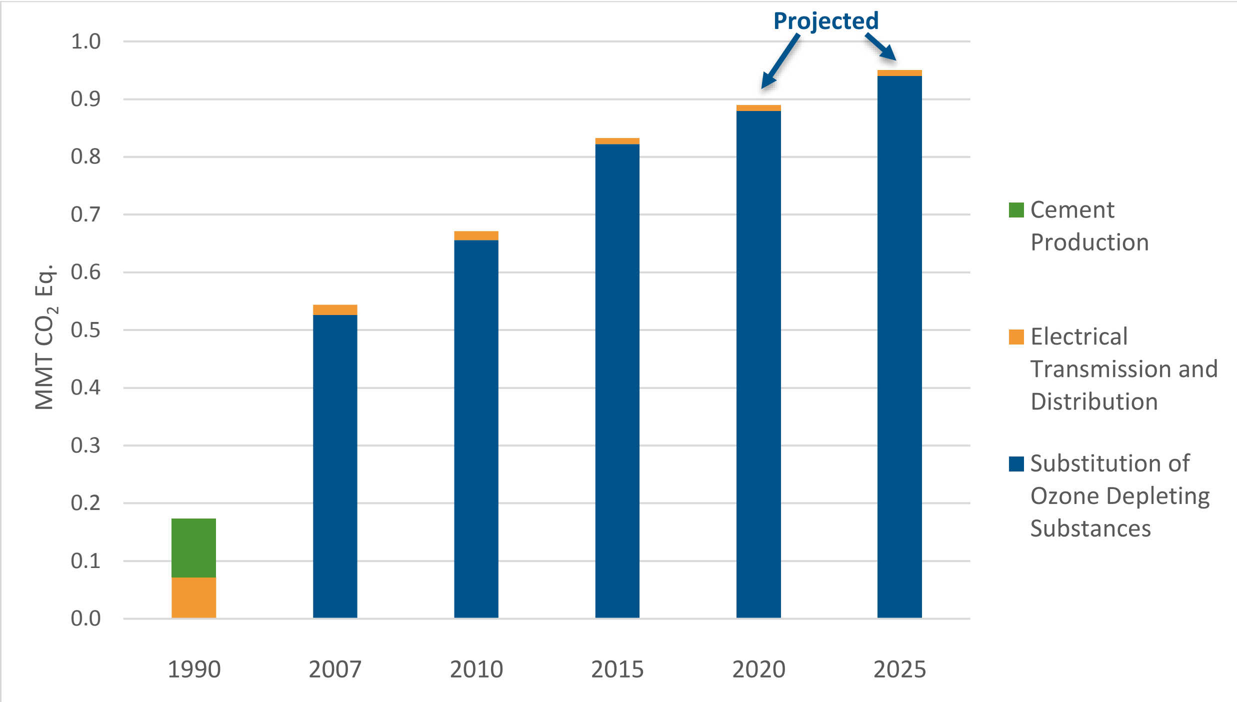
Source	2020	2025
Cement Production	NO	NO
Electrical Transmission and Distribution	0.01	0.01
Substitution of Ozone Depleting Substances	0.88	0.94
Total	**0.89**	**0.95**

NO (emissions are Not Occurring).

Note: Totals may not sum due to independent rounding.

Emissions from the substitution of ozone depleting substances are projected to continue to represent the majority of emissions from the IPPU sector through 2025. Relative to 2015, electrical transmission and distribution emissions in 2020 and 2025 are projected to decline slightly, while emissions from the substitution of ozone depleting substances are projected to increase. Emissions from cement production, which were zero in 2015, are projected to remain at zero in 2020 and 2025. Figure 7-3 shows historical and projected emissions from the IPPU sector by source category for select years.

Figure 7-3: GHG Emissions and Projections from the IPPU Sector



Note: 2020 and 2025 represent emissions projections.

7.4. AFOLU

Total emissions (excluding sinks) from the AFOLU sector are projected to be 1.18 MMT CO_2 Eq. in 2020 and 1.11 MMT CO_2 Eq. in 2025, accounting for 6 percent of total Hawaii emissions in both 2020 and 2025. Carbon sinks are projected to be 3.57 MMT CO_2 Eq. in 2020 and 3.60 MMT CO_2 Eq. in 2025. Overall, the AFOLU sector is projected to result in a net increase in carbon sinks (i.e., net CO_2 removals) of 2.39 MMT CO_2 Eq. in 2020 and 2.49 MMT CO_2 Eq. in 2025. Projected emissions by source and sink category for 2020 and 2025 are summarized in Table 7-4.

Table 7-4: GHG Emission Projections from the AFOLU Sector by Source and Sink (MMT CO_2 Eq.)

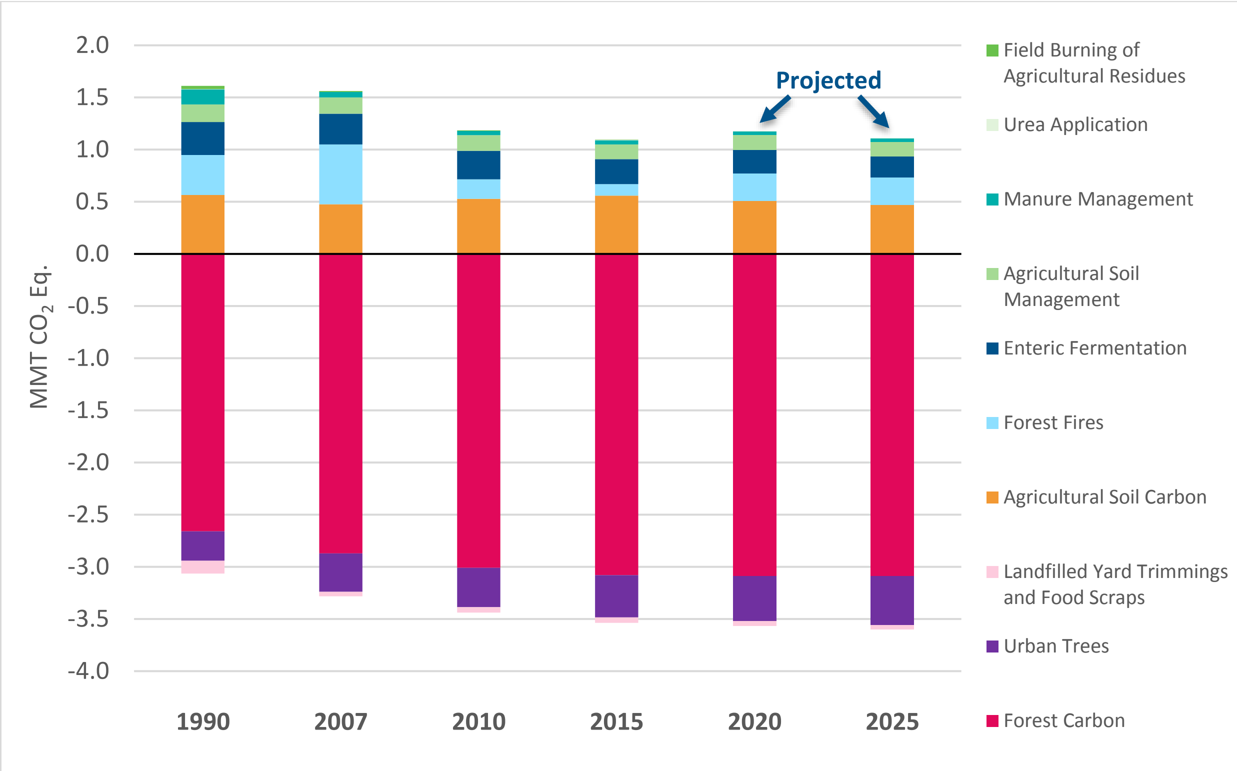
Category	2020	2025
Agriculture	**0.41**	**0.38**
Enteric Fermentation	0.23	0.21
Manure Management	0.04	0.03
Agricultural Soil Management	0.14	0.14
Field Burning of Agricultural Residues	NO	NO
Urea Application	+	+
Land Use, Land-Use Change, and Forestry	**(2.80)**	**(2.87)**
Agricultural Soil Carbon	0.51	0.47
Forest Fires	0.26	0.26
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.04)
Urban Trees	(0.43)	(0.47)
Forest Carbon	(3.09)	(3.09)
Total (Sources)	**1.18**	**1.11**
Total (Sinks)	**(3.57)**	**(3.60)**
Net Emissions	**(2.39)**	**(2.49)**

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).
Note: Totals may not sum due to independent rounding.

Forest carbon and urban trees are projected to sequester more carbon (i.e., become a larger sink) over the projected time series due to expected increases in forest and urban areas, while landfilled yard trimmings and food scraps are projected to sequester less carbon (i.e., become a smaller sink) over time consistent with the historical trend. Emissions from enteric fermentation, manure management, field burning of agricultural residues, and agricultural soil carbon are similarly projected to decrease based largely on the assumption that historical trends will continue, while emissions from forest fires are projected to increase due to projected increases in dry forest area burned. Emissions from agricultural soil management and urea application are projected to remain relatively flat in 2020 and 2025.

Overall, in 2020 and 2025, AFOLU sink categories are projected to sequester more carbon, and emissions from AFOLU sources are projected to decrease. These trends are driven largely by projected increases in forest area and the assumption that historical trends will continue. Further research into the accuracy and drivers of historical trends may be considered in future analyses. In addition, the recently adopted Act 15, which was not directly considered in this analysis, may impact future trends. Figure 7-4 shows historical and projected emissions from the AFOLU sector by source and sink category for select years.

Figure 7-4: GHG Emissions and Projections from the AFOLU Sector



7.5. Waste

Emissions from the Waste sector are projected to be 0.84 MMT CO_2 Eq. in 2020 and 0.90 MMT CO_2 Eq. in 2025, accounting for 4 percent and 5 percent of total projected statewide emissions, respectively. Projected emissions by source for 2020 and 2025 are summarized in Table 7-5.

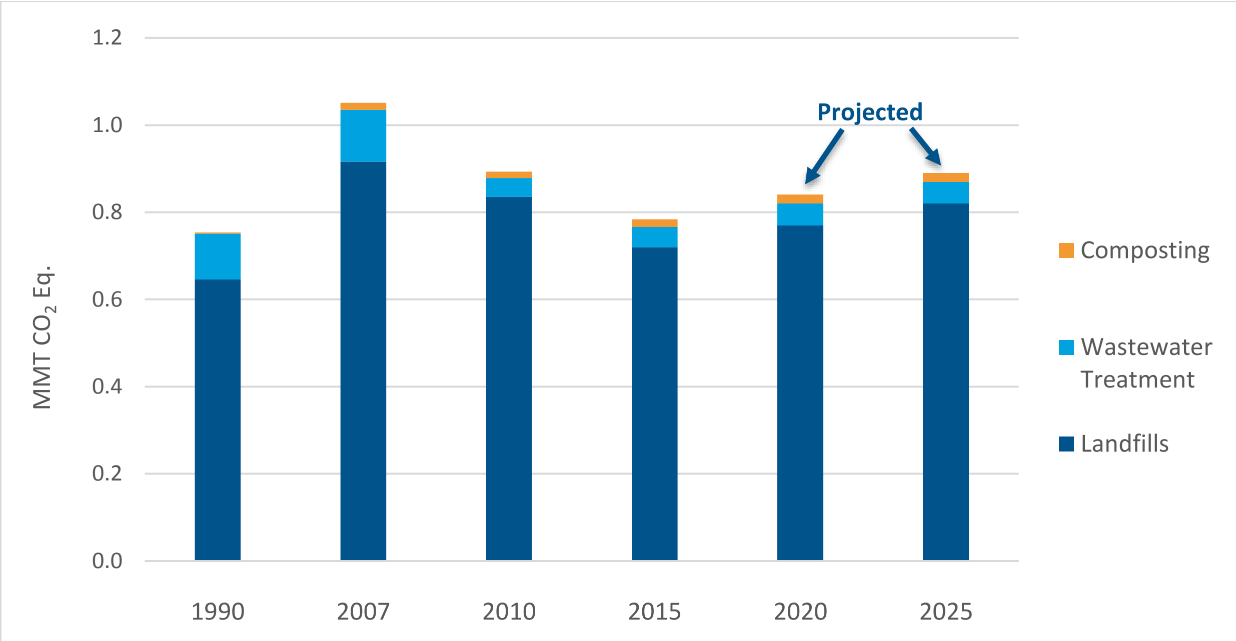
Table 7-5: GHG Emission Projections from the Waste Sector by Source (MMT CO_2 Eq.)

Source	2020	2025
Landfills	0.77	0.82
Composting	0.02	0.02
Wastewater Treatment	0.05	0.05
Total	**0.84**	**0.90**

Note: Totals may not sum due to independent rounding.

Relative to 2015, emissions from landfills, composting, and wastewater treatment are projected to increase in 2020 and 2025. Figure 7-5 shows historical and projected emissions from the waste sector by source category for select years.

Figure 7-5: GHG Emissions and Projections from the Waste Sector



8. GHG Reduction Goal Progress

Act 234, Session Laws of Hawaii 2007, establishes as state policy statewide GHG emission limits at or below the statewide GHG emissions levels in 1990 to be achieved by January 1, 2020. While domestic aviation emissions are included in the inventory totals for the state of Hawaii, **Act 234 specifies that emissions from airplanes (i.e., domestic aviation) shall not be included in Hawaii's GHG target.[37]** In 1990, domestic aviation emissions accounted for 4.66 MMT CO_2 Eq. or 21 percent of total emissions. In 2015, domestic aviation emissions accounted for 3.23 MMT CO_2 Eq. or 15 percent of total emissions.

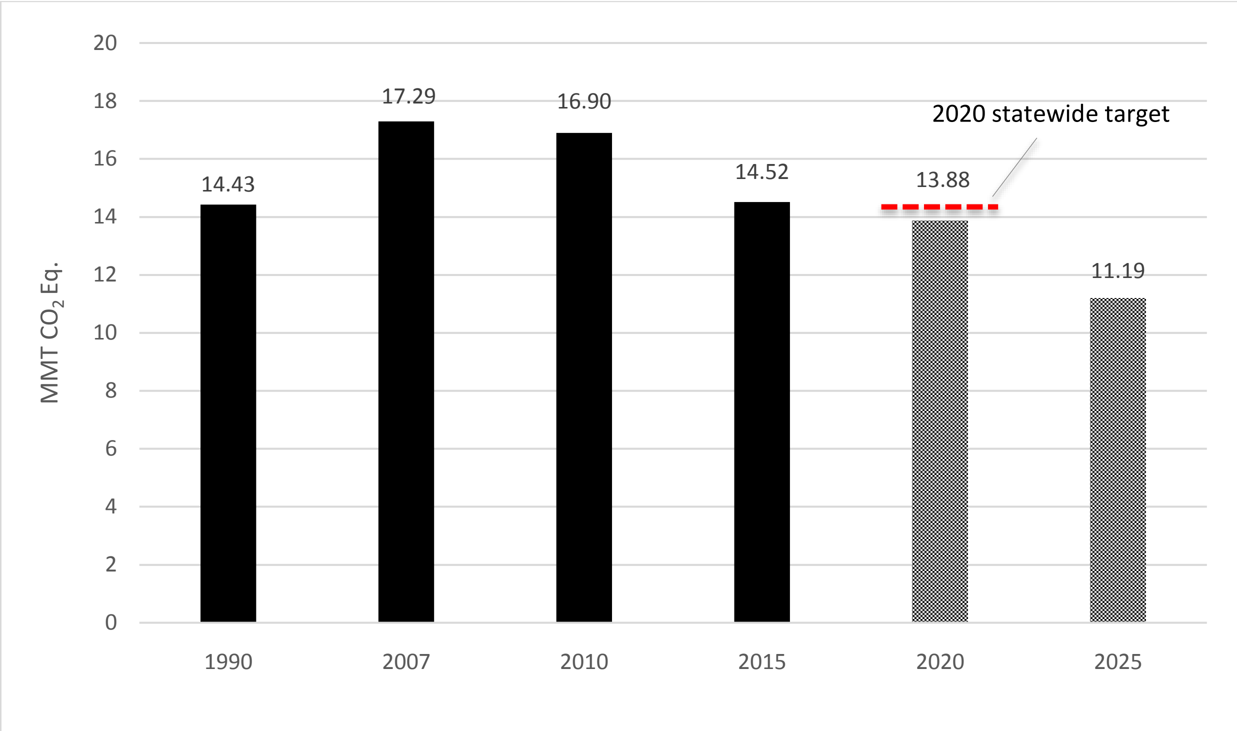
Excluding aviation, 1990 statewide emissions were estimated to be 14.43 MMT CO_2 Eq., which represents the 2020 emission target.[38] This target could change with any future updates to the 1990 emission estimates, but it is not likely to change significantly.[39] Figure 8-1 shows net emissions (excluding aviation) in Hawaii for the inventory years presented in this report as well as emission projections for 2020 and 2025. Net GHG emissions in 2015 (excluding aviation) were less than 1 percent higher than the 2020 statewide goal (1990 levels). As net emissions excluding aviation are projected to be 13.88 MMT CO_2 Eq. in 2020, this report finds that Hawaii is on track to meet its 2020 statewide emissions target.

Uncertainty

While the results of this analysis indicate that Hawaii is currently on track to meet the 2020 statewide goal, there is some degree of uncertainty in both the historic and projected emission estimates (described in detail within this report). The development of future inventory reports, which will include the review and update to the estimates presented in this report as well as a quantitative assessment of uncertainties, will further inform the likelihood of Hawaii meeting its 2020 statewide target.

[37] Emissions from International Aviation, which are reported under the International Bunker Fuels source category, are also not included in Hawaii's GHG target in accordance with IPCC (2006) guidelines for inventory development.
[38] The 1990 statewide emissions estimate presented in the 2008 inventory report was updated to account for updated activity data and methods, and to ensure time-series consistency across all inventory years. Relative to the 2008 inventory report, 1990 statewide emissions presented in this report, excluding aviation, increased by 6 percent. This change is largely due to updates to the GWP values and emission factors. Additional detail on the reason for the change in the 1990 emissions estimate by source and sink category is provided in Appendix B.
[39] When preparing GHG inventories, it is best practice to review GHG estimates for prior inventory years and revise them, as necessary, to take into account updated activity data and improved methodologies or emission factors that reflect advances in the field of GHG accounting.

Figure 8-1: Hawaii GHG Emissions Inventory Estimates and Projections (Including Sinks, Excluding Aviation)



Note: 2020 and 2025 represent emissions projections.

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Appendix A: IPCC Source and Sink Categories

Table A-1: Summary of IPCC Source and Sink Categories Included/Excluded from the Analysis

Category Code and Name		Included in Inventory	Notes
Energy			
1A1	Fuel Combustion Activities	✓	Includes emissions from fuel combustion for electricity generation and petroleum refining.
1A2	Manufacturing Industries and Construction	✓	
1A3	Transport	✓	
1A4	Other Sectors	✓	
1A5	Non-Specified	✓	
1B1	Fugitive Emissions from Solid Fuels		NO: Solid fuels (e.g., coal) are not produced or processed in Hawaii.
1B2	Oil and Natural Gas	✓	There are no natural gas systems in Hawaii.
1C	Carbon Dioxide Transport and Storage		NO: CO_2 is not transported or stored in Hawaii.
IPPU			
2A1	Cement Production	✓	
2A2	Lime Production		NO: Activity is not applicable to Hawaii.
2A3	Glass Production		NO: Activity is not applicable to Hawaii.
2A4	Other Process Uses of Carbonates		NO: Activity is not applicable to Hawaii.
2B	Chemical Industry		NO: Activity is not applicable to Hawaii.
2C	Metal Industry		NO: Activity is not applicable to Hawaii.
2D	Non-Energy Products from Fuels and Solvent Use		NO: Activity is not applicable to Hawaii.
2E	Electronics Industry		NO: Activity is not applicable to Hawaii.
2F	Product Uses as Substitutes for ODS	✓	
2G1	Electrical Equipment	✓	
2G2	SF_6 and PFCs from Other Product Uses		NO: Activity is not applicable to Hawaii.
2G3	N_2O from Product Uses		NO: Activity is not applicable to Hawaii.

AFOLU			
3A1	Livestock Enteric Fermentation	✓	
3A2	Livestock Manure Management	✓	
3B1a	Forest Land Remaining Forest Land	✓	
3B1b	Land Converted to Forest Land		NE: Data on land conversion are not readily available.
3B2	Cropland	✓	
3B3	Grassland	✓	
3B4	Wetlands		NE: Data is not readily available and emissions are likely very small.
3B5a	Settlements Remaining Settlements	✓	
3B5b	Land Converted to Settlements		NE: Data on land conversion are not readily available.
3B6	Other Land		NE: Other Land is assumed to be unmanaged in Hawaii.
3C1a	Biomass Burning in Forest Lands	✓	
3C1b	Biomass Burning in Croplands	✓	
3C1c	Biomass Burning in Grassland		NE: Data is not readily available and emissions are likely very small.
3C1d	Biomass Burning in All Other Land		NO: Activity is not applicable to Hawaii.
3C2	Liming		NE: Activity data are either withheld or zero.
3C3	Urea Application	✓	
3C4	Direct N_2O Emissions from Managed Soils	✓	
3C5	Indirect N_2O Emissions from Managed Soils	✓	
3C6	Indirect N_2O Emissions from Manure Management	✓	
3C7	Rice Cultivation		NO: Activity is not applicable to Hawaii.
3D1	Harvested Wood Products		NE: Data is not readily available and sinks are likely very small.
Waste			
4A1	Managed Waste Disposal Sites	✓	
4A2	Unmanaged Waste Disposal Sites		NO: All waste disposal is assumed to occur in managed sites in Hawaii.
4B	Biological Treatment of Solid Waste	✓	
4C	Incineration and Open Burning of Waste		In Hawaii, incineration of MSW occurs at waste-to-energy facilities and thus emissions are accounted for under the Energy sector.
4D	Wastewater Treatment and Discharge	✓	

NO (emissions are Not Occurring); NE (emissions are Not Estimated).

Appendix B: Summary of Updates to Emission Estimates since the Previous Inventory Report

Relative to the 2008 inventory report, total emissions presented in this inventory report decreased by 4 percent for 1990 and increased by 3 percent for 2007, while total net emissions decreased by 7 percent for 1990 and increased by 1 percent for 2007. Net emissions excluding aviation increased by 6 percent for 1990 and 4 percent for 2007. These changes are largely due to (1) updates to the GWP values, which previously reflected values from the *IPCC Second Assessment Report* and were updated to reflect values from the *IPCC Fourth Assessment Report*,[40] (2) updates to emission factors, and (3) revised international aviation mileage data, which resulted in apportioning a higher amount of jet fuel to international bunker fuels and a lower amount to domestic aviation. In addition, for the 2008 inventory report, in some cases 2006 data were used as a proxy for 2007 data; for this inventory report, 2007 data, which has since become available, were used instead. Other updates also impacted emission estimates, which are discussed on a source-by-source basis below. A summary of the change in emission estimates by inventory report is provided in Table B-1.

Table B-1: Change in Emissions Relative to the 2008 Inventory Report (MMT CO_2 Eq.)

Sector	1990			2007		
	2008 Report	This Report	Percent Change	2008 Report	This Report	Percent Change
Energy[a]	21.12	19.61	-7.2%	21.83	21.84	0.03%
IPPU	0.18	0.17	-3.5%	0.54	0.54	1.4%
AFOLU (Sources)	0.98	1.61	63.6%	0.83	1.56	88.1%
AFOLU (Sinks)	(2.67)	(3.06)	14.7%	(2.75)	(3.28)	19.4%
Waste[a]	0.85	0.75	-11.1%	1.07	1.05	-1.6%
Total Emissions (Excluding Sinks)	**23.13**	**22.15**	**-4.3%**	**24.27**	**25.00**	**3.0%**
Net Emissions (Including Sinks)	**20.46**	**19.08**	**-6.7%**	**21.52**	**21.71**	**0.9%**
Domestic Aviation	6.80	4.66	-31.5%	4.82	4.42	-8.4%
Net Emissions (Including Sinks, Excluding Aviation)[b]	**13.66**	**14.43**	**5.6%**	**16.69**	**17.29**	**3.6%**

[a] In the 2008 inventory report, emissions from incineration of waste were categorized under the Waste sector. In this inventory report, the emissions are categorized under the Energy sector, consistent with the U.S. Inventory.
[b] Domestic aviation emissions, which are reported under the transportation source category under the Energy sector, are excluded from Hawaii's GHG emissions reduction goal established in Act 234.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[40] Key changes to the GWP values, assuming a 100-year time horizon, include the value for CH_4 increasing from 21 to 25 and the value for N_2O decreasing from 310 to 298.

Energy

Stationary Combustion: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from stationary combustion have increased by less than 0.1 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, all emission factors obtained from the U.S. Inventory were updated based on the most recent version of the report (EPA 2017a).

Transportation: Relative to the 2008 inventory report, 1990 emission estimates for transportation decreased by 15 percent, and 2007 emission estimates decreased by 3 percent. The primary reason for the 15 percent decrease in 1990 emissions was due to higher estimates of the proportion of jet fuel used for international bunker fuels, which reduced the estimate for domestic aviation.[41] Updates to international bunker fuel consumption estimates are described below; these estimates impacted domestic marine and domestic aviation consumption totals. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). All emission factors obtained from the U.S. Inventory were also updated based on the most recent version of the report (EPA 2017a). Additionally, transportation emissions previously categorized as "Other" were disaggregated into Military, Ground, and Domestic Marine. Because of this change, Military is now listed as a separate sub-category. Finally, highway diesel for 2007 was reclassified as Ground transportation from Domestic Marine transportation after a time-series analysis was performed to confirm the reclassification.

Incineration of Waste: In the 2008 inventory report, this emission source was included in the Waste sector; this inventory report moves this category to the Energy sector.[42] 1990 and 2007 emission estimates from the incineration of waste increased by less than 0.01 percent. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, revised data on the proportion of plastics, synthetic rubber, and synthetic fibers in the waste stream in 1990 and 2007 was used based on updated figures from EPA's State Inventory Tools – Solid Waste Module (EPA 2017c). Finally, an updated emission factor for N_2O emissions from MSW combustion was used based on the revised methodology in EPA's State Inventory Tools – Solid Waste Module (EPA 2017c).

Oil and Natural Gas Systems: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from oil and gas operations are roughly 10,000 times and 2,000 times larger, respectively. In the previous inventory, emissions were estimated by multiplying the quantity of crude oil refined by the appropriate emission factors. For this inventory, emissions from this source were estimated by scaling 2010 emissions data from EPA's GHGRP (EPA 2017b) based on the ratio of crude oil throughput in 1990 and 2007 relative to 2010. This change in methodology resulted in a large percentage change in

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[41] Note that while this change affects total statewide emissions, it does not affect the 1990 statewide baseline, as aviation emissions are excluded.

[42] Emissions from the incineration of waste were moved under the Energy sector to be consistent with the U.S. Inventory (EPA 2017a) and because in Hawaii the incineration of waste generally occurs at facilities where energy is recovered.

emissions from this source; however, these emissions still only comprise roughly 1 percent of total energy sector emissions.

International Bunker Fuels: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from international bunker fuel combustion have increased by roughly 193 percent and 17 percent, respectively. In the previous inventory, flight mileage data were downloaded from the BTS Transtats database to apportion jet fuel consumption to the International Bunker Fuels source category. For this inventory, flight mileage data were re-downloaded from the BTS Transtats database for 1990 and 2007. While domestic flight mileage did not change, international mileage was significantly higher in both 1990 and 2007, resulting in a higher percentage of international miles relative to total miles. Since total jet fuel consumption did not change, this reallocation of jet fuel resulted in an increase in emissions for International Bunker Fuels, and a decrease in emissions for Domestic Aviation compared to the 2008 inventory report. While this reallocation resulted in lower emissions from the Energy sector in Hawaii and higher emissions from International Bunker Fuels for both 1990 and 2007, the sum total of these two sources do not change significantly.

Additionally, 2007 marine bunker fuel data were available for this inventory report, whereas the 2008 inventory report used 2006 data, the latest year available, as a proxy for 2007. This updated data resulted in a decrease in marine bunker fuel emissions estimates in 2007, as fuel use was lower in 2007 relative to 2006. Corrected calculations for converting marine bunker fuels from volume to energy units in both 1990 and 2007 also resulted in lower bunker fuel estimates, and accordingly resulted in higher emissions from the transportation sector, as fewer bunker fuels were deducted from consumption totals.

Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Additionally, all emission factors obtained from the U.S. Inventory were updated based on the most recent version of the report (EPA 2017a).

CO_2 from Wood Biomass and Biofuel Consumption: This category was newly quantified for this inventory report.

IPPU

Cement Production: No changes were made to the 1990 and 2007 emission estimates from cement production relative to the 2008 inventory report as no changes were made to the methodology, GWP values, emission factors, or activity data.

Electrical Transmission and Distribution: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from electrical transmission and distribution systems decreased by 10 percent and 54 percent, respectively. This change is due to three factors: (1) Hawaii electricity sales data were updated using the most recent State of Hawaii Data Book; (2) U.S. electricity sales data were updated using the most recent time series from the EIA Detailed State Data tables; and (3) U.S. SF_6 emissions from electrical transmission and distribution systems were updated based on the most recent version of the U.S. Inventory (EPA 2017a), which uses GWP values from the *IPCC Fourth Assessment Report* (IPCC 2007).

Substitution of Ozone Depleting Substances: Relative to the 2008 inventory report, 1990 emission estimates from substitutes of ODS have increased to 0.001 MMT CO_2 Eq. relative to the previous estimate of zero. This change is due to updated data obtained from the U.S. Inventory (EPA 2017a), which previously indicated that there were zero emissions from ODS substitutes in 1990. 2007 emission estimates increased by 5.6 percent. The change in 2007 emissions is due to the following four reasons: (1) Hawaii vehicle registration data were updated using the most recent time series for the State of Hawaii Data Book; (2) U.S. emissions from Substitutes for ODS were updated based on the U.S. Inventory (EPA 2017a), which uses GWP values from the *IPCC Fourth Assessment Report* (IPCC 2007); (3) U.S. vehicle registrations were updated using the most recent FHWA Highway Statistics; and (4) U.S. population data were updated with the most recent data from the U.S. Census Bureau.

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Enteric Fermentation: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from enteric fermentation have increased by 18 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Emission factors were updated to reflect Hawaii-specific values rather than values for the U.S. "West" region. These emission factors were higher for most cattle types. Animal population data for sheep, goats, and horses for 2007, which were estimated in the 2008 inventory report based on 1997 and 2002 USDA Census of Agriculture data, increased based on the 2007 USDA Census of Agriculture (USDA 2009). Population data for cattle and swine remained unchanged as did the emission factors for sheep, goats, horses, and swine.

Manure Management: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from manure management have increased by 19 percent and 2 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Volatile solids excretion rates were updated to reflect Hawaii-specific values rather than values for the U.S. "West" region. Typical animal mass and nitrogen excretion rates for cattle types were updated to annually variable values from the U.S. Inventory (EPA 2017a). The typical animal mass for sheep and assumed distribution of manure among manure management system types for sheep, goats, swine, and horses were also updated based on the U.S. Inventory (EPA 2017a). Animal population data for sheep, goats, and horses for 2007, which were estimated in the 2008 inventory report based on 1997 and 2002 USDA Census of Agriculture data, increased based on the 2007 USDA Census of Agriculture (USDA 2009). Population data for cattle, swine, and chicken remained unchanged.

Agricultural Soil Management: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from agricultural soil management have decreased by 11 percent and 5 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). Crop production data for 2007 for pineapples, sweet potatoes, ginger root, taro and corn for grain were updated based on the 2007 Census of Agriculture (USDA 2009). In addition, the typical animal mass for sheep and assumed distribution of manure among manure management system types for sheep, goats, swine, and horses were updated based on the U.S. Inventory (EPA 2017a). Nitrogen excretion rates for cattle types were also updated to annually variable values from the U.S. Inventory (EPA 2017a). Also, animal population data, used to calculate N inputs to agricultural soils from manure, increased for sheep, goats, and horses for 2007 based on the 2007 USDA Census of Agriculture (USDA 2009) and remained unchanged for cattle, swine, and chicken.

Field Burning of Agricultural Residues: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from field burning of agricultural residues have increased by 15 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

Urea Application: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from urea application have not changed as no changes were made to the methodology, GWP values, emission factors, or activity data.

Agricultural Soil Carbon: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from agricultural soil carbon have increased by 157 percent and 102 percent, respectively. For the 2008 inventory report, 1990 estimates were obtained from the 1990-2005 USDA Agriculture and Forest Greenhouse Gas Inventory, and 2006 estimates from the 1990-2006 U.S. Inventory were used as a proxy for 2007 estimates. For this inventory report, the estimates for 1990 and 2007 were updated based on the U.S. Inventory (EPA 2017a). Relative to previous U.S. Inventory reports, the emission estimates were updated for the full time series to incorporate updated data on land transitions, management practices, and sequestration rates in agricultural soils (EPA 2017a).

Forest Fires: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from forest fires have increased by 140 percent and 370 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007). The methodology for estimating emissions from forest fires was revised to be consistent with IPCC (2006) guidelines, as opposed to IPCC (2003) guidelines. Combustion and emissions factors were also updated using the *2006 IPCC Guidelines* (IPCC 2006).

The amount of wildland under protection in 2002 was revised to the correct units for this calculation (hectares), and the area of wildland under protection was updated in 2007 based on data from DLNR, resulting in a higher ratio of forest to wildland and thus higher emissions relative to the 2008 inventory report. The amount of fuel available for combustion was updated to the annual carbon density for the lower 48 states as provided by the USFS (2014). Previously, an average carbon density for all years was assumed in the 2008 inventory report.

In addition, for the 2008 inventory report, forest acres burned data were not available for the year 2007 and were proxied using 2006 data. The estimates presented in this inventory report were updated using forest acres burned data for year 2007, as reported by the DLNR. Actual forest acres burned data for year 2007 were more than twice the amount assumed for the 2008 inventory report.

Lastly, combustion factors were weighted based on the share of forestland and shrubland in Hawaii. In the 2008 inventory report, the share of forestland and shrubland was constant across all inventory years using data from NOAA-CCAP (2000). In this inventory, the share of forest and shrubland in 2007 was interpolated based on the percent change between forest and shrubland area in 2000 and 2014 (NOAA-CCAP 2000; Selmants et al. 2017).

Landfilled Yard Trimmings and Food Scraps: Relative to the 2008 inventory report, 1990 and 2007 carbon stock change estimates from landfilled yard trimmings and food scraps have increased (i.e., resulted in more sinks) by 14 percent and 30 percent, respectively. The current version of the State Inventory Tool contains updated data on the amount of national landfilled yard trimmings and food scraps; updated factors for the proportion of carbon stored in grass, leaves, branches, and food scraps; and the decay rate of these materials. In addition, the ratio of Hawaii population to national population for 1990 and 2007 increased, leading to greater amounts of landfilled yard trimmings and food scraps scaled down to Hawaii from the national level, and therefore, increased carbon stock estimates.

Urban Trees: Relative to the 2008 inventory report, 1990 and 2007 carbon sequestration from urban trees has increased (i.e., resulted in more sinks) by 148 percent and 185 percent, respectively. The significant increases in estimates of urban area and tree cover resulted in increased sequestration from urban trees in Hawaii for 1990 and 2007 relative to the 2008 inventory report.

For the 2008 inventory report, a state-specific estimate of Hawaii's urban tree cover was not available. The national average urban tree cover (27.1 percent) was previously used to estimate how much of Hawaii's urbanized area is covered by tree canopy. Since the 2008 inventory report, Nowak and Greenfield (2012) published *Tree and impervious cover in the United States*, which determined that 39.9 percent of urban area in Hawaii is covered by trees circa 2005. The current methodology applies this Hawaii-specific percentage to Hawaii's urban area.

To ensure time-series consistency between urban area estimates from U.S. Census reports, urban clusters were incorporated into the 1990 and 2000 urban area activity data, increasing the urban area estimates used in the previous inventory report. Urban clusters are defined in the 2000 U.S. Census as "surrounding census blocks that have an overall density of at least 500 people per square mile." The 1990 U.S. Census did not include urban clusters as a classification but instead defined "urban places" as an additional category for urban area based on population and political boundaries (EPA 2009). Urban area estimates for 1990 in Nowak et al. (2005) were used in this report because they are consistent with the definition of urban area and clusters provided in the 2000 U.S. Census. 2010 U.S. Census data were also incorporated to develop estimates of urban area for 2007.

Forest Carbon: Relative to the 2008 inventory report, 1990 and 2007 sink estimates from forest carbon have increased (i.e., resulted in more sinks) by 9 and 11 percent, respectively, due to changes made to activity data and emission factors. Forest activity data were updated to include woodland on farms, which increased total forest area by approximately 40,000 hectares in 1990 and 10,000 hectares in 2007. In addition, biomass growth and carbon fraction factors were weighted based on the share of forestland and shrubland in Hawaii. In the 2008 inventory report, the share of forestland and shrubland was constant across all inventory years using data from NOAA-CCAP (2000). In this inventory, the share of forest and shrubland in 2007 was interpolated based on the percent change between forest and shrubland area in 2000 and 2014 (NOAA-CCAP 2000; Selmants et al. 2017).

Waste

Landfills: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from landfilling have increased by 19 percent for both inventory years. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

Composting: This category was newly quantified for this inventory report.

Wastewater Treatment: Relative to the 2008 inventory report, 1990 and 2007 emission estimates from wastewater treatment have decreased by 20 percent and 19 percent, respectively. Calculations were updated to use GWP values from the *IPCC Fourth Assessment Report*, assuming a 100-year time horizon (IPCC 2007).

Appendix C: Hawaii Administrative Rule (HAR) Facility Data

Hawaii Administrative Rule (HAR) affected facilities refers to large existing stationary sources with potential GHG emissions at or above 100,000 tons per year.[43] These facilities are subject to an annual facility-wide GHG emissions cap of 16 percent below the facility's total 2010 baseline GHG emission levels to be achieved by January 1, 2020. Based on data obtained from EPA's GHGRP (EPA 2017b), the PSIP (PUC 2016; DCCA 2017) and the KIUC GHG Reduction Plan (KIUC 2016), Table B-1 summarizes annual GHG emissions from HAR affected facilities for 2010 to 2015 and projections for 2020 and 2025. This table includes stationary combustion emissions from electric power plants, petroleum refineries, and industrial facilities as well as fugitive emissions from petroleum refineries. Biogenic CO_2 emissions from HAR affected facilities are not presented, as these emissions are excluded from the annual facility-wide GHG emission cap.

Table B-1: HAR Affected Facility Emissions (excluding biogenic CO_2 emissions) (MMT CO_2 Eq.)

HAR Affected Facility	Inventory Sector (IPCC Source Category)	2010	2011	2012	2013	2014	2015	2020	2025
AES Hawaii, Inc.[a]	Energy Industries (1A1ai)	1.53	1.68	1.82	1.69	1.77	1.64	1.51	+
Hamakua Energy Partners	Energy Industries (1A1ai)	0.17	0.13	0.14	0.10	0.11	0.13	0.16	0.11
Hawaiian Commercial & Sugar Company[b]	Industrial (1A2)	0.14	0.13	0.12	0.15	0.14	0.12	NO	NO
HELCO Kanoelehua Hill Generating Station	Energy Industries (1A1ai)	0.20	0.19	0.17	0.17	0.17	0.18	+	+
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.17	0.18	0.15	0.19	0.21	0.21	0.13	0.07
HELCO Shipman Generating Station[c]	Energy Industries (1A1ai)	NE	NE	NE	NO	NO	NO	NO	NO
HELCO Puna Generating Station	Energy Industries (1A1ai)	0.09	0.09	0.08	0.09	0.05	0.02	0.02	0.02
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.97	0.88	0.86	0.86	0.88	1.01	0.53	0.26

[43] Hawaii Administrative Rules, Chapter 11-60.1, available online at http://health.hawaii.gov/cab/files/2014/07/HAR_11-60_1-typed.pdf, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.

HECO Kahe Generating Station	Energy Industries (1A1ai)	2.52	2.63	2.41	2.22	2.13	2.02	1.27	0.18
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	NO	+	+	+	+	+	0.01	0.02
HECO Honolulu Generating Station[d]	Energy Industries (1A1ai)	0.12	0.10	0.05	0.06	+	NO	NO	NO
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[e]	Energy Industries (1A1ai)	NO	NO	NO	NO	NO	NO	NO	NO
Kalaeloa Cogeneration Plant	Energy Industries (1A1ai)	0.95	0.99	0.91	0.96	0.92	0.95	0.95	1.06
Kauai Island Utility Co. Kapaia Power Station	Energy Industries (1A1ai)	0.13	0.12	0.13	0.12	0.13	0.12	0.11	0.07
Kauai Island Utility Co. Port Allen Generating Station	Energy Industries (1A1ai)	0.15	0.15	0.14	0.14	0.13	0.12	0.05	0.03
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.21	0.19	0.18	0.13	0.14	0.11	0.10	+
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.56	0.55	0.52	0.49	0.46	0.49	0.40	0.24
MECO Palaau Generating Station[f]	Energy Industries (1A1ai)	0.03	0.03	0.02	0.02	0.02	0.02	NE	NE
Island Energy Services Refinery[g]	Energy Industries (1A1b)	0.34	0.35	0.34	0.30	0.32	0.33	0.30	0.26
	Oil and Natural Gas (1B2)	0.19	0.21	0.23	0.16	0.21	0.19	0.16	0.14
Par Hawaii Refinery[g]	Energy Industries (1A1b)	0.44	0.45	0.41	0.26	0.43	0.44	0.40	0.35
	Oil and Natural Gas (1B2)	0.12	0.13	0.12	0.07	0.13	0.11	0.01	0.01
Total		**9.04**	**9.19**	**8.82**	**8.19**	**8.36**	**8.23**	**6.11**	**2.82**

[a] Annual GHG emissions for AES Hawaii, Inc. were obtained from Hawaii DOH (2017c).

[b] The Hawaiian Commercial & Sugar Company plant closed in December 2016.

[c] The HELCO Shipman Generating Station was deactivated in 2012 and closed at the end of 2015. Emissions data for 2010-2012 was not available from GHGRP.

[d] The HECO Honolulu Generating Station was deactivated in January 2014.

[e] The Hu Honua Bioenergy, LLC Pepeekeo Power Plant is currently under development. Once the plant becomes operational, emissions are still expected to not occur, based on the definitions set forth in administrative rules, because the plant will use biomass as its fuel source.

[f] Emissions for the MECO Palaau Generating Station are not provided within the PSIP and therefore are not estimated. This data uncertainty will be an area of inquiry in future analysis.

[g] The Island Energy Services Refinery was previously known as the Chevron Products Company Hawaii Refinery; the Par Hawaii Refinery was previously known as the Hawaii Independent Energy Petroleum Refinery.

+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring); NE (emissions are Not Estimated).

Notes: Totals may not sum due to independent rounding.

Appendix D: Activity Data

This section summarizes activity data used to develop the inventory presented in this report.

Energy

Table D-1: Stationary Fuel Consumption by Fuel Type, Economic Sector, and Year (Bbtu)

Sector/Fuel Type	1990	2007	2010	2015
Residential	**490**	**749**	**1,437**	**1,334**
Propane	490	427	820	761
Natural Gas	0	322	617	573
Commercial	**5,918**	**4,102**	**8,690**	**13,059**
Diesel Fuel	274	60	53	4,840
Motor Gasoline	412	0	881	1,021
Propane	5,159	1,963	3,766	3,495
Residual Fuel	73	0	0	0
Natural Gas	0	2,079	3,989	3,702
Ethanol	0	0	57	64
Biodiesel	0	0	21	45
Industrial	**8,966**	**2,036**	**10,733**	**4,969**
Coal	697	1,795	1,385	1,084
Diesel Fuel	3,735	105	6,000	1,777
Motor Gasoline	404	111	223	162
Residual Fuel	4,130	0	3,076	1,900
Natural Gas	0	26	49	46
Ethanol	0	0	14	10
Biodiesel	0	0	27	337
Energy Industries	**86,731**	**110,374**	**105,623**	**88,181**
Coal	0	14,780	15,700	14,500
Diesel Fuel	9,712	15,682	13,773	12,300
Fuel Gas	0	1,763	0	0
Jet Fuel Kerosene	0	1,224	0	0
Naphtha[a]	0	4,065	4,519	6,381
Residual Fuel	77,019	72,860	71,632	55,000

[a] Naphtha data were obtained from EPA's GHGRP (EPA 2017b) and were only available in MMT CO_2 Eq. Fuel consumption in Bbtu was estimated by back-calculating emissions using the corresponding naphtha emissions factor from the U.S. Inventory (EPA 2017a).

Note: Totals may not sum due to independent rounding.

Table D-2: Transportation Fuel Consumption by Fuel Type, Mode, and Year (Bbtu)

Mode/Fuel Type	1990	2007	2010	2015
Aviation	**64,852**	**61,780**	**40,086**	**45,111**
Aviation Gasoline	226	102	212	0
Jet Fuel Kerosene	64,626	61,678	39,873	45,111
Ground	**45,346**	**67,871**	**72,581**	**77,878**
Diesel Fuel	3,464	11,552	16,989	24,675
Motor Gasoline	41,549	56,311	55,577	53,190
Propane	329	8	15	13
Residual Fuel	4	0	0	0
Ethanol	0	2,302	6,386	7,382
Biodiesel	0	0	659	1,221
Marine	**23,718**	**22,966**	**11,903**	**5,012**
Diesel Fuel	10,839	6,640	7,150	801
Motor Gasoline	19	36	51	58
Residual Fuel	12,860	16,290	4,702	4,153
Ethanol	0	0	3	4
Military	**18,978**	**14,108**	**15,131**	**7,371**
Diesel Fuel	4,860	5,350	9,301	173
Jet Fuel Kerosene	1,449	8,659	5,626	6,945
Motor Gasoline	4,785	0	18	81
Naphtha[1]	7,122	0	0	0
Propane	0	64	120	111
Residual Fuel	762	0	0	0
Natural Gas	0	36	67	62
Ethanol	0	0	1	5

[1] Naphtha data were obtained from EPA's GHGRP (EPA 2017b) and were only available in MMT CO_2 Eq. Fuel consumption in Bbtu was estimated by back-calculating emissions using the corresponding naphtha emissions factor from the U.S. Inventory (EPA 2017a).

Note: Totals may not sum due to independent rounding.

Table D-3: International Bunker Fuel Consumption by Fuel Type, Mode, and Year (Bbtu)

Mode/Fuel Type	1990	2007	2010	2015
Aviation	**39,343**	**20,840**	**13,740**	**21,074**
Jet Fuel Kerosene	39,343	20,840	13,740	21,074
Marine	**1,621**	**676**	**5,167**	**1,331**
Diesel Fuel	1,146	251	2,398	1,084
Residual Fuel	475	425	2,769	247

Note: Totals may not sum due to independent rounding.

IPPU

Table D-4: Clinker production by Year (MT)

	1990	2007	2010	2015
Clinker Production	195,044	0	0	0

Source: Wurlitzer (2008).

Table D-5: Electricity Sales by Year (MWh)

	1990	2007	2010	2015
Hawaii	8,310,537	10,585,037	10,013,104	9,388,577
U.S.	2,712,554,665	3,764,560,712	3,754,841,368	3,758,992,390

Sources: EIA (2016); DBEDT (2017b).

Table D-6: Registered Vehicles by Year

	1990	2007	2010	2015
Hawaii	870,657	1,103,782	1,086,185	1,193,863
U.S.	188,170,927	246,430,169	241,214,494	254,120,376

Sources: FHWA (2016); DBEDT (2017b).

Table D-7: U.S. GHG Emissions by Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015
Cars and Trucks A/C ODS Substitutes	0	68.71	65.62	45.09
Other ODS Substitutes	0.29	45.92	75.90	123.70
Electrical Transmission and Distribution	23.11	6.22	5.88	4.15

Source: EPA (2017a).

AFOLU

Table D-8: Animal Population by Animal Type, Year (Head)

Animal Type	1990	2007	2010	2015
Cattle	**205,000**	**158,000**	**151,000**	**133,000**
Dairy Cattle	**19,174**	**5,013**	**2,930**	**3,355**
Dairy Cows	11,000	3,800	1,800	2,200
Dairy Replacement Heifers	6,000	1,000	1,000	1,000
Other Dairy Heifers	2,174	213	130	155
Beef Cattle	**185,826**	**152,987**	**148,070**	**129,645**
Beef Cows	75,000	85,200	81,200	68,800
Beef Replacement Heifers	16,000	15,000	12,000	11,000
Other Beef Heifers	14,826	4,787	5,870	4,845

Animal Type	1990	2007	2010	2015
Steers	26,000	8,000	8,000	9,000
Calves	49,000	35,000	36,000	32,000
Bulls	5,000	5,000	5,000	4,000
Sheep and Lambs	**22,526**	**22,376**	**22,103**	**22,923**
Goats	**192**	**863**	**1,000**	**1,301**
Swine	**36,000**	**15,000**	**12,500**	**9,000**
Horses and ponies	**3,770**	**6,547**	**5,687**	**5,737**
Chickens	**1,183,000**	**398,000**	**366,000**	**272,964**

Sources: USDA (2017a, 2017b, 2017c) (cattle, swine, and chicken); USDA (1989, 1994, 2009, and 2014) (sheep, goats, and horses).

Table D-9: Crop Area by Crop Type, Year (Acres)

Crop Type	1990	2007	2010	2015
Sugarcane for sugar	72,000	20,400	15,500	12,900
Pineapples	18,205	7,875	6,738	5,196
Sweet potatoes	193	297	648	979
Ginger root	300	80	64	36
Taro	462	535	503	458
Corn for grain	0	3,115	4,365	4,986

Sources: USDA (2017d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain).

Table D-10: Crop Production by Crop Type, Year (Tons)

Crop Type	1990	2007	2010	2015
Sugarcane for sugar	6,538,000	1,493,000	1,195,000	1,139,000
Pineapples	607,322	242,967	208,065	160,676
Sweet potatoes	1,024	1,430	3,120	4,975
Ginger root	4,503	1,266	908	443
Taro	3,511	2,554	2,060	1,728
Corn for grain	0	3,497	7,567	10,431

Sources: USDA (2017d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain).

Table D-11: Fertilizer Consumption by Fertilizer Type, Fertilizer Years

Fertilizer Type	1990	2007	2010	2015
Urea Fertilizer Consumption (short tons)	2,638	2,038	2,002	2,403
Synthetic Fertilizer Consumption (kg N)	16,218,014	12,550,066	12,324,312	13,953,712

Source: TVA (1991 through 1994) (urea fertilizer); AAPFCO (1995 through 2017) (urea and synthetic fertilizer).

Table D-12: Wildfire Area Burned by Year (Hectares)

Area Burned	1990	2007	2010	2015
Area Burned (Hectares)	8,172	11,975	3,856	2,264

Source: DLNR (1994 through 2008, 2011, 2016).

Table D-13: Forest and Shrubland Area (Hectares)

Forest and Shrubland Area	1990	2007	2010	2015
Forest and Shrubland Area (Hectares)	497,430	486,100	491,039	487,449

Source: DBEDT (2017b).

Table D-14: Forest and Shrubland Area (Percent)

Forest and Shrubland Area	1990	2007	2010	2015
Forest	52.0%	60.9%	64.5%	68.4%
Shrubland	48.0%	39.1%	35.5%	31.6%

Source: NOAA-CCAP (2000); Selmants et al. (2017).

Table D-15: Hawaii Landfilled Yard Trimmings and Food Scraps (thousand short tons, wet weight)

Yard Trimming and Food Scraps	1990	2007	2010	2015
Landfilled Yard Trimmings	**126**	**45**	**55**	**52**
Grass	38	14	17	16
Leaves	51	18	22	21
Branches	37	13	16	15
Food Scraps	**85**	**119**	**132**	**144**

Source: EPA (2017f).

Table D-16: Hawaii Urban Area (km^2)

Hawaii Urban Area	1990	2007	2010	2015
Urban Area (km^2)	757.0	988.9	1,018.2	1,089.4

Sources: U.S. Census (1990, 2002, 2012); Nowak et al. (2005).

Waste

Table D-17: Quantity of MSW Landfilled (MT)

Year	Amount	Year	Amount	Year	Amount
1960	312,381	**1979**	809,071	**1998**	763,193
1961	336,277	**1980**	837,840	**1999**	759,442
1962	360,910	**1981**	852,137	**2000**	780,692
1963	372,098	**1982**	868,330	**2001**	817,079
1964	394,914	**1983**	887,551	**2002**	822,814

Year	Amount	Year	Amount	Year	Amount
1965	410,684	**1984**	903,600	**2003**	814,567
1966	428,276	**1985**	916,714	**2004**	881,034
1967	450,956	**1986**	930,154	**2005**	994,112
1968	473,394	**1987**	947,296	**2006**	924,488
1969	500,171	**1988**	960,756	**2007**	803,274
1970	530,921	**1989**	976,832	**2008**	692,983
1971	565,703	**1990**	996,000	**2009**	572,399
1972	598,176	**1991**	702,000	**2010**	546,656
1973	629,328	**1992**	702,000	**2011**	555,138
1974	656,404	**1993**	980,000	**2012**	517,978
1975	685,793	**1994**	1,040,000	**2013**	480,571
1976	716,076	**1995**	827,142	**2014**	500,888
1977	744,188	**1996**	889,342	**2015**	513,824
1978	772,606	**1997**	851,153	**2016**	535,324

Sources: Hawaii DOH (2017a and 2008a); EPA (2017c).

Table D-18: Volume of Composted MSW (MT)

MSW Composted	1990	2007	2010	2015
Hawaii	18,934	92,564	85,861	102,549
U.S.	3,810,000	19,695,000	18,298,000	21,052,000

Sources: DBEDT (2017b); EPA (2017a).

Table D-19: Per Capita Biological Oxygen Demand for Wastewater treatment (kg/person/day)

Island	1990	2007	2010	2015
Hawaii	0.0615	0.0615	0.0004	0.0002
Kauai	0.0615	0.0615	0.0001	0.0002
Lanai/Molokai/Niihau	0.0615	0.0615	0.0615	0.0615
Maui	0.0615	0.0615	0.0003	0.0003
Oahu	0.0615	0.0615	0.0001	0.0001

Source: Pruder (2008) and Hawaii DOH (2017b).

Table D-20: Fraction of Population not on Septic (Percent)

Island	1990	2007	2010	2015
Hawaii	99.976%	87.885%	87.885%	87.885%
Kauai	99.773%	84.753%	84.753%	84.753%
Lanai/Maui/Molokai	99.973%	93.745%	93.745%	93.745%
Niihau	99.999%	99.967%	99.967%	99.967%
Oahu	99.960%	99.353%	99.353%	99.353%

Sources: DBEDT (2017b) and U.S. Census Bureau (1990b, 2007).

Appendix E: Emission Factors

This section summarizes emission factors used to develop the inventory presented in this report.

Energy

Table E-1: CO_2 Emission Factors Used to Estimate Emissions from Stationary Fuel Use by Fuel Type, Economic Sector, and Year (lb C/MMBtu)

Sector/Fuel Type	1990	2007	2010	2015
Residential				
Propane	37.65	37.93	37.93	37.93
Natural Gas	31.90	31.90	31.90	31.90
Commercial				
Diesel Fuel	43.98	43.98	43.98	43.98
Motor Gasoline	42.82	43.12	42.85	42.85
Propane	37.65	37.93	37.93	37.93
Residual Fuel	47.38	47.38	47.38	47.38
Natural Gas	31.90	31.90	31.90	31.90
Ethanol	41.16	41.16	41.16	41.16
Biodiesel	33.49	33.49	33.49	33.49
Industrial				
Coal	56.62	56.78	56.78	56.78
Diesel Fuel	43.98	43.98	43.98	43.98
Motor Gasoline	42.82	42.89	42.89	42.89
Residual Fuel	47.38	47.38	47.38	47.38
Natural Gas	31.90	31.90	31.90	31.90
Ethanol	41.16	41.16	41.16	41.16
Biodiesel	33.49	33.49	33.49	33.49
Energy Industries				
Coal	56.62	56.78	56.78	56.78
Diesel Fuel	43.98	43.98	43.98	43.98
Fuel Gas	38.60	38.60	38.60	38.60
Jet Fuel Kerosene	42.77	42.62	42.62	42.62
Naphtha	39.99	39.99	39.99	39.99
Residual Fuel	47.38	47.38	47.38	47.38

Sources: EPA (2017a) (Fossil fuels); EIA (2017d) (Biofuels).

Table E-2: CH_4 and N_2O Emission Factors Used to Estimate Emissions from Stationary Fossil Fuel Use by Fuel Type and End-Use Sector (g/GJ)

Fuel Type/Sector	CH_4	N_2O
Coal		
Industrial	1.5	10
Energy Industries	1.5	1
Petroleum		
Residential	0.6	10
Commercial	0.6	10
Industrial	0.6	3
Energy Industries	0.6	3
Natural Gas		
Residential	0.1	5
Commercial	0.1	5
Industrial	0.1	1

Source: IPCC (2006).

Table E-3: CH_4 and N_2O Emission Factors Used to Estimate Emissions from Biofuel Use by Fuel Type (kg/TJ fuel)

Fuel Type	CH_4	N_2O
Ethanol	18	NA
Biodiesel	147	4

NA (emissions are Not Applicable).

Sources: IPCC (2006) (Ethanol); EPA (2017a) (Biodiesel).

Table E-4: CO_2 Emission Factors Used to Estimate Emissions from Non-Highway Vehicles by Fuel Type and Year (lb C/MMBtu)

Fuel Type	1990	2007	2010	2015
Aviation Gasoline	41.60	41.60	41.60	41.60
Diesel Fuel	43.98	43.98	43.98	43.98
Jet Fuel Kerosene	42.77	42.62	42.62	42.62
Motor Gasoline	42.82	42.89	42.89	42.89
Naphtha	43.50	43.50	43.50	43.50
Propane	37.65	37.93	37.93	37.93
Residual Fuel	47.38	47.38	47.38	47.38
Natural Gas	31.90	31.90	31.90	31.90
Ethanol	41.16	41.16	41.16	41.16
Biodiesel	33.49	33.49	33.49	33.49

Sources: EPA (2017a) (Fossil fuels); EIA (2017d) (Biofuels).

Table E-5: CH_4 and N_2O Emission Factors Used to Estimate Emissions from Highway Vehicles by Vehicle Type and Control Technology (g/mile)

Vehicle Type/Control Technology	CH_4	N_2O
Gasoline Passenger Cars		
EPA Tier 3 / ARB LEV III	0.0022	0.0067
EPA Tier 2	0.0078	0.0082
ARB LEV II	0.0061	0.0082
ARB LEV	0.0100	0.0205
EPA Tier 1[a]	0.0271	0.0429
EPA Tier 0 [a]	0.0704	0.0647
Oxidation Catalyst	0.1355	0.0504
Non-Catalyst Control	0.1696	0.0197
Uncontrolled	0.1780	0.0197
Gasoline Light-Duty Trucks		
EPA Tier 3 / ARB LEV III	0.0020	0.0067
EPA Tier 2	0.0080	0.0082
ARB LEV II	0.0056	0.0082
ARB LEV	0.0148	0.0223
EPA Tier 1[a]	0.0452	0.0871
EPA Tier 0[a]	0.0776	0.1056
Oxidation Catalyst	0.1516	0.0639
Non-Catalyst Control	0.1908	0.0218
Uncontrolled	0.2024	0.0220
Gasoline Heavy-Duty Vehicles		
EPA Tier 3 / ARB LEV III	0.0115	0.0160
EPA Tier 2	0.0085	0.0082
ARB LEV II	0.0212	0.0175
ARB LEV	0.0300	0.0466
EPA Tier 1[a]	0.0655	0.1750
EPA Tier 0[a]	0.2630	0.2135
Oxidation Catalyst	0.2356	0.1317
Non-Catalyst Control	0.4181	0.0473
Uncontrolled	0.4604	0.0497
Diesel Passenger Cars		
Advanced	0.0005	0.0010
Moderate	0.0005	0.0010
Uncontrolled	0.0006	0.0012
Diesel Light-Duty Trucks		
Advanced	0.0010	0.0015
Moderate	0.0009	0.0014

Uncontrolled	0.0011	0.0017
Diesel Medium- and Heavy-Duty Trucks and Buses		
Aftertreatment	0.0051	0.0048
Advanced	0.0051	0.0048
Moderate	0.0051	0.0048
Uncontrolled	0.0051	0.0048
Motorcycles		
Non-Catalyst Control	0.0672	0.0069
Uncontrolled	0.0899	0.0087

Source: EPA (2017a).

Table E-6: CH_4 and N_2O Emission Factors Used to Estimate Emissions from Off-Road Vehicles by Vehicle Type and Fuel Type (g/kg fuel)

Vehicle/Fuel Type	CH_4	N_2O
Ships and Boats		
Residual Fuel	0.23	0.08
Aircraft		
Aviation Gasoline	2.64	0.04
Industrial and Commercial Equipment		
Motor Gasoline	0.18	0.08
Diesel Fuel	0.18	0.08

Source: IPCC (1996).

Table E-7: CH_4 and N_2O Emission Factors Used to Estimate Emissions from Natural Gas Use for Off-Road Vehicles (kg/TJ fuel)

Fuel Type	CH_4	N_2O
Natural Gas	92	3

Source: IPCC (2006).

Table E-8: CH_4 and N_2O Emission Factors Used to Estimate Emissions from International Bunker Fuels by Fuel Type (g/kg fuel)

Fuel Type	CH_4	N_2O
Jet Fuel Kerosene	0.10	0.000
Diesel Fuel	0.08	0.315
Residual Fuel	0.08	0.315

Source: IPCC (1996).

IPPU

Table E-9: Clinker Production Emission Factors and Correction Factor by Year (Ton CO_2/Ton clinker produced)

	1990	2007	2010	2015
Clinker Production Emission Factor	0.51	0.51	0.51	0.51
Cement kiln dust (CKD) correction factor	1.02	1.02	1.02	1.02

Source: IPCC (2006).

AFOLU

Table E-10: CH_4 Cattle Emission Factors Used to Estimate Emissions from Enteric Fermentation by Cattle Type, and Year (kg CH_4 per head per year)

Cattle Type	1990	2007	2010	2015
Dairy Cows	117.93	107.74	110.59	120.12
Dairy Replacement Heifers	60.24	58.01	57.62	57.27
Other Dairy Heifers	60.24	58.01	57.62	57.27
Beef Cows	94.40	100.47	100.47	100.47
Beef Replacement Heifers	62.67	69.39	69.41	69.33
Other Beef Heifers	36.36	36.63	31.20	36.45
Steers	34.10	35.81	30.85	36.05
Calves	11.57	11.29	11.27	11.31
Bulls	96.45	103.89	103.89	103.89

Source: EPA (2017a).

Table E-11: Typical Animal Mass (TAM) by Cattle Type and Year (kg)

Cattle Type	1990	2007	2010	2015
Dairy Cows	679.77	679.77	679.77	679.77
Dairy Replacement Heifers	407.72	406.35	406.87	406.32
Other Dairy Heifers	407.72	406.35	406.87	406.32
Beef Cows	553.34	610.89	610.89	610.89
Beef Replacement Heifers	371.54	405.73	406.33	403.98
Other Beef Heifers	383.38	420.76	424.92	445.25
Steers	418.46	449.66	451.89	470.36
Calves	122.10	122.54	122.48	122.54
Bulls	830.00	916.34	916.34	916.34

Source: EPA (2017a).

Table E-12: Volatile Solids (VS) by Cattle Type and Year (kg VS/1000 kg animal mass/day)

Cattle Type	1990	2007	2010	2015
Dairy Cows	7.99	8.21	8.44	9.22
Dairy Replacement Heifers	7.86	8.48	8.44	8.44
Other Dairy Heifers	7.86	8.48	8.44	8.44
Beef Cows	8.80	8.48	8.48	8.48
Beef Replacement Heifers	7.96	8.52	8.44	8.50
Other Beef Heifers	5.72	4.37	4.36	4.25
Steers	5.18	3.99	4.00	3.89
Calves	6.41	7.59	7.70	7.70
Bulls	5.99	5.85	5.85	5.85

Source: EPA (2017a).

Table E-13: Nitrogen Excreted (Nex) Produced by Cattle Type and Year (kg Nex per head per year)

Cattle Type	1990	2007	2010	2015
Dairy Cows	146.32	127.82	126.51	134.83
Dairy Replacement Heifers	79.10	71.27	68.93	68.84
Other Dairy Heifers	79.10	71.27	68.93	68.84
Beef Cows	52.71	59.14	59.14	59.14
Beef Replacement Heifers	33.60	41.18	40.75	40.80
Other Beef Heifers	57.36	53.07	54.64	55.80
Steers	59.86	54.57	56.13	56.82
Calves	13.37	19.57	20.12	20.13
Bulls	61.14	68.53	68.53	68.53

Source: EPA (2017a).

Table E-14: Weighted Methane Conversion Factor (MCF) by Animal Type and Year

Animal Type	1990	2007	2010	2015
Dairy Cows	62%	58%	62%	65%
Dairy Replacement Heifers	2%	2%	2%	2%
Other Dairy Heifers	2%	2%	2%	2%
Beef Cows	2%	2%	2%	2%
Beef Replacement Heifers	2%	2%	2%	2%
Other Beef Heifers	2%	2%	2%	2%
Steers	2%	2%	2%	2%
Calves	2%	2%	2%	2%
Bulls	2%	2%	2%	2%
Sheep	2%	2%	2%	2%
Goats	2%	2%	2%	2%

Animal Type	1990	2007	2010	2015
Swine	35%	47%	47%	47%
Horses	2%	2%	2%	2%
Chickens	60%	20%	20%	20%

Sources: EPA (2017a) (all animal types except chicken and swine); EPA (2017e) (chicken and swine).

Table E-15: Non-Cattle Emission Factors Used to Estimate Emissions from Enteric Fermentation and Manure Management by Animal Types

Animal Type	Enteric CH_4 (kg CH_4 per head per year)	Typical Animal Mass (kg)	Volatile Solids (VS) (kg VS/1000 kg animal mass/day)	Nitrogen Excreted (kg per day per 1000 kg)
Sheep	8	68.60	9.20	0.42
Goats	5	64.00	9.50	0.45
Swine	1.5	82.61	5.54	0.42
Horse	18	450.00	10.00	0.30
Chickens	NA	1.80	10.82	0.83

Sources: EPA (2017a); EPA (2017e) (VS for horses and Nitrogen Excretion rates).
NA (Not Applicable).

Table E-16: Maximum Potential Emissions for Estimating Emissions from Manure Management by Animal Type

Animal Type	Maximum Potential Emissions (B_O)
Dairy Cows	0.24
Dairy Replacement Heifers	0.17
Other Dairy Heifers	0.17
Beef Cows	0.17
Beef Replacement Heifers	0.17
Other Beef Heifers	0.33
Steers	0.33
Calves	0.17
Bulls	0.17
Sheep	0.34
Goats	0.17
Swine	0.48
Horses	0.33
Chickens	0.39

Source: EPA (2017a)

Table E-17: Fraction Volatile Solids Distribution by Animal Type, Waste Management System (WMS), and Year

Animal Type	WMS	1990	2007	2010	2015
Dairy Cows	Pasture	0%	10%	5%	0.69%
Dairy Cows	Anaerobic Lagoon	68%	57%	63%	67%
Dairy Cows	Liquid/Slurry	21%	23%	22%	21%
Dairy Cows	Solid Storage	11%	9%	10%	11%
Dairy Cows	Deep Pit	0%	0%	0%	0%
Dairy Replacement Heifers	Liquid/Slurry	1%	1%	1%	1%
Dairy Replacement Heifers	Dry Lot	100%	100%	100%	100%
Dairy Replacement Heifers	Pasture	0%	0%	0%	0%
Other Dairy Heifers	Liquid/Slurry	1%	1%	1%	1%
Other Dairy Heifers	Dry Lot	100%	100%	100%	100%
Other Dairy Heifers	Pasture	0%	0%	0%	0%
Beef Cows	Pasture	100%	100%	100%	100%
Beef Cows	Other WMS	0%	0%	0%	0%
Beef Replacement Heifers	Pasture	100%	100%	100%	100%
Beef Replacement Heifers	Other WMS	0%	0%	0%	0%
Other Beef Heifers	Liquid/Slurry	1%	1%	1%	1%
Other Beef Heifers	Dry Lot	100%	100%	100%	100%
Other Beef Heifers	Pasture	0%	0%	0%	0%
Steers	Liquid/Slurry	1%	1%	1%	1%
Steers	Dry Lot	100%	100%	100%	100%
Steers	Pasture	0%	0%	0%	0%
Calves	Pasture	100%	100%	100%	100%
Calves	Other WMS	0%	0%	0%	0%
Bull	Pasture	100%	100%	100%	100%
Bull	Other WMS	0%	0%	0%	0%
Sheep	Pasture	55%	69%	69%	69%
Sheep	Dry Lot	45%	31%	31%	31%
Goats	Pasture	92%	92%	92%	92%
Goats	Dry Lot	8%	8%	8%	8%
Swine	Pasture	36%	31%	41%	47%
Swine	Anaerobic Lagoon	13%	14%	13%	11%
Swine	Liquid/Slurry	18%	19%	16%	15%
Swine	Deep Pit	30%	32%	28%	25%
Swine	Solid Storage	3%	3%	3%	2%
Horses	Pasture	92%	92%	92%	92%
Horses	Dry Lot	8%	8%	8%	8%
Chickens	Pasture	0%	0%	0%	0%
Chickens	Anaerobic Lagoon	80%	25%	25%	25%

Animal Type	WMS	1990	2007	2010	2015
Chickens	Poultry without bedding	10%	75%	75%	75%
Chickens	Solid Storage	10%	0%	0%	0%

Source: EPA (2017a).

Table E-18: Urea Emission Factor

Emissions Factor	Value
Urea Emission Factor (MT C/MT urea)	0.2

Source: IPCC (2006).

Table E-19: N_2O Emission Factors by Waste Management System Type (kg N20-N/kg N)

Waste Management System	Emission Factor
Anaerobic lagoons and liquid systems	0
Solid storage of manure	0.005
Deep pit manure	0.002
Drylot manure	0.02
Poultry without bedding	0.005

Source: IPCC (2006).

Table E-20: Crop Residue Factors by Crop for Estimating Emissions from Agricultural Soil Management

Crop	IPCC Crop Proxy	Dry matter fraction of harvested product (DRY)	Above-ground residue dry matter $AG_{DM(T)}$ (Mg/ha): $AG_{DM(T)} = Crop_{(T)} * slope_{(T)} + intercept_{(T)}$		N content of above-ground residues (N_{AG})	Ratio of below-ground residues to above-ground biomass (R_{BG-BIO})	N content of below-ground residues (N_{BG})
			Slope	Intercept			
Sugarcane	Perennial grasses	0.90	0.30	0.00	0.015	0.80	0.012
Pineapples	Perennial grasses	0.90	0.30	1.00	0.015	0.80	0.012
Sweet potatoes	Tubers	0.22	0.10	1.06	0.019	0.20	0.014
Ginger root	Tubers	0.22	0.10	2.06	0.019	0.20	0.014
Taro	Tubers	0.22	0.10	3.06	0.019	0.20	0.014
Corn for grain	Maize	0.87	1.03	0.61	0.006	0.22	0.007

Source: IPCC (2006).

Table E-21: Sugarcane Residue and Crop Factors for Estimating Emissions from Field Burning of Agricultural Residues

Crop	Res/Crop Ratio	Fraction Residue Burned	Dry Matter Fraction	Fraction Carbon	Fraction Nitrogen	Burning Efficiency	Combustion Efficiency
Sugarcane	0.2	0.95	0.62	0.424	0.004	0.81	0.68

Sources: Kinoshita (1988) (res/crop ratio and burning efficiency); Ashman (2008) (fraction residue burned); Turn et al. (1997) (dry matter fraction, fraction carbon, fraction nitrogen, and combustion efficiency).

Table E-22: Volatilization and Leaching/Runoff Fraction Lost and Emission Factors for Estimating Emissions from Agricultural Soil Management

Emission Factor	Value
Fraction lost to volatilization (used for synthetic nitrogen applied)	0.1
Fraction lost to volatilization (used for all non-Pasture, Range and Paddock (PRP) manure deposited)	0.2
Fraction lost to leaching/runoff	0.3
Emission Factor for volatilization	0.01
Emission Factor for leaching/ runoff	0.0075

Source: IPCC (2006).

Table E-23: Fuel Available, Wildfire Carbon Density (MT dry matter/ha)

Factor	1990	2007	2010	2015
Wildfire carbon density	63.0	70.0	71.5	73.1

Source: USFS (2014).

Table E-24: Ratio of Hawaii Forest Land to Wildland (Dimensionless)

Factor	1990	2007	2010	2015
Ratio of Hawaii forestland to wildland	0.37	0.36	0.36	0.36

Source: National Association of State Foresters (1998, 2002); DLNR (2011, 2016).

Table E-25: Forest Fire Emission Factor (g/kg dry matter burnt)

Emission Factor	Value
CO_2	1,569
CH_4	4.70
N_2O	0.26

Source: IPCC (2006).

Table E-26: Carbon Storage Factors for Landfilled Yard Trimmings and Food Scraps

Type of Waste	Content of Yard Trimmings (%)	Moisture Content of Waste, MC_i (%)	Proportion of Carbon Stored Permanently in Waste, CS_i (%)	Initial Carbon Content of Waste, ICC_i (%)	First Order Decay Rate, k
Grass	30.3	70.0	53.5	44.9	0.139
Leaves	40.1	30.0	84.6	45.5	0.035
Branches	29.6	10.0	76.9	49.4	0.030
Food Scraps	NA	70.0	15.7	50.8	0.156

Source: EPA (2017f).

NA (Not Applicable).

Table E-27: Urban Tree Sequestration Factor, S_c (MT C/km^2)

Factor	Value
Average net C sequestration per km^2 tree cover (MT C/km^2)	-253.8

Source: Vargas et al. (2007).

Table E-28: Forest Carbon Net Sequestration Factors

Type of Forest	Annual Biomass Growth Rate (MT dry matter/ha/year)	Carbon Fraction of Dry Matter (MT C/MT dry matter)
Forest	4.658	0.47
Shrubland	1.4	0.47

Source: IPCC (2006).

Waste

Table E-29: Landfilling CH_4 Emission Factors for Estimating Emissions from Waste Sector

Emissions Factor	Value
Methane Generation Constant (yr^{-1})	0.04
Methane Generation Potential (m^3 CH_4/Mg of refuse)	100
Methane Oxidation Rate (%)	10%

Source: EPA (2017a).

Table E-30: Composting CH_4 and N_2O Emission Factors for Estimating Emissions from Waste Sector

Emissions Factor	CH_4	N_2O
Waste Treated on a Wet Weight Basis (g of gas/Kg waste)	4	0.24

Source: IPCC (2006).

Table E-31: Wastewater CH_4 and N_2O Emission Factors for Estimating Emissions from Waste Sector

Emissions Factor	Value
Direct Emissions from Wet waste (MT CH_4/MT of waste)	0.6
Direct Emissions from Wet waste (g N_2O/person/year)	4.0
Indirect Emissions from Wet waste (kg N_2O-N/kg sewage N-produced)	0.005
Fraction of wastewater BOD anaerobically digested	16.25%
Total Annual Protein Consumption (kg/person/year)	41.98
Fraction of Nitrogen in Protein (kg N/kg protein)	16%
Fraction of Nitrogen not Consumed	1.75
Percentage of Biosolids used as Fertilizer	0%

Source: EPA (2017g).

Appendix F: Estimates of Fuel Consumption from Various Sources

As part of our QA/QC procedures, the fuel consumption data provided by DBEDT (2018a) that was used for this analysis were compared with other available top-down and bottom-up data sources. Other data sources that were used for this comparison include the following:

- **EIA's State Energy Data System (SEDS).** SEDS reports comprehensive historical energy statistics by state, fuel type, and end-use sector. These data are obtained through EIA's surveys of energy suppliers that report consumption, sales, or distribution of energy at the state-level.
- **EPA's Greenhouse Gas Reporting Program (GHGRP).** EPA's GHGRP collects greenhouse gas emissions data reported by individual facilities. Facilities are required to report based on their emission levels, the types of industrial operations located at the facility, or other factors.
- **EIA's Detailed Electric Power Data (Form EIA-923).** Form EIA-923 collects data on electricity generation, fuel consumption, fossil fuel stocks, and receipts for all power plants in the U.S. collected through monthly surveys.
- **Hawaii DOH State and Local Emissions Inventory System (DOH SLEIS).** SLEIS collects point source emissions inventory data submitted by permitted facilities based on statutory obligations within Hawaii.

Consumption totals across all fuel types and sectors were compared, to the extent possible. While no two data sources has the same estimates of fuel consumption, the differences in diesel fuel and residual fuel consumption data are notable. The table below presents 2015 diesel and residual fuel consumption by economic sector and data source. The bolded values represent the data used in this inventory report.

Table F-1: 2015 Diesel Fuel Consumption by End-Use Sector and Data Source (Bbtu)

End-Use Sector	DBEDT[a,b]	SEDS	GHGRP[c,d]	EIA-923[e]	DOH SLEIS[d]
Commercial/Industrial	**6,627**	3,200	NA	NA	NA
Transportation	**26,733**	11,800	NA	NA	NA
Energy Industries	7,544	**12,300**	13,277	12,468	12,661

NA (data are Not Applicable).

[a] As DBEDT is the conduit of this data but not the source of it, DBEDT cannot ascertain the data's accuracy. Use of this data was at the discretion of the authors of this report.

[b] Diesel fuel consumption was provided in aggregate with marine gasoil, fuel oil, and kerosene consumption. These fuels are assumed to make up a very small portion of the total.

[c] Data from EPA's GHGRP were only available in MMT CO_2 Eq. Fuel consumption from EPA's GHGRP for the energy industries sector was estimated by multiplying emissions by the ratio of fuel consumption to emissions for diesel fuel in the inventory.

[d] Commercial and industrial sector diesel fuel consumption from EPA's GHGRP and DOH SLEIS are not presented in this table as many of the facilities in these sectors do not meet the reporting thresholds for these data sources.

[e] The EIA-923 dataset contains fuel consumption for the energy industries sector only.

Table F-2: 2015 Residual Fuel Consumption by End-Use Sector and Data Source (Bbtu)

End-Use Sector	DBEDT[a,b]	SEDS	GHGRP[c,d]	EIA-923[e]	DOH SLEIS[d]
Industrial	**1,284**	1,900	NA	NA	NA
Transportation	**2,974**	4,400	NA	NA	NA
Energy Industries	37,178	**55,000**	55,619	54,377	55,135

NA (data are Not Applicable).

[a] As DBEDT is the conduit of this data but not the source of it, DBEDT cannot ascertain the data's accuracy. Use of this data was at the discretion of the authors of this report.

[b] Residual fuel consumption was provided in aggregate with intermediate fuel oil, ethanol, and gasoline (E85). In addition, the data was provided as a total across all end-use sectors. Intermediate fuel oil is assumed to contain mostly residual fuel and therefore is included in the totals presented. Ethanol and gasoline (E85) were disaggregated from residual fuel based on SEDS data (i.e., SEDS reports consumption of 3,900 Bbtu of ethanol). The remaining total was disaggregated by end-use sector based on the breakout of SEDS data by sector (i.e., 3% industrial, 7% transportation, and 90% energy industries).

[c] Data from EPA's GHGRP were only available in MMT CO_2 Eq. Fuel consumption from EPA's GHGRP for the energy industries sector was estimated by multiplying emissions by the ratio of fuel consumption to emissions for residual fuel in the inventory.

[d] Commercial and industrial sector diesel fuel consumption from EPA's GHGRP and DOH SLEIS are not presented in this table as many of the facilities in these sectors do not meet the reporting thresholds for these data sources.

[e] The EIA-923 dataset contains fuel consumption for the energy industries sector only.

This inventory report relied on DBEDT data in most cases to allow for consistency across fuel types and inventory years. In cases where significant discrepancies existed between the DBEDT data and multiple other data sources (e.g., diesel and residual fuel consumption by energy industries), EIA SEDS data were used in place of DBEDT data. EIA SEDS was selected as the alternate data source because it is the only other dataset that contains fuel consumption for most fuel types and end-use sectors included in the DBEDT data. While other discrepancies were observed between the DBEDT data and the EIA SEDS data, EIA SEDS data was only used in place of DBEDT data if the discrepancy was supported by other data sources. ICF will continue to investigate the differences between historical DBEDT data and other data sources and may revise the data source selections in the future, as appropriate.

Appendix G: ODS Emissions

Ozone depleting substances (ODS)—including chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, hydrochlorofluorocarbons (HCFCs), and other chlorine and bromine containing compounds—have been found to deplete the ozone levels in the stratosphere. In addition to contributing to ozone depletion, CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFCs are also potent greenhouse gases. The GWP values for ODS are summarized in Table F-1.

The *Montreal Protocol on Substances that Deplete the Ozone Layer* is the international treaty that controls ODS; parties to the *Montreal Protocol* are required to provide statistical data about ODS to the Ozone Secretariat annually. In the United States, the Clean Air Act Amendments of 1990 implement the *Montreal Protocol* controls. Because these gases are controlled under the *Montreal Protocol*, IPCC (2006) guidelines exclude the reporting of ODS emissions.

For informational purposes, ODS emissions were estimated for the state of Hawaii. To estimate ODS emissions for Hawaii, national ODS emissions were apportioned based on the ratio of Hawaii population to U.S. population. Estimates of national ODS emissions (in kilotons (kt) by gas) were obtained from the U.S. Inventory (EPA 2017a). National population numbers were obtained from the U.S. Census Bureau (2016) while Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2017b). Table G-2 summarizes ODS emissions in Hawaii by gas for 1990, 2007, 2010, and 2015.

Table G-1: 100-year Direct Global Warming Potentials for Ozone Depleting Substances

Gas	GWP
CFC-11	4,750
CFC-12	10,900
CFC-113	6,130
CFC-114	10,000
CFC-115	7,370
Carbon Tetrachloride	1,400
Methyl Chloroform	146
Halon 1211	1,890
Halon 1301	7,140
HCFC-22	1,810
HCFC-123	77
HCFC-124	609
HCFC-141b	725
HCFC-142b	2,310
HCFC-225ca	122
HCFC-225cb	595

Source: *IPCC Fourth Assessment Report* (2007).

Table G-2: ODS Emissions by Gas (kt)

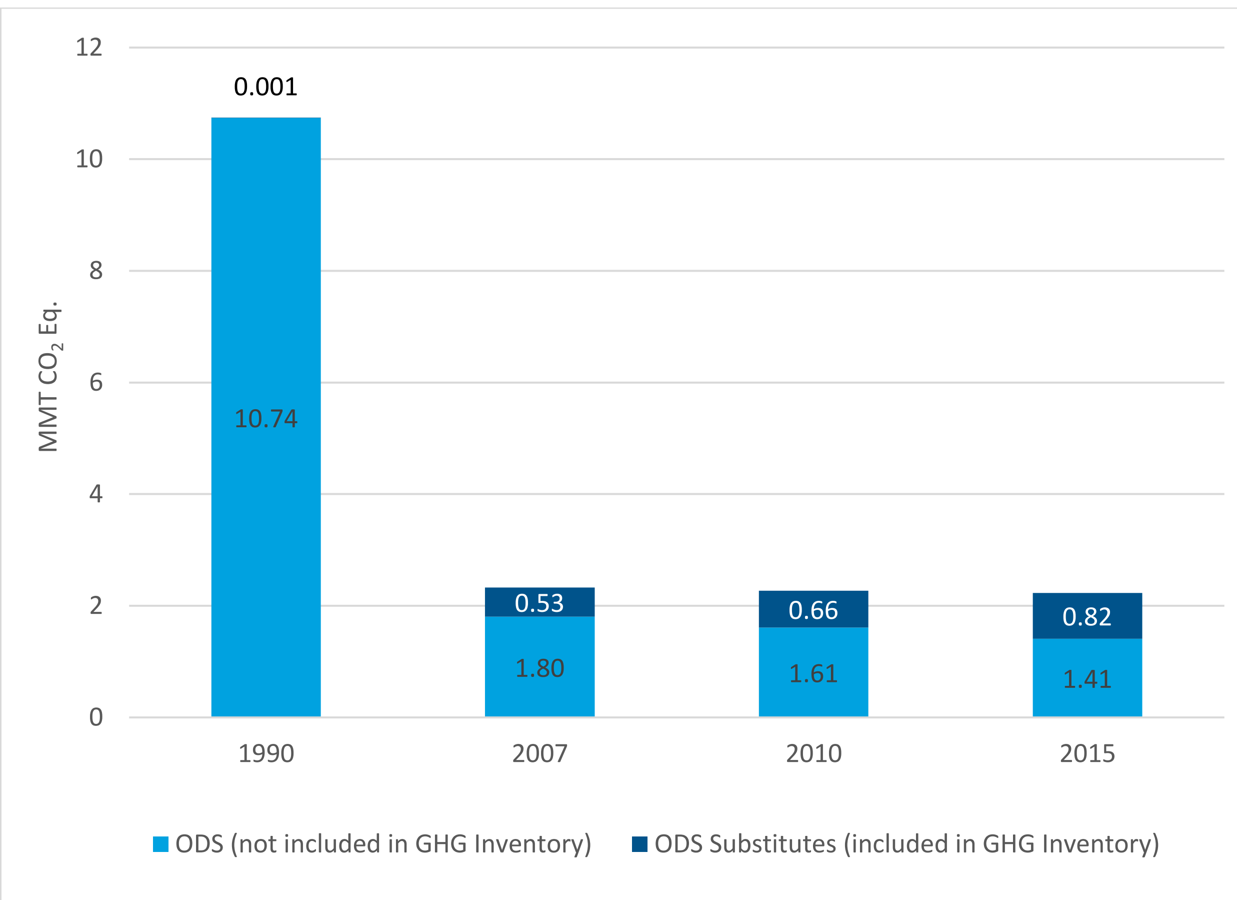
Gas	1990	2007	2010	2015
CFC-11	0.15	0.05	0.11	0.12
CFC-12	0.64	0.06	0.03	0.02
CFC-113	0.30	+	+	+
CFC-114	0.02	+	+	+
CFC-115	0.04	0.01	+	+
Carbon Tetrachloride	0.02	NO	NO	NO
Methyl Chloroform	1.12	NO	NO	NO

Gas	1990	2007	2010	2015
Halon 1211	0.01	+	+	+
Halon 1301	0.01	+	+	+
HCFC-22	0.25	0.40	0.39	0.32
HCFC-123	NO	+	+	+
HCFC-124	NO	0.01	+	+
HCFC-141b	0.01	0.03	0.04	0.05
HCFC-142b	0.01	0.02	0.01	0.01
HCFC-225ca/cb	+	+	+	+
Total	**2.56**	**0.59**	**0.59**	**0.52**

+ Does not exceed 0.005 kt; NO (emissions are Not Occurring).
Source: EPA (2017a).

Emissions from ODS in Hawaii have decreased significantly since 1990, following the implementation of the *Montreal Protocol*. Figure G-1 below presents combined emissions from ODS and ODS substitutes in Hawaii. Combined emissions have similarly decreased between 1990 and 2015, even though emissions from ODS substitutes increased during the same period.

Figure G-1: Emissions from ODS and ODS Substitutes



Appendix H: Emission Projections Methodology

This section summarizes the methodology used to project emissions for 2020 and 2025 by source and sink category. A discussion of key uncertainties and areas for improvement is also provided.

Stationary Combustion

Methodology

Emissions from stationary combustion were projected based on the UHERO macroeconomic forecast as well as utility-specific emission projections. For the residential, commercial, and industrial sectors, emissions are assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast. For the energy industries sector, emissions were projected for the two petroleum refineries (Island Energy Services and Par Hawaii)[44] and each of the two electric utilities in Hawaii: the Hawaiian Electric Industries (HEI), which comprises the Hawaiian Electric Company (HECO) operating on Oahu, Hawaii Electric Light Company (HELCO) operating on Hawaii Island, and the Maui Electric Company (MECO) operating on Maui County; and the Kauai Island Utility Cooperative (KIUC), which operates on the island of Kauai.

For the petroleum refineries, emissions were projected based on the weighted average growth in petroleum consumption in the Stationary Combustion and Transportation sectors, consistent with the equations used to estimate emissions from Oil and Natural Gas Systems, as described below.

For the service area under HEI, emissions projections for 2020 and 2025 were developed based on the utility's Power Supply Improvement Plan (PSIP) (PUC 2016; DCCA 2017). This plan provides utility generation scenarios out to 2045. For the purposes of this analysis, projections are based on the least-cost pathway scenario to achieve the RPS, without the introduction of large-scale natural gas into the power system (i.e., the E3 Plan).[45,46]

Electric sector emissions for KIUC in the year 2020 were obtained from the KIUC GHG Reduction Plan (KIUC 2016). For 2025, emissions were estimated based on projections of energy generation as well as an estimate of the portion of generation that will be met by renewable sources. Specifically, the

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[44] The Island Energy Services Refinery was previously known as the Chevron Products Company Hawaii Refinery; the Par Hawaii Refinery was previously known as the Hawaii Independent Energy Petroleum Refinery.

[45] Total emissions were aggregated based on burner level CO_2 equivalents and then converted to metric tons. The plan without liquefied natural gas (LNG) was selected because Governor Ige has openly opposed bringing in LNG for the power sector (Walton 2015). There is also an "E3 Plan with Grid Modernization," which has become the preferred plan based on Public Utilities Commission guidance. The emissions estimates between the plans are similar, as the grid modernization strategy focuses on energy distribution.

[46] The PSIP does not account for the closure of the Puna Geothermal unit on Hawaii Island due to the active lava flow. In 2017, the Puna Geothermal facility produced 322.6 gigawatt-hours (GWh) of electricity (DBEDT 2018c). If energy demand remains constant and is replaced by diesel generators, this could increase emissions by approximately 0.25 MMT CO_2e a year. Projections in this report were completed prior to the closure of the unit. Forthcoming updates to this analysis will address the substitution of geothermal with other fuels.

generation data from KIUC (2016) was projected forward to 2025 using a constant growth rate based on the 2010 to 2020 trend. To forecast the proportion of generation that will be met in 2025 by renewable sources, an S-Shaped curve was calibrated to reflect renewable generation data in 2015 that achieves KIUC's GHG Reduction Plan target of 40 percent renewables in 2020 and the state's 100 percent RPS mandate by 2045, shown by the following equation:

$$P(t) = {P_0 e^{rt}}\Big/{(1 + P_0(e^{rt} - 1))}$$

where,

$P(t)$	= Proportion of generation met by renewables in year t
P_0	= Proportion of generation met by renewables in 2015
r	= Growth rate
t	= Year

This calibration yields a growth rate of 23 percent and results in a projected share of renewable generation for KIUC in 2025 of 67 percent. Emissions were then estimated by calculating the amount of energy generated by fossil fuels in 2025 and multiplying this value by KIUC's average GHG emissions factor from the years 2010-2020 (KIUC 2016).

Uncertainties and Areas for Improvement

This analysis assumes that the two utilities will meet the 2020 RPS target and continue to make progress towards the 2030 goal by the year 2025 (State of Hawaii 2018). However, in both 2016 and 2017, actual emissions for HEI were higher than those estimated in their PSIP, indicating that there is uncertainty associated with whether the utilities will actually meet the RPS target, as outlined in their plans, due to changes in factors such as estimated electricity demand and underlying economic conditions. In addition, there are multiple energy technology build-outs that could lead to compliance with the RPS for both HEI and KIUC. Appendix I shows alternative scenarios for capital investments towards power generation and their impact on the HEI-based electric sector emissions forecast for 2020 and 2025. As shown, alternate build-out scenarios could result in higher emissions in both 2020 and 2025 than projected in this report. Furthermore, this analysis and the alternative scenarios do not take into account the recent closure of the Puna Geothermal unit on Hawaii Island due to the active lava flow. Projections in this report were completed prior to the closure of the unit. Forthcoming updates to this analysis will address the substitution of geothermal with other fuels and will also further analyze alternate forecast scenarios.

Transportation

Methodology

Emissions from transportation were projected based on the UHERO macroeconomic forecast, which is used to project forward GSP, as well as projections of on-road vehicle fossil fuel consumption. For select smaller sources, emissions are assumed to remain constant in the future relative to 2015 due to a lack of data availability and inconsistencies in the historic emissions trend. Further discussion of these assumptions is provided in the sections that follow.

Ground Transportation

Emissions from ground transportation were projected based on projections of fossil fuel consumption by light duty vehicles (LDVs), heavy duty vehicles (HDVs), and motorcycles.

Light Duty Vehicles

For light duty vehicles, on-road gasoline consumption was estimated based on future LDV vehicle miles traveled (VMT) and fuel efficiency. New LDV fuel efficiency was estimated using EPA's corporate average fuel economy (CAFE) standards for cars and light trucks (EPA 2014),[47] accounting for the difference in EPA rated fuel efficiency and true on-road efficiency, which is assumed to be 15 percent. The share of sales for cars and light trucks (including vans and sports utility vehicles) was obtained from Hawaii Automobile Dealers Association sales records (HADA 1989-2013).[48] The fuel efficiency of new vehicles was then calculated using the following equation:

$$FE(t)_{new} = 1 \Big/ \left(\frac{S(t)_{cars}}{0.85 \times CAFE(t)_{cars}} + \frac{S(t)_{trucks}}{0.85 \times CAFE(t)_{trucks}} \right)$$

where,

$FE(t)_{new}$	= Fleet fuel efficiency for new vehicles in year *t*
$S(t)_{cars}$	= Share of sales for cars in year *t*
$CAFE(t)_{cars}$	= CAFE standards for cars in year *t*
$S(t)_{trucks}$	= Share of sales for light trucks in year *t*
$CAFE(t)_{trucks}$	= CAFE standards for light trucks in year *t*

Each year, 5 percent of vehicles on the road are assumed to be new. This assumption is based on the percentage of new car sales relative to the total (DBEDT 2017b). Taking the fuel efficiency of vehicles in 2015 and the portion of vehicles that are new on the road each year, fleet fuel efficiency for future years was calculated using the following equation:

$$FE(t)_{fleet} = 1 \Big/ \left(\frac{1 - 0.05}{FE(t-1)_{fleet}} + \frac{0.05}{FE(t)_{new}} \right)$$

where,

$FE(t)_{fleet}$	= Fleet fuel efficiency for all vehicles in year *t* (mpg)
0.05	= Portion of vehicles that are new each year
$FE(t-1)_{fleet}$	= Fleet fuel efficiency for new vehicles in year *t* (mpg)
$FE(t)_{new}$	= Fleet fuel efficiency for new vehicles in year *t* (mpg)

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[47] The EPA has issued a notice of proposed rulemaking to revise the CAFE standards for model years 2022-2025. Any changes to these standards will be accounted for in future iterations of this analysis.
[48] For further discussion of the share of vehicle sales between cars and light trucks, see Coffman et al. (2015).

To estimate future LDV VMT, the team estimated an Ordinary Least Squares regression between historic GSP (UHERO 2018) and VMT (DBEDT 2018d) from 1992 to 2016. Using the UHERO macroeconomic forecast to project forward GSP, LDT VMT was then calculated using the following equation:

$$VMT(t) = 570 + 0.12 \times GSP(t)$$

where,

$VMT(t)$	= LDV VMT in year *t*
570	= Intercept term in the least squares fit
0.12	= Slope term in the least squares fit
$GSP(t)$	= Gross state product in year *t*

Vehicles miles traveled by electric vehicles (EV) were calculated based on projections of the average VMT per vehicle and the number of EVs on the road, shown in the equation below. The projected number of EVs on the road is based on an EV sales and on-road forecast developed by Coffman et al. (2015). In this study, EV sales were estimated to be approximately 9 percent of new car sales in 2020 and 12 percent in 2025.

$$VMT(t)_{EV} = VMT(t)_{average} \times Q(t)_{EV}$$

where,

$VMT(t)_{EV}$	= EV VMT in year *t* (Billions of miles)
$VMT(t)_{average}$	= Average VMT per vehicle in year *t* (Billions of miles)
$Q(t)_{EV}$	= Number of EV on the road in year *t*

To estimate LDV gasoline consumption, VMT was divided by the fuel efficiency of the LDT fleet. The energy consumed by EVs was removed from total energy consumption by light duty vehicles through a reduction in the energy that EVs would consume if measured in gasoline gallon equivalents, where the fuel efficiency of EVs was estimated to be 80 percent of the reported fuel efficiency of a Nissan Leaf (112 mpg). The equation used to estimate LDV gasoline consumption is shown below.

$$C(t)_{gasolineblend} = \frac{VMT(t)}{FE(t)_{fleet}} - \frac{VMT(t)_{EV}}{FE_{EV}}$$

where,

$C(t)_{gasolineblend}$	= Total LDV gasoline consumption in year *t* (Billions of gallons)
$VMT(t)$	= LDV VMT in year *t* (Billions of miles)
$FE(t)_{fleet}$	= Fleet fuel efficiency for all vehicles in year *t* (miles per gallon)
$VMT(t)_{EV}$	= EV VMT in year *t* (Billions of miles)
FE_{EV}	= Fuel efficiency of EV in year *t* (miles per gallon)

It is assumed that all gasoline consumed in Hawaii is E10—a blend of 10 percent ethanol and 90 percent pure motor gasoline. To calculate the quantity of pure motor gasoline consumed, total LDT gasoline consumption was multiplied by 0.9. Emissions from LDT were then calculated by multiplying pure motor gasoline consumption by emission factors obtained from the U.S. Inventory (EPA 2017a).

<u>Heavy Duty Vehicles</u>

For heavy duty trucks,[49] diesel consumption was estimated based on future VMT and fuel efficiency. Heavy duty vehicle VMT is assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast. The fuel efficiency of new trucks is assumed to increase over time and was estimated based on a fuel efficiency forecast for vocational trucks (ACEEE et al. 2014). Specifically, the Union of Concerned Scientists (UCS) forecasts efficiency to improve from 9.7 mpg in 2010 to 14.3 mpg in 2025. Assuming an average lifetime of 14 years (Fleetowner 2014; Statista 2018) and a fleet average fuel efficiency in 2015 equal to the 2010 fuel efficiency for new trucks, the fleet average fuel efficiency for HDVs was calculated using the following equation:

$$FE(t)_{HDTfleet} = 1 \Big/ \left(\frac{1 - \frac{1}{14}}{FE(t-1)_{HDTfleet}} + \frac{\frac{1}{14}}{FE(t)_{HDTnew}} \right)$$

where,

$FE(t)_{HDTfleet}$	= Fleet fuel efficiency for all HDT in year *t*
1/14	= Portion of HDT that are new each year
$FE(t-1)_{HDTfleet}$	= Fleet fuel efficiency for new HDT in year *t*
$FE(t)_{HDTnew}$	= Fleet fuel efficiency for new HDT in year *t*

Fuel consumption by heavy duty vehicles was then calculated using the following equation:

$$C(t)_{totaldiesel} = VMT(t)_{HDV} \Big/ FE(t)_{HDTfleet}$$

where,

$C(t)_{totaldiesel}$	= Total HDV diesel and biodiesel consumption in year *t*
$VMT(t)_{HDV}$	= HDV VMT in year *t*
$FE(t)_{HDTfleet}$	= Fleet fuel efficiency for all HDT in year *t*

Assuming biodiesel consumption grows at the same rate as GSP, fossil fuel diesel consumption was calculated by subtracting projected biodiesel consumption from total diesel consumption. Emissions from HDT were then calculated by multiplying fossil fuel diesel consumption by emission factors obtained from the U.S. Inventory (EPA 2017a).

[49] Heavy duty vehicles include heavy duty trucks and buses. Because buses consume only 2 percent of the diesel fuel consumed by HDV, for the purposes of this analysis, buses are not distinguished from other heavy duty trucks.

Motorcycles

Emissions from motorcycles were calculated based on the number of motorcycles on the road, the average fuel efficiency of motorcycles, and the average annual VMT for motorcycles. Data on the number of motorcycles registered in Hawaii in 2015 were obtained from DBEDT (2018d). The number of motorcycles is assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast. The average annual VMT per motorcycle is based on the national average, adjusted for Hawaii driving conditions (U.S. DOT 2016),[50] which is assumed to remain constant over time. The average fuel efficiency of motorcycles was obtained from U.S. DOT (2016). Motorcycle gasoline consumption was then calculated using the following equation:

$$C(t)_{gasoline} = N(t)_{Motorcycles} \times FE(t)_{Motorcycles} \times VMT(t)_{Motorcycles}$$

where,

$C(t)_{gasoline}$	= Total motorcycle gasoline consumption in year *t*
$N(t)_{Motorcycles}$	= Number of motorcycles on the road in year *t*
$FE(t)_{Motorcycles}$	= Fuel efficiency for motorcycles
$VMT(t)_{Motorcycles}$	= Motorcycle VMT in year *t*

Emissions from motorcycles were calculated by multiplying gasoline consumption by emissions factors obtained from the U.S. Inventory (EPA 2017a).

Domestic Aviation

Emissions from domestic aviation were projected based on the UHERO macroeconomic forecast and projected gains in energy efficiency. Specifically, jet fuel consumption is assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast. The forecast was then adjusted to reflect expected gains in energy efficiency of 0.5 percent annually, based on ICAO (2016), using the following equation.

$$C(t)_{Jetfuel} = C(2015)_{Jetfuel} * G(t)_{GSP} * (1 - E)\text{^}(\mathrm{t} - 2015)$$

where,

$C(t)_{Jetfuel}$	= Total jet fuel consumption in year *t*
$C(2015)_{Jetfuel}$	= Total jet fuel consumption in 2015
$G(t)_{GSP}$	= Growth in GSP in year *t* relative to 2015
E	= Annual efficiency gains
t	= Year

[50] Hawaii LDVs are driven on average 17 percent fewer miles than the national average. This reduction in travel was applied to the national average VMT for motorcycles to compute average VMT for motorcycles in Hawaii.

Emissions from domestic aviation were calculated by multiplying jet fuel consumption by emissions factors obtained from the U.S. Inventory (EPA 2017a).

Domestic Marine and Military

Emission projections were not developed for domestic marine or military. Instead, future emissions are assumed to remain constant relative to 2015. For domestic marine, emissions were not projected due to inconsistencies in the historic emissions trend. Emissions from military operations were also not projected because decisions regarding the magnitude of activities are generally external to Hawaii's economy. As such, growing emissions based on GSP, the method used to project emissions for other small sources, was determined to be inappropriate. Further discussion of data uncertainties for these sources is provided in the section below.

Uncertainties and Areas for Improvement

There are a number of notable uncertainties associated with projecting emissions from the transportation sector. For LDVs, there is uncertainty in the fleet fuel efficiency due to uncertainty in the future adoption of EVs as well as the fuel efficiency of new vehicles. Though the CAFE standard implies a certain amount of EV adoption, it does not account for variation in Hawaii's level of EV adoption relative to the national trend. Due to shorter driving differences and strong mandates for public charging stations, there is reason to believe that Hawaii's rate of uptake for EVs will continue to exceed the national average. As such, this analysis estimates there will be additional EV adoption in Hawaii, which is an optimistic outlook on emissions and also highly uncertain. Regarding the fuel efficiency of new vehicles, this analysis assumes there is a 15 percent difference in CAFE and on-road fuel efficiency. However, UCS has said that the difference could be as high as 40 percent (UCS 2011), though improvements to close this gap have been made (EPA 2014). None of these numbers are Hawaii-specific.

There is also uncertainty in the breakout of LDV into trucks and cars due to a discrepancy between vehicle registration data from DBEDT (2018d) and vehicle sales data from (HADA 1989-2013). In addition, there is uncertainty regarding the impact of the Honolulu Rail Project on LDV VMT trends. The Honolulu Authority for Rapid Transportation currently expects the system to be operational from Kapolei to Aloha Stadium by late 2020, and entirely operational through Ala Moana Center by 2025. This study does not account for the potential substitution of trips from vehicles to transit due to this project.

For HDVs, there is uncertainty in the future fuel efficiency of the fleet as well as the rate of fleet turnover. In addition, there is uncertainty in the future consumption of biodiesel, which was projected based on GSP. Additional research into the drivers of future trends may be considered in future iterations of this work to further improve the assumptions used in the analysis.

For domestic aviation, jet fuel consumption by the commercial sector is projected based on GSP, even though commercial jet fuel consumption from 2010 to 2015 grew by 14 percent from 2010 to 2015, which is inconsistent with GSP, which grew by 8 percent over the same period. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Emission projections were not developed for domestic marine or military. For domestic marine, there were large fluctuations in marine-based fuel consumption from 2010 to 2015. Specifically, marine-based fuel consumption decreased by 60 percent from 2010 to 2015, which does not align with the activities of the overall economy. For the military, there similarly was a significant decrease in fuel consumption from 2010 to 2015. Furthermore, decisions regarding future military operations in Hawaii are largely external to Hawaii's economy, and, therefore, are not expected to correlate with GSP. Further research into the accuracy and drivers of historical trends will be explored in future analyses to determine an appropriate approach for projecting emissions for these sectors.

Incineration of Waste

Methodology

Emissions from incineration of waste were projected using data from the PSIP, representing the waste-to-power plant operating on Oahu (PUC 2016). The PSIP includes both biogenic and non-biogenic sources of emissions. To exclude biogenic sources, the team applied the ratio of non-biogenic emissions to total emissions (34:100) from the 2015 inventory results.

Uncertainties and Areas for Improvement

There are no notable uncertainties or areas for improvement.

Oil and Natural Gas Systems

Methodology

Emissions from oil and natural gas systems were projected based on the weighted average growth in petroleum consumption in the Stationary Combustion and Transportation sectors. Growth in each sector was estimated using the following equations:

$$SG(t) = {(SE_t - SE_{2015})}\Big/{SE_{2015}}$$

where,

$SG(t)$	= Growth in stationary combustion emissions by year *t*
SE_t	= Stationary combustion emissions in year *t*
SE_{2015}	= Stationary combustion emissions in 2015

$$TG(t) = {(TE_t - TE_{2015})}/{TE_{2015}}$$

where,

$TG(t)$	= Growth in transportation emissions by year *t*
TE_t	= Transportation emissions in year *t*
TE_{2015}	= Transportation emissions in 2015

The growth estimates for each sector were then weighted using the following equation:

$$OG(t) = \frac{SG(t) \times SE_{2015} + TG(t) \times TE_{2015}}{SE_{2015} + TE_{2015}}$$

where,

$OG(t)$	= Growth in oil emissions by year t
$SG(t)$	= Growth in stationary combustion emissions by year t
SE_{2015}	= Stationary combustion emissions in 2015
$TG(t)$	= Growth in transportation emissions by year t
TE_{2015}	= Transportation emissions in 2015

Finally, total emissions in the oil sector were calculated using the following equation:

$$OE(t) = OE_{2015} \times OG(t)$$

where,

$OE(t)$	= Oil emissions by year t
OE_{2015}	= Oil emissions in 2015
$OG(t)$	= Growth in oil emissions by year t

Uncertainties and Areas for Improvement

The methodology used to project emissions from oil and natural gas systems is based on the assumption that the two oil refineries that are currently in operation will remain in operation in 2020 and 2025. There is a possibility that one or both refineries will shut down due to decline in demand from the Stationary Combustion and Transportation sectors, however recent expansion efforts in response to jet fuel demand suggest otherwise (Mai 2018).

Electrical Transmission and Distribution

Methodology

Electrical transmission and distribution emissions were projected based on the PSIP electricity sales forecast for 2016-2025. The HEI utility expects a 4 percent decline in sales from 2016-2045 due to a combination of efficiency gains and on-site generation. Due to rounding and the relatively small magnitude of emissions, the emission projections presented in Table 7-3 show that emissions from this source remain constant across the time series even though they are projected to decrease slightly.

Uncertainties and Areas for Improvement

The methodology used to project electrical transmission and distribution emissions is based on the historical trend of emissions from this source being largely correlated with the trend in electricity sales. Because emissions from this source are small, future improvements to electrical transmission and distribution systems that could reduce the intensity of emissions (kg SF_6 per kWh sold), which has decreased over time, were not considered for the projections, but may be considered in future analyses.

Substitution of Ozone Depleting Substances

Methodology

Emissions from the substitution of ozone depleting substances are assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast.

Uncertainties and Areas for Improvement

The methodology used to project emissions from the substitution of ozone depleting substances is based on the fact that emissions from this source typically correlate with economic activity. International and federal programs and policies (e.g., Kigali Amendment to the *Montreal Protocol*, Executive Order 13693, EPA SNAP Rules 20 and 21) that aim to reduce emissions from the substitution of ozone depleting substances were not considered for the projections, but may be considered for future analyses.

Enteric Fermentation

Methodology

Emissions from enteric fermentation were projected by projecting animal populations and animal-specific emission factors, and applying the same methodology used to estimate 2015 emissions. Animal population data were projected based on the trend of the last ten years of data, as obtained from the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) (USDA 2017a) and the USDA Census of Agriculture (USDA 2004, USDA 2009, USDA 2014). Annually variable enteric fermentation emission factors were projected using the ten-year average by cattle type from the U.S. Inventory (EPA 2017a). Emission factors for sheep, goats, horses, and swine, which come from IPCC (2006), are assumed to remain constant.

Uncertainties and Areas for Improvement

The methodology used to project emissions from enteric fermentation is based on the assumption that animal populations will follow a trend consistent with the past. However, there is potential for future animal populations to deviate from the historical trend. In addition, historical population estimates for sheep, goats, and horses are not reported every year from 2006 through 2015. As a result, historic estimates for these animals are interpolated between years and extrapolated through 2015. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Manure Management

Methodology

Emissions from manure management were projected by projecting activity data and emission factors, and applying the same methodology used to estimate 2015 emissions. Animal population data were projected based on the trend of the last ten years of data, as obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c) and the USDA Census of Agriculture (USDA 2004, USDA 2009, USDA

2014). For chicken populations, which have been historically decreasing over time, an annualized percent change method was applied instead to maintain projections greater than zero.

For non-cattle animal types, the typical animal mass (TAM), maximum potential emissions, volatile solids (VS) excretion rates, nitrogen excretion (Nex) rates, and weighted methane conversion factors (MCF) are assumed to remain constant relative to 2015 values (EPA 2017a; EPA 2017e). The percent distribution of waste to animal waste management systems for non-cattle types were projected using the ten-year average by system and animal type from the U.S. Inventory (EPA 2017a). For cattle, TAM, maximum potential emissions, VS excretion rates, Nex rates, MCF, and percent distribution of waste to waste management systems, which are all from the U.S. Inventory (EPA 2017a), were projected using the ten-year average by factor.

Uncertainties and Areas for Improvement

The methodology used to project emissions from manure management is based on the assumption that animal populations will follow a trend consistent with the past. However, there is potential for future animal populations to deviate from the historical trend. In addition, historical population estimates for sheep, goats, horses, and chicken are not reported every year from 2006 through 2015. As a result, historic estimates for these animals are interpolated between years and extrapolated through 2015. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Agricultural Soil Management

Methodology

Emissions from agricultural soil management were projected by projecting animal populations, crop area, crop production, as well as emission factors and other inputs, and applying the same methodology used to estimate 2015 emissions. Animal population data for cattle, swine, sheep, goats, horses, and chicken were projected based on the trend of the last ten years of data, as obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c) and the USDA Census of Agriculture (USDA 2004, USDA 2009, USDA 2014). For chicken populations, which have been historically decreasing over time, an annualized percent change method was applied instead to maintain projections greater than zero.

Sugarcane crop area and production were projected to be zero starting in 2017 due to the closing of the last sugar mill in Hawaii (American Sugar Alliance 2017). For other crops, crop area and production data were projected based on the ten-year trend of historical data obtained from the USDA Census of Agriculture (USDA 2004, USDA 2009, USDA 2014). For pineapples and ginger root production, which has been historically decreasing over time, an annualized percent change method was applied instead to maintain projections greater than zero.

The percent distribution of waste to animal waste management systems was projected based on the ten-year average of data from the U.S. Inventory (EPA 2017a). Synthetic fertilizer consumption was projected based on the five-year historical trend (AAPFCO 2010 through 2017) while commercial organic fertilizer consumption is assumed to remain at zero. Crop residue factors from IPCC (2006) are also assumed to remain constant.

Uncertainties and Areas for Improvement

The methodology used to project emissions from agricultural soil management is based on the assumption that animal populations, crop area, crop production, and fertilizer consumption will follow a trend consistent with the past. However, there is potential for future animal populations and agricultural activity data to deviate from the historical trend. In addition, historical animal populations, crop area, and crop production are not reported every year from 2006 through 2015. As a result, historic estimates for these data are interpolated between years and extrapolated through 2015. Historical fertilizer consumption data are also extrapolated through 2015 from data in 2013. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Emissions from seed production, including emissions from fertilizer consumption for seed production, are not fully captured in total emissions from agricultural soil management, because acres harvested for seed crops are reported in aggregate with other crop acreage data in USDA Census of Agriculture reports. It is also unclear whether seed producers report fertilizer consumption to AAPFCO. Conducting further research to identify seed production activity data may be considered to estimate emissions from seed production in future analyses.

Field Burning of Agricultural Residues

Methodology

Sugarcane crop area and production is projected to be zero starting in 2017 due to the closing of the last sugar mill in Hawaii (American Sugar Alliance 2017). Historically, sugarcane was the only major crop in Hawaii whose residues were regularly burned (Hudson 2008). As a result, no emissions from field burning of agricultural residues are projected in 2020 and 2025.

Uncertainties and Areas for Improvement

It is uncertain whether sugarcane production will return to Hawaii as markets and trade regulations evolve. In addition, it is possible that other crop residues will be burned in the future. Further research into field burning practices in Hawaii may be considered in future analyses.

Urea Application

Methodology

Emissions from urea application were projected by projecting fertilizer consumption and applying the same methodology used to estimate 2015 emissions. Fertilizer consumption data were projected based on the five-year historical trend (AAPFCO 2010 through 2017).

Uncertainties and Areas for Improvement

The methodology used to project urea application is based on the assumption that urea consumption will follow a trend consistent with the past. However, there is potential for urea application activity to deviate from the historical trend. Further research into the drivers of historical trends may be considered in future analyses.

Agricultural Soil Carbon

Methodology

Emissions from agricultural soils—both grassland and cropland—were projected based on projected changes in land cover and carbon stock from 2011 to 2061 by the U.S. Geological Survey (USGS) (Selmants et al., 2017). Specifically, the estimated percent change in carbon stored in grassland and the estimated percent change in cropland area from 2011 to 2061 were annualized and applied to the 2015 emission estimates for grassland and cropland, respectively, to obtain 2020 and 2025 estimates.

Uncertainties and Areas for Improvement

The methodology used to project emissions from agricultural soil carbon in grassland and cropland is based on USGS projections of emissions and area that are specific to Hawaii and consider land transitions, impacts of climate change, and other factors under a business-as-usual (BAU) scenario (Selmants et al. 2017). There is potential for these projections to change as the impacts of climate change are realized and policies evolve. The projections are also based on the assumption that emissions from grassland and cropland will decrease at constant rates annually from 2011 to 2061. This methodology does not consider inter-annual variability in emissions from grassland or cropland.

In addition, the methodology assumes that emissions from cropland will decrease at the same rate as cropland area. However, emissions may not align with trends in cropland area if carbon sequestration rates in cropland improve over time, such as through improved management practices (e.g., no tilling). The Hawaii Greenhouse Gas Sequestration Task Force established by Act 15 will work to identify practices in agriculture to improve soil health, which may also reduce future emissions from cropland (Hawaii Legislature 2018). Further research into emissions reductions from improved agricultural soil management practices may be considered in future analyses.

Forest Fires

Methodology

Emissions from forest fires were projected by projecting activity data and emission factors, and applying the same methodology used to estimate 2015 emissions. Wildfire acres burned were projected based on the projected average area of land burned annually from 2012 to 2061, as obtained from USGS (Selmants et al. 2017). Forest and shrubland areas were projected based on projected changes in forest and shrubland area from 2011 to 2061 by the USGS (Selmants et al. 2017). Specifically, the percent change in forest and shrubland area from 2011 to 2061 was annualized and applied to the 2016 estimates of forest and shrubland area from the State of Hawaii Data Book to obtain 2020 and 2025 estimates (DBEDT 2017b).

The annual carbon density of wildfires for the lower 48 states (i.e., the carbon available for combustion), as obtained from the U.S. Forest Service (2014) was assumed to remain constant, based on USGS estimates that statewide carbon density in Hawaii will remain relatively stable through 2061 (Selmants et al., 2017). Emission factors for CH_4 and N_2O as obtained from IPCC (2006) were also assumed to remain constant. IPCC (2006) default combustion factors for tropical forest and shrubland were weighted using an estimated ratio of Hawaii forest to shrubland fires based on USGS projections (Selmants et al. 2017).

Uncertainties and Areas for Improvement

The methodology used to project emissions from forest fires is based on USGS projections of area that are specific to Hawaii and consider land transitions, impacts of climate change, and other factors under a BAU scenario (Selmants et al. 2017). There is potential for these projections to change as the impacts of climate change are realized and policies evolve. The projections are also based on the assumption that forest and shrubland area will change at constant rates annually from 2011 to 2061. This methodology does not consider inter-annual variability in forest and shrubland area. Further research into the composition of forest and shrubland in Hawaii may be considered in future analyses.

Landfilled Yard Trimmings and Food Scraps

Methodology

Estimates of carbon sequestration in landfilled yard trimmings and food scraps were projected by projecting activity data, emission factors, and other inputs, and applying the same methodology used to estimate 2015 emissions.

Estimates of the amount of yard trimmings and food scraps discarded in landfills in the United States were projected using the five-year historical trend, based on data obtained from EPA's State Inventory Tool (EPA 2017f). Hawaii and U.S. population estimates were projected based on five-year growth rates in Hawaii's population from the State of Hawaii Data Book (DBEDT 2017b) and annual growth rates in national population from the U.S. Census Bureau (2014).

The estimated carbon conversion factors and decomposition rates obtained from the State Inventory Tool (EPA 2017f) were assumed to remain constant over the projected time series.

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in landfilled yard trimmings and food scraps is based on the assumption that the amount of landfilled yard trimmings and food scraps in Hawaii will follow a trend consistent with the past. The methodology does not consider increases in composting yard trimmings and food scraps. For example, Honolulu County prohibits commercial and government entities from disposing yard trimmings in landfills (City & County of Honolulu's Department of

Environmental Services 2005). Further research into Hawaii trends in diverting yard trimmings and food scraps from landfills may be considered in future analyses.

Urban Trees

Methodology

Estimates of carbon sequestration in urban trees were projected by projecting urban area and other inputs, and applying the same methodology used to estimate 2015 emissions. Urban area was projected based on projected changes in developed area from 2011 to 2061 by the USGS (Selmants et al. 2017). Specifically, the percent change in developed area was annualized and applied to the 2015 estimate of urban area to project 2020 and 2025 estimates. The estimated carbon sequestration rates for urban trees and the percent tree cover in urban areas in Hawaii were assumed to remain constant with 2015 estimates (Vargas et al. 2007; Nowak et al. 2012).

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in urban trees is based on USGS projections of area that are specific to Hawaii and consider land transitions, impacts of climate change, and other factors under a BAU scenario (Selmants et al. 2017). There is potential for these projections to change as the impacts of climate change are realized and policies evolve. The projections are also based on the assumption that urban area and carbon sequestration will increase linearly over the projected time series. This methodology does not consider potential changes in the rate of urbanization over time. The sequestration rate in urban trees may also vary over time due to possible changes in the percent tree cover, which can be impacted by urban planning initiatives. In addition, the Hawaii Greenhouse Gas Sequestration Task Force established by Act 15 will work to identify opportunities to increase urban tree cover (Hawaii Legislature 2018). Further research into urban planning initiatives that involve tree cover and trends in urbanization may be considered in future analyses.

Forest Carbon

Methodology

Estimates of carbon sequestration in forests and shrubland were projected by projecting forest and shrubland area and emission factors, and applying the same methodology used to estimate 2015 emissions. Forest and shrubland areas were projected based on projected changes in forest and shrubland area from 2011 to 2061 by the USGS (Selmants et al. 2017). Specifically, the percent change in forest and shrubland area from 2011 to 2061 was annualized and applied to the 2016 estimates of forest and shrubland area from the State of Hawaii Data Book to obtain 2020 and 2025 estimates (DBEDT 2017b). The IPCC (2006) default biomass growth and carbon fraction factors were used and assumed to remain constant over the projected time series, based on USGS estimates that statewide carbon density in Hawaii will remain relatively stable through 2061 (Selmants et al., 2017).

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in forests and shrubland is based on USGS projections of area that are specific to Hawaii and consider land transitions, impacts of climate change, and other factors under a BAU scenario (Selmants et al. 2017). There is potential for these projections to change as the impacts of climate change are realized and policies evolve. The projections also assume that forest and shrubland area will change at constant rates annually from 2011 to 2061. This methodology does not consider inter-annual variability in forest and shrubland area. Further research into the composition of forest and shrubland in Hawaii may be considered in future analyses.

The projections similarly assume that carbon sequestration will increase linearly with forest and shrubland area. This methodology does not consider potential changes in sequestration rates due to the age of the forest ecosystem and forest management practices. USGS notes that there are uncertainties associated with the age of Hawaii forest ecosystems, which can impact sequestration rates (Selmants et al. 2017). In addition, the Hawaii Greenhouse Gas Sequestration Task Force established by Act 15 will work to identify practices to increase forest carbon and promote sequestration, which may increase future sequestration rates in forests (Hawaii Legislature 2018). Further research into the age of Hawaii forests, improved forest management practices, and their emissions reduction potential may be considered in future analyses.

Landfills

Methodology

Emissions from landfills are assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast.

Uncertainties and Areas for Improvement

The methodology used to project emissions from landfills is based on the observation that emissions from this source correlate with economic activity. The analysis does not account for waste diversion policies or programs that could impact future waste generation, a potential increase in methane capture activities, or an increase in waste-to-power generation, as there are no clearly stated plans for this within the PSIP. Additional research may be done on the impact of waste diversion policies or programs for consideration in future analyses.

Composting

Methodology

Emissions from composting are assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast.

Uncertainties and Areas for Improvement

The methodology used to project emissions from composting is based on the observation that emissions from this source correlate with economic activity. The analysis does not account for policies or programs that could impact composting activities but may be considered in future analyses.

Wastewater Treatment

Methodology

Emissions from wastewater treatment are assumed to grow at the rate of GSP, which was projected based on the UHERO macroeconomic forecast.

Uncertainties and Areas for Improvement

The methodology used to project emissions from wastewater treatment is based on the observation that emissions from this source correlate with economic activity. The analysis does not account for policies or programs that could impact future water use or methane capture activities but may be considered in future analyses.

Appendix I: Emission Scenarios for Electricity Generation by HECO

The Power Supply Improvement Plan (PSIP) conducted by Hawaii Energy Companies (HECO) contains several scenarios for meeting Hawaii's renewable portfolio standard (RPS) of 100 percent renewable energy by 2045, as well as intermediate targets including that of 30 percent renewable energy by 2020. These scenarios cover electricity emissions for Oahu, Maui, and Hawaii County and thus represent the majority of emissions in the energy industries sector. Variation in emissions between scenarios reflect differing timelines and resource choices for buildout of renewable technologies as well as the retirement of existing fossil fuel units on the other.

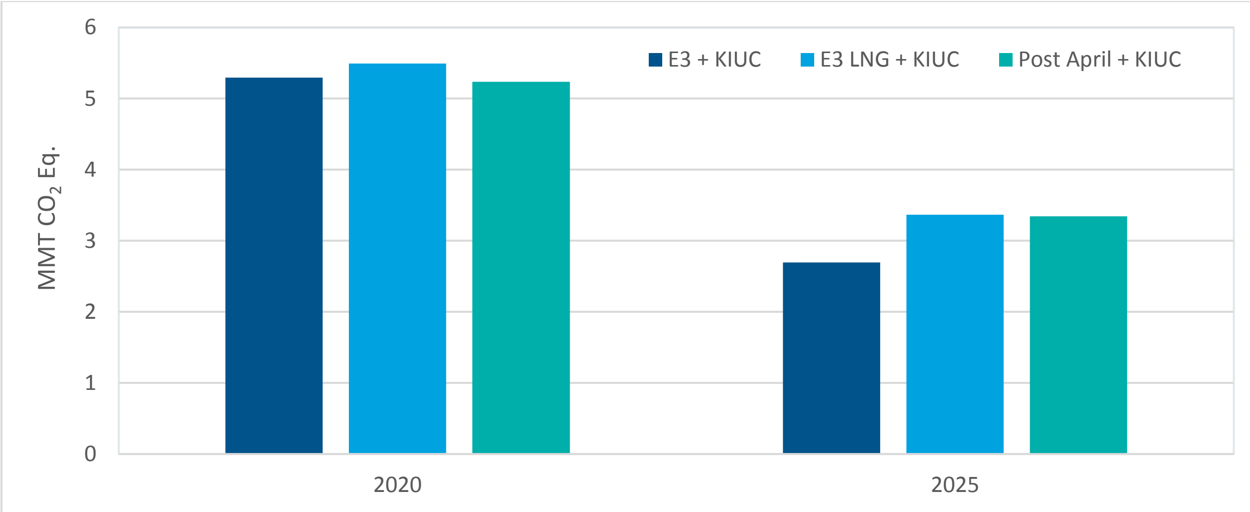
The scenarios were developed combining three modelling tools: Energy & Environmental Economics (E3) RESOLVE, PowerSim, and PLEXOS. The E3 RESOLVE developed least-cost scenarios for achieving Hawaii's RPS goals and included considerations of alternatives such as liquefied natural gas (LNG), generation modernization, and an interisland cable. PLEXOS provided hourly and sub-hourly analysis of the E3 RESOLVE results. HECO's PowerSimm Planner integrated cost and risk considerations into the scenarios. A summary of the key distinctions between the three scenarios is provided in Table I-1 below.

Table I-1: Total Capacity Buildouts for the Years 2017-2025 by PSIP Scenario (MW)

Energy Source	E3	E3 with LNG	Post April
Wind	368	113	187
Utility-Scale Photovoltaic	572	329	732
Biofuels	40	20	40
Geothermal	0	0	0
Hydro	4	1	0
Battery storage	568	496	252
Liquefied natural gas	0	106	0
Flexible dispatchable generation	54	54	54
Combined cycle turbine	0	3	151
Synchronized condenser	61	55	61
Internal combustion engine	18	0	9
Unspecified	150	50	150

For the purposes of this report, the team used the E3 scenario to forecast emissions for the year 2020 and 2025. A comparison of emissions under each scenario is provided in Figure I-1.

Figure I-1: Emissions for HEI Utilities by PSIP Scenario, Excluding Biodiesel



Emissions by fuel type under each scenario are summarized in Table I-2, based on the assumptions for sources of electricity generation provided in Table I-1.

Table I-2: 2020 and 2025 Power Sector Emissions by Fuel Type and PSIP Emissions Scenario (MMT CO_2 Eq.)

	Coal	Residual Fuel	DFO	ULSD	Natural Gas	Biodiesel	Total
2020							
E3	1.51	2.78	0.80	0.02	NO	0.06	5.17
E3 LNG	1.57	2.90	0.82	0.02	NO	0.05	5.37
Post April	1.53	2.87	0.64	0.02	NO	0.04	5.10
2025							
E3	NO	1.25	0.69	0.64	NO	0.12	2.71
E3 LNG	NO	NO	0.68	0.43	2.15	0.02	3.28
Post April	NO	1.72	0.46	1.07	NO	0.04	3.28

NO (emissions are Not Occurring).

Note: All PSIP data for emissions were converted from tons to metric tons.

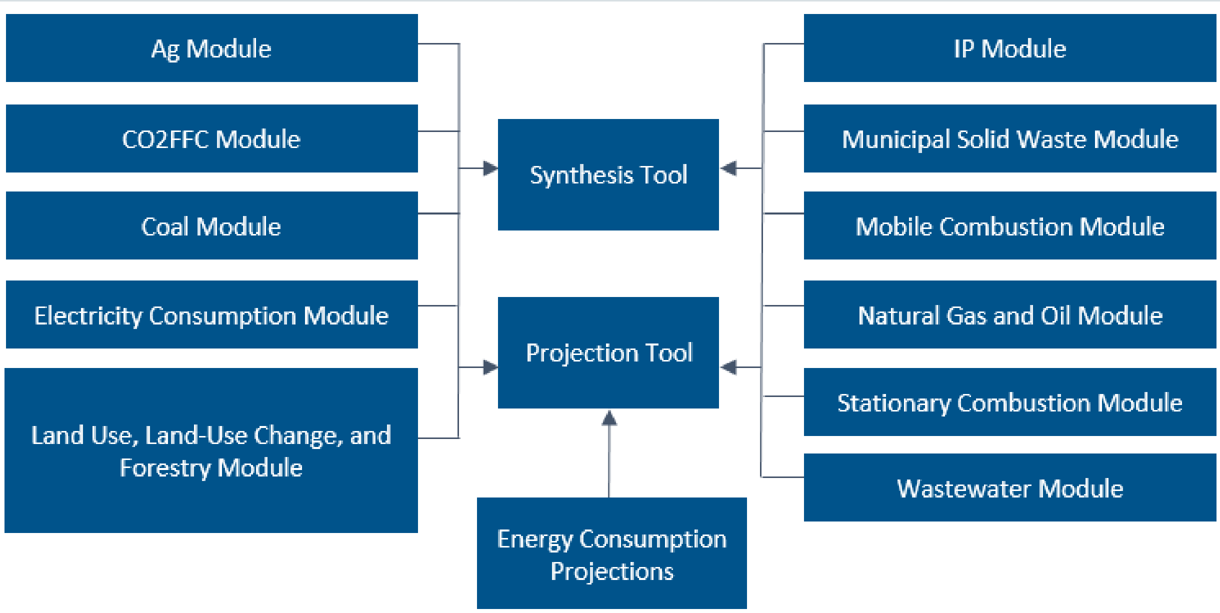
Appendix J: Comparison of Results with the State Inventory Tool and Projection Tool

EPA's State Inventory and Projection Tool is an interactive spreadsheet model designed to help states develop GHG emissions inventories.[51] The tool has two components:

- **The State Inventory Tool** (SIT) consists of 11 estimation modules applying a top-down approach to calculate GHG emissions, and one module to synthesize estimates across all modules. The SIT gives users the option of applying their own state-specific data or using default data pre-loaded for each state. The default data are gathered by federal agencies and other resources covering fossil fuels, electricity consumption, agriculture, forestry, waste management, and industry. All of the modules estimate direct GHG emissions, with the exception of the electricity consumption module which estimates indirect GHG emissions from electricity consumption. The methods used are, for the most part, consistent with the U.S. GHG Inventory.
- **The Projection Tool** allows users to create a simple forecast of emissions through 2030 based on historical emissions that are imported from the SIT modules, combined with projections of future energy consumption, population, and economic factors.

Figure J-1 below provides an overview of the files that make up the SIT and projection tool.

Figure J-1: Overview of the SIT and Projection Tool File Structure



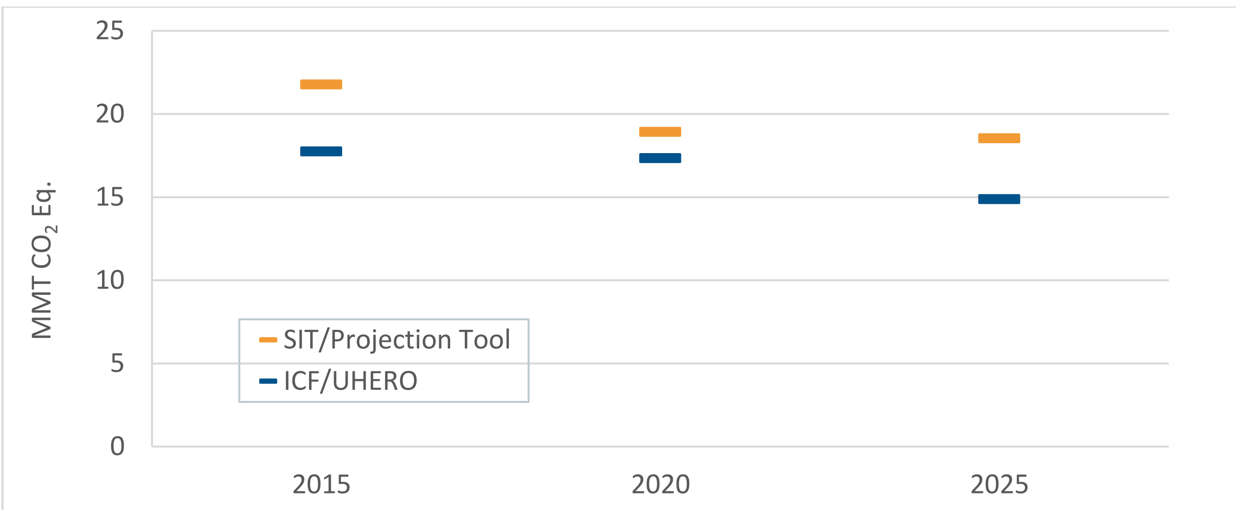
[51] The State Inventory and Projection Tool is designed to estimate emissions at the state level; the tool does not currently have the capability to generate county level emissions.

To support QA/QC of the inventory results, and in an effort to evaluate the accuracy[52] and usability of the SIT and Projection Tool estimates for the state of Hawaii, ICF ran the tool for Hawaii using default values and compared the output against the 2015 inventory and the inventory projections for 2020 and 2025, as developed by ICF and UHERO.[53] This appendix presents the results of this comparison.

Key Observations

Net GHG emissions for 2015 estimated using the SIT are 23 percent greater than this inventory. About half of this difference is due to the lack of default forest carbon flux data available in the SIT. Net GHG emissions for Hawaii is 9 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, and 22 percent higher in 2025. The Projection Tool notably does not estimate emissions from Land Use, Land Use Change, and Forestry (LULUCF) source and sink categories. Net emissions for 2015, 2020, and 2025, as estimated by ICF/UHERO and the SIT/Projection Tool, are shown in Figure I-2 below.

Figure J-2: Comparison of Net Emission Estimates (2015, 2020, and 2025)



Key observations from using the SIT for 2015 GHG estimates include the following:

- Over 50 percent of the difference is from Forest Carbon (see Table J-2). The SIT does not provide default data for estimating Forest Carbon sinks.
- Estimates for seven categories comprise 90 percent of the difference between the SIT and ICF analysis. These include Forest Carbon, Incineration of Waste, Transportation, Iron & Steel Production, Urban Trees, Oil and Natural Gas, and Landfills.

[52] While there is some level of uncertainty in the estimates prepared by ICF and UHERO (as discussed in the body of this report), the estimates prepared by ICF and UHERO are believed to be a more accurate representation of statewide emissions based on the use of best available data and methodologies that are specific to Hawaii.

[53] The SIT and Projection Tool are available online at https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool. The SIT modules and Synthesis Tool used for this analysis were downloaded from EPA's website in January 2018. The Projection Tool was downloaded from EPA's website in July 2018.

- Relative to ICF's estimates, which relies more heavily on Hawaii-specific activity data, the SIT estimates higher emissions from all sectors; however, for individual source categories, in some cases, the SIT estimates lower emissions.

Key observations from using the Projection Tool for 2020 and 2025 GHG estimates include the following:

- The Projection Tool does not estimate emissions from LULUCF source and sink categories.
- Over 60 percent of the difference in 2020 emission projections is from Forest Carbon, Stationary Combustion, and Incineration of Waste source and sink categories (see Table J-4).
- The estimate for Stationary Combustion is 36 percent lower in 2020 using the SIT (however, it is 4 percent higher in 2025).
- Roughly 60 percent of the difference in 2025 emission projections are from the Forest Carbon, Incineration of Waste, and Substitution of ODS source and sink categories (see Table J-6).
- Relative to ICF/UHERO's estimates, the Projection Tool estimates lower emissions from the Energy sector in 2020, but higher emissions in 2025.
- Relative to ICF/UHERO's estimates, the Projection Tool estimates lower emissions from the IPPU sector but higher emissions from the Waste sector in both 2020 and 2025.

Uncertainty and QA/QC

There is uncertainty associated with the GHG estimates from the SIT and Projection Tool; however, this uncertainty is not quantified. The SIT modules include qualitative descriptions of the uncertainties involved in estimating emissions from each source category. The uncertainty of the default data and parameters in the SIT and Projection vary by source category and may be reviewed in more detail within the individual modules. In general, where national level data is relatively accurate (e.g., energy consumption data), there can be more uncertainty at the state level. This is because when the SIT allocates national level data to the states, it may not fully account for variations across states that impact emissions for a given source category.

The SIT and Projection Tool do not include standardized QA/QC plans or procedures. The tools are designed in a way that restricts the user's ability to edit and review background data and calculations by locking and password protecting most of the Excel spreadsheets. This limits the potential for the user to make data entry and calculation errors, but also limits the ability to review calculations for accuracy.

Next Steps for Future Analyses

In forthcoming reports, ICF will explore whether the SIT and Projection Tool can be tailored to more accurately estimate emissions for the state of Hawaii. Specific next steps may include:

- Replacing default data in the SIT and Projection Tool with state-specific data.
- Inserting data into the SIT and Projection Tool for source and sink categories where default data is not provided (e.g., forest carbon).
- Identifying potential improvements to the SIT and Projection Tool that could be suggested to EPA.

Comparison of Results

To compare the results from the SIT against the 2015 inventory developed by ICF, results from each of estimation modules were compared against the source and sink categories defined in the 2015 inventory. All modules were run except for the Electricity Consumption Module and the Coal Module; the Electricity Consumption Module double counts emissions estimated by the Fossil Fuel Combustion Module and the Coal Module, which estimates emissions from coal mining, is not applicable to the state of Hawaii. Figure J-3 summarizes how the results from the SIT were mapped to the 2015 inventory.

Figure J-3: Mapping of SIT Modules to Hawaii's 2015 Inventory

Inventory Source	Inventory Source Category	SIT Module (Source)
Energy	Stationary Combustion	Stationary Combustion
		CO_2FFC (Residential, Commercial, Industrial, and Electric Utilities)
	Transportation	CO_2FFC (Transportation)
		Mobile Combustion
	Oil and Natural Gas Systems	Natural Gas and Oil
	Incineration of Waste	Municipal Solid Waste (Combustion)
IPPU	Substitution of ODS	IP (ODS Substitutes)
	Electrical Transmission and Distribution	IP (Electric Power Transmission and Distribution Systems)
AFOLU	Enteric Fermentation	Ag (Enteric Fermentation)
	Manure Management	Ag (Manure Management)
	Agricultural Soil Management	Ag (Ag Soils)
	Field Burning of Agricultural Residues	Ag (Agricultural Residue Burning)
	Forest Carbon	LULUCF (Forest Carbon Flux)
	Urea Application	LULUCF (Urea Fertilization)
	Urban Trees	LULUCF (Urban Trees)
	Landfilled Yard Trimmings and Food Scraps	LULUCF (Landfilled Yard Trimmings and Food Scraps)
	Forest Fires	LULUCF (Forest Fires)
	Agricultural Soil Carbon	LULUCF (Agricultural Soil Carbon Flux)
Waste	Landfills	Municipal Solid Waste (Landfills)
	Wastewater	Wastewater
	Composting	

2015 Inventory Comparison

For the state of Hawaii, ICF and the SIT estimate that in 2015 total GHG emissions were 21.28 MMT CO_2 Eq. and 22.49 MMT CO_2 Eq., respectively, a difference of 6 percent. At the same time, ICF and the SIT estimate that in 2015 net emissions were 17.75 MMT CO_2 Eq. and 21.77 MMT CO_2 Eq., respectively, a difference of 23 percent. A summary of 2015 emissions and sinks by sector and category, as estimated by ICF and the SIT, are provided in Table J-1.

Table J-1: Comparison of 2015 Emission Results (MMT CO_2 Eq.)

Sector/Category	ICF	SIT	Difference	% Difference
Energy	**18.57**	**19.36**	**0.79**	**4%**
Stationary Combustion	8.38	8.27	(0.12)	(1%)
Transportation	9.79	10.32	0.53	5%
Incineration of Waste	0.20	0.78	0.58	285%
Oil and Natural Gas Systems[a]	0.19	NE	(0.19)	NA
IPPU	**0.83**	**1.07**	**0.24**	**29%**
Electrical Transmission and Distribution	0.01	0.01	+	1%
Substitution of ODS	0.82	0.75	(0.07)	(9%)
Soda Ash Manufacture and Consumption[b]	NO	0.01	0.01	NA
Urea Consumption[b]	NO	+	+	NA
Iron and Steel Production[b]	NO	0.30	0.30	NA
AFOLU	**(2.44)**	**0.30**	**2.74**	**112%**
Enteric Fermentation	0.24	0.24	+	1%
Manure Management	0.04	0.05	0.01	33%
Agricultural Soil Management	0.14	0.16	0.01	10%
Field Burning of Agricultural Residues	0.01	NO	(0.01)	NA
Urea Application	+	+	(+)	(10%)
Agricultural Soil Carbon	0.56	0.56	0	0%
Forest Fires[a]	0.11	NE	(0.11)	NA
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.05)	+	(9%)
Urban Trees	(0.40)	(0.67)	(0.27)	67%
Forest Carbon[a]	(3.08)	NE	3.08	NA
N_2O from Settlement Soils[c]	NE	0.01	0.01	NA
Waste	**0.78**	**1.04**	**0.25**	**32%**
Landfills	0.72	0.88	0.16	22%
Composting[d]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.05	0.16	0.11	240%
Total Emissions (Excluding Sinks)	**21.28**	**22.49**	**1.21**	**6%**
Net Emissions (Including Sinks)	**17.75**	**21.77**	**4.02**	**23%**

+ Does not exceed 0.005 MMT CO_2 Eq.

NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[a] The SIT does not provide default data for this category.

[b] ICF estimates that this activity is not applicable to Hawaii, and therefore emissions are not occurring.

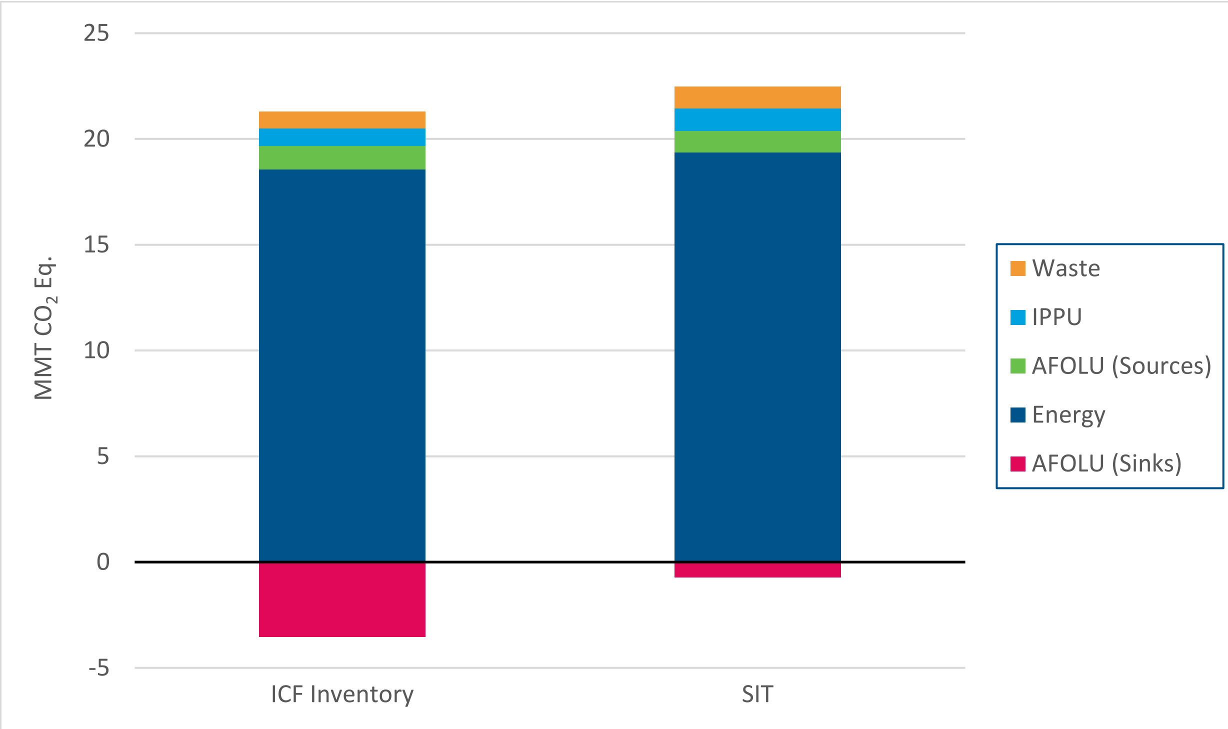
[c] ICF did not estimate emissions from N_2O from Settlement Soils due to lack of available state-specific data.

[d] The SIT does not estimate emissions from Composting.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions by sector as calculated by ICF and the SIT are presented in Figure J-4.

Figure J-4: Comparison of 2015 Emission Results (Including Sinks)



The difference in emission estimates between ICF's Inventory and the SIT are driven by differences in seven source and sink categories, which account for 90 percent of the absolute difference. Table J-2 summarizes the absolute and cumulative difference in emission estimates for these seven categories.

Table J-2: Key Sources of Differences between ICF Inventory and SIT 2015 Emission Results

Category	ICF	SIT	Absolute Difference	Cumulative % of Total Difference
Forest Carbon	(3.08)	NE	3.08	55%
Incineration of Waste	0.20	0.78	0.58	65%
Transportation	9.79	10.32	0.53	75%
Iron & Steel Production	NO	0.30	0.30	80%
Urban Trees	(0.40)	(0.67)	0.27	85%
Oil and Natural Gas	0.19	NE	0.19	88%
Landfills	0.72	0.88	0.16	91%
All Other Categories			0.50	100%

NO (emissions are Not Occurring); NE (emissions are Not Estimated).

2020 Projection Comparison

ICF, with support from the University of Hawaii Economic Research Organization (UHERO), projects 2020 total GHG emissions to be 20.91 MMT CO_2 Eq., while net emissions are projected to be 17.34 MMT CO_2 Eq. The Projection Tool, which does not project emissions from LULUCF categories, projects total and net emissions in 2020 to be 18.92 MMT CO_2 Eq. A summary of projected emissions and sinks by sector and category, as estimated by ICF/UHERO and the Projection Tool for 2020, are provided in Table J-3.

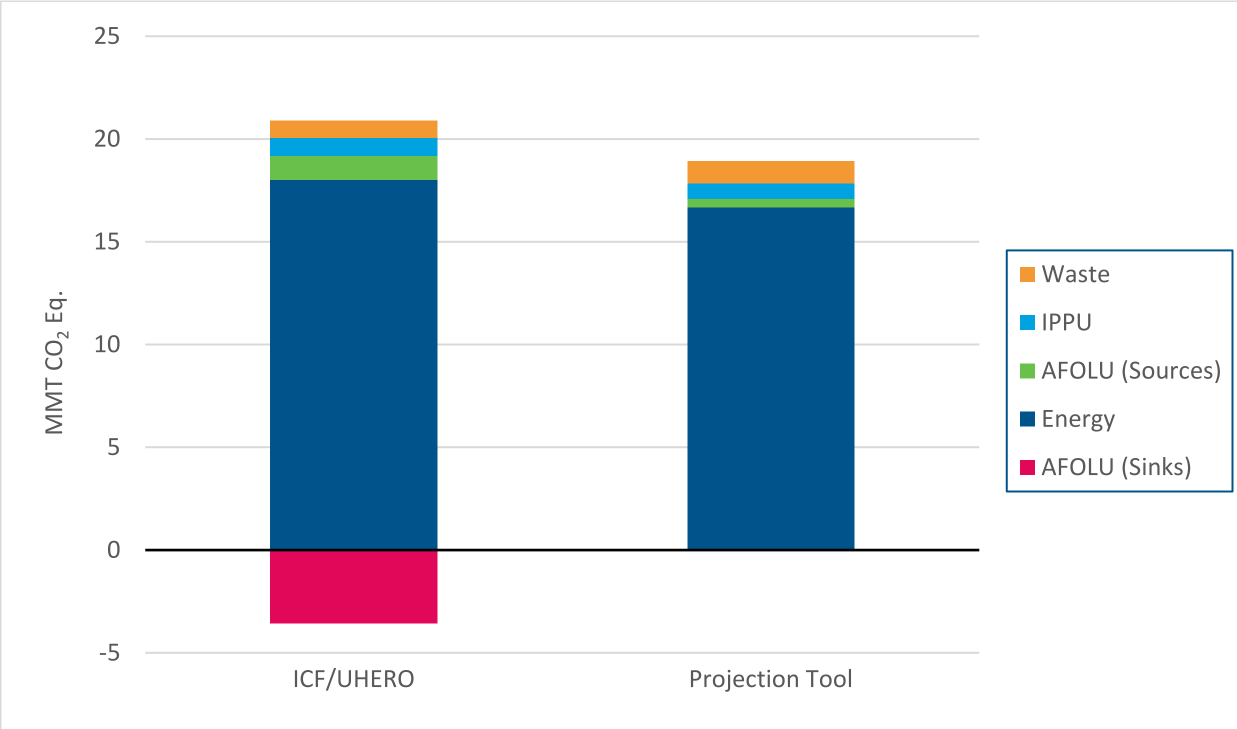
Table J-3: Comparison of 2020 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**18.00**	**16.67**	**(1.33)**	**(8%)**
Stationary Combustion	7.41	5.45	(1.96)	(36%)
Transportation	10.22	10.35	0.13	1%
Incineration of Waste	0.20	0.86	0.66	77%
Oil and Natural Gas Systems	0.17	0.01	(0.16)	(1433%)
IPPU	**0.89**	**0.78**	**(0.11)**	**(14%)**
Electrical Transmission and Distribution	0.01	0.01	+	(30%)
Substitution of ODS	0.88	0.28	(0.60)	(211%)
Limestone and Dolomite Use	NO	+	+	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.48	0.48	NA
AFOLU[a]	**(2.39)**	**0.40**	**2.79**	**701%**
Enteric Fermentation	0.23	0.21	(0.02)	(10%)
Manure Management	0.04	0.06	0.02	36%
Agricultural Soil Management	0.14	0.14	(0.01)	(5%)
Field Burning of Agricultural Residues	NO	NO	NA	NA
Urea Application[a]	+	NE	(+)	NA
Agricultural Soil Carbon[a]	0.51	NE	(0.51)	NA
Forest Fires[a]	0.26	NE	(0.26)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.05)	NE	0.05	NA
Urban Trees[a]	(0.43)	NE	0.43	NA
Forest Carbon[a]	(3.09)	NE	3.09	NA
Waste	**0.84**	**1.07**	**0.23**	**22%**
Landfills	0.77	0.91	0.14	16%
Composting[a]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.05	0.16	0.11	69%
Total Emissions (Excluding Sinks)	**20.91**	**18.92**	**(1.98)**	**(10%)**
Net Emissions (Including Sinks)	**17.34**	**18.92**	**1.59**	**8%**

+ Does not exceed 0.005 MMT CO_2 Eq.
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).
[a] The Projection Tool does not project emissions from LULUCF categories or from Composting.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions projections for 2020 by sector as calculated by ICF/UHERO and the Projection Tool are presented in Figure J-5.

Figure J-5: Comparison of 2020 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 89 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table J-4 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table J-4: Key Sources of Differences between ICF/UHERO Projections and Projection Tool Estimates in 2020

Sector/Category	ICF/UHERO	Projection Tool	Absolute Difference	Cumulative % of Total Difference
Forest Carbon	(3.09)	NE	3.09	36%
Stationary Combustion	7.41	5.45	1.96	58%
Incineration of Waste	0.20	0.86	0.66	66%
Substitution of ODS	0.88	0.28	0.60	73%
Agricultural Soil Carbon	0.51	NE	0.51	79%
Iron & Steel Production	NO	0.48	0.48	84%
Urban Trees	(0.43)	NE	0.43	89%
All Other Categories			1.11	100%

NO (emissions are Not Occurring); NE (emissions are Not Estimated).

2025 Projection Comparison

ICF, with support from UHERO, project 2025 total GHG emissions to be 18.46 MMT CO_2 Eq., while net emissions are projected to be 14.86 MMT CO_2 Eq. The Projection Tool projects in 2025 total and net emissions to be 18.54 MMT CO_2 Eq. A summary of projected emissions and sinks by sector and category, as estimated by ICF/UHERO and the Projection Tool, are provided in Table J-5

Table J-5: Comparison of 2025 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**15.51**	**16.13**	**0.62**	**4%**
Stationary Combustion	4.82	5.02	0.20	4%
Transportation	10.32	10.11	0.21	2%
Incineration of Waste	0.22	0.99	0.77	78%
Oil and Natural Gas Systems	0.15	0.01	(0.14)	(1163%)
IPPU	**0.95**	**0.91**	**(0.04)**	**(5%)**
Electrical Transmission and Distribution	0.01	0.01	(+)	(34%)
Substitution of ODS	0.94	0.36	(0.58)	(159%)
Limestone and Dolomite Use	NO	+	+	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.53	0.53	NA
AFOLU[a]	**(2.49)**	**0.36**	**2.85**	**797%**
Enteric Fermentation	0.21	0.17	(0.03)	(18%)
Manure Management	0.03	0.05	0.02	36%
Agricultural Soil Management	0.14	0.13	(0.01)	(6%)
Field Burning of Agricultural Residues	NO	+	+	NA
Urea Application[a]	+	NE	(+)	NA
Agricultural Soil Carbon[a]	0.47	NE	(0.47)	NA
Forest Fires[a]	0.26	NE	(0.26)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.04)	NE	0.04	NA
Urban Trees[a]	(0.47)	NE	0.47	NA
Forest Carbon[a]	(3.09)	NE	3.09	NA
Waste	**0.90**	**1.15**	**0.25**	**21%**
Landfills	0.82	0.98	0.16	16%
Composting[a]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.05	0.17	0.12	70%
Total Emissions (Excluding Sinks)	**18.46**	**18.54**	**0.08**	**0%**
Net Emissions (Including Sinks)	**14.86**	**18.54**	**3.68**	**20%**

+ Does not exceed 0.005 MMT CO_2 Eq.

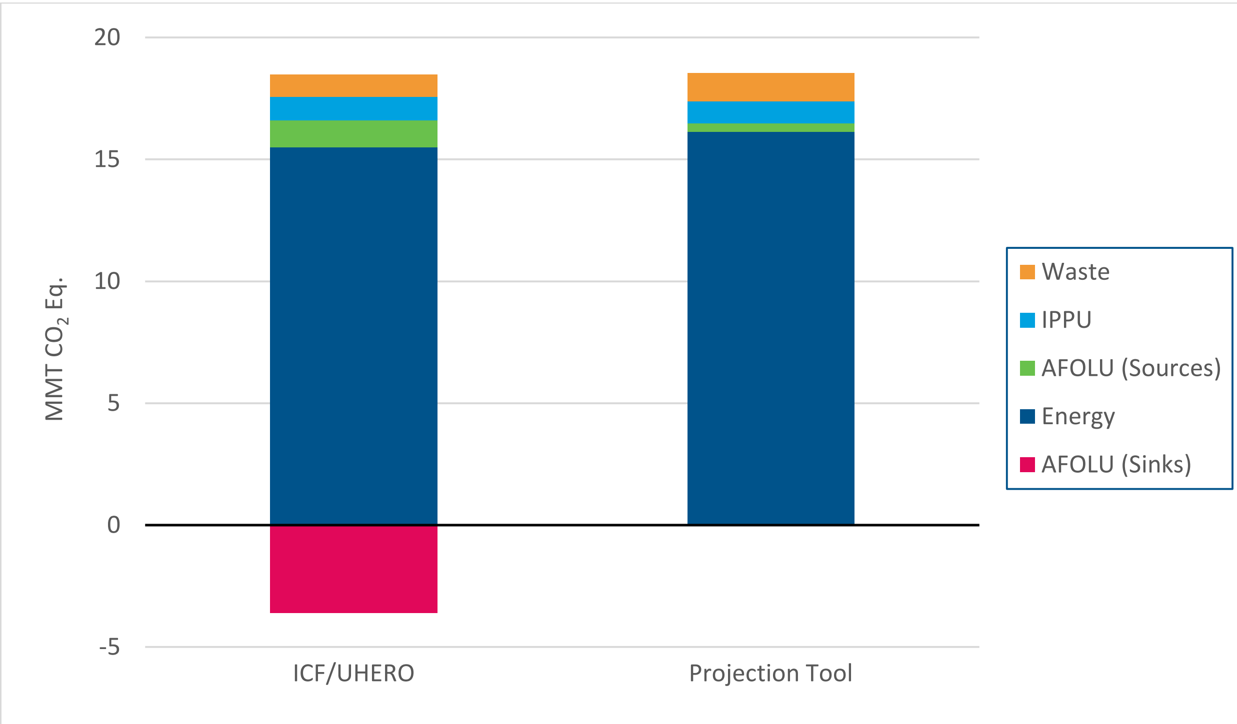
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[a] The Projection Tool does not project emissions from LULUCF categories or from Composting.

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions projections for 2025 by sector as calculated by ICF/UHERO and the Projection Tool are presented in Figure J-6.

Figure J-6: Comparison of 2025 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 87 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table J-6 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table J-6: Key Sources of Differences between ICF/UHERO Projections and Projection Tool Estimates in 2025

Sector/Category	ICF/UHERO	Projection Tool	Absolute Difference	Cumulative % of Total Difference
Forest Carbon	(3.09)	NE	3.09	43%
Incineration of Waste	0.22	0.99	0.77	54%
Substitution of ODS	0.94	0.36	0.58	62%
Iron & Steel Production	NO	0.53	0.53	70%
Agricultural Soil Carbon	0.47	NE	0.47	76%
Urban Trees	(0.47)	NE	0.47	83%
Forest Fires	0.26	NE	0.26	87%
All Other Categories			0.94	100%

NO (emissions are Not Occurring); NE (emissions are Not Estimated).

Methodology Comparison - 2015 Inventory Estimates

This section compares the methodology and data sources used by ICF and the SIT for each source and sink category to develop the 2015 inventory estimates. A more detailed description of the methodology and data sources used by ICF can be found in the body of this report.

Energy

For the Energy sector, the methodology used by ICF and SIT to calculate emissions from stationary combustion and transportation are similar, while the source of activity data differs. For emissions from the incineration of waste and oil and natural gas systems, both the methodologies and data sources used by ICF and SIT differ. A description of the key differences in methodology and data sources used by ICF and the SIT to estimate emissions for the Energy sector are presented in Table J-7.

Table J-7: Key Differences in Methodology and Data Sources for the Energy Sector

Source	ICF Inventory	SIT
Stationary Combustion	• Fuel consumption data is provided by DBEDT, and taken from the SEDS database and the EPA's GHGRP.	• Fuel consumption data is taken from EIA's SEDS database and EIA's Natural Gas Annual report.
Transportation	• Fuel consumption data, which includes consumption of ethanol and biodiesel, was provided by DBEDT.	• Fuel consumption data is taken from EIA's SEDS database. Emissions from alternative fuel vehicles are calculated separately.
Incineration of Waste	• Emissions are taken from EPA's GHGRP.	• Calculates combustion of fossil-derived carbon in waste for plastics, synthetic fibers, and synthetic rubber by estimating the mass of waste combusted (obtained from BioCycle), applying a carbon content, and assuming a 98% oxidation rate.
Oil and Natural Gas Systems	• Emissions are taken from EPA's GHGRP.	• Uses activity data on natural gas production, number of wells, the transmission and distribution of natural gas, and the refining and transportation of oil.

IPPU

For the IPPU sector, the methodology used by ICF and SIT to calculate emissions from electrical transmission and distribution and substitution of ODS is similar, while the source of activity data differs. ICF determined that soda ash manufacturing and consumption, urea consumption, and iron and steel production do not occur in Hawaii; however, the SIT includes estimates for these sources based on allocations of national or regional data. A description of the key differences in methodology and data sources used by ICF and the SIT to estimate emissions for the IPPU sector are presented in Table J-8.

Table J-8: Key Differences in Methodology and Data Sources for the IPPU Sector

Source	ICF Inventory	SIT
Electrical Transmission and Distribution	• National electricity sales data are taken from EIA. Hawaii's electricity sales data are taken from the State of Hawaii Data Book.	• Both national and state-level electricity sales data are taken from EIA.
Substitution of ODS	• Population data are taken from the U.S. Census Bureau. Hawaii's population data are taken from the State of Hawaii Data Book.	• Both national and state-level population are taken from the U.S. Census Bureau.
Soda Ash Manufacture and Consumption	• Emissions from soda ash manufacturing and consumption were determined to not occur in Hawaii.	• Allocates national emissions from soda ash consumption using the ratio of state population to national population.
Urea Consumption	• Emissions from urea consumption were determined to not occur in Hawaii.	• Multiplies the total urea applied to Ag Soils in each state (from LULUCF module) by 0.13 to obtain urea consumption.
Iron and Steel Production	• Emissions from iron and steel production were determined to not occur in Hawaii.	• Evenly distributes regional production data among states within the region.

AFOLU

For the AFOLU sector, the methodology used by ICF and SIT to calculate emissions and sinks from enteric fermentation, forest fires, and urban trees are similar, while the activity data differs. For emissions from manure management, agricultural soil management, field burning of agricultural residues, urea application, and landfilled yard trimmings, both the methodologies and data sources used by ICF and SIT differ. The SIT does not provide default estimates for forest fires or forest carbon. ICF did not estimate emissions from N_2O from Settlement Soils, but the SIT does provide an estimate for this source. A description of the key differences in methodology and data sources used by ICF and the SIT to estimate emissions for the IPPU sector are presented in Table J-9.

Table J-9: Key Differences in Methodology and Data Sources for the AFOLU Sector

Source	ICF Inventory	SIT
Enteric Fermentation	• Obtains sheep and goat population data from the USDA Census of Agriculture.	• Obtains sheep population data from the U.S. Inventory. • Beef cow population data are taken from USDA NASS.*

	• Beef cow population data are taken from USDA National Agricultural Statistics Service (NASS).*	
Manure Management	• Includes hens within the chicken population but does not include turkeys. • Obtains sheep and goat population data from the USDA Census of Agriculture. • Uses constant VS rates for non-cattle animal types.	• Estimates emissions from turkeys and hens greater than one year old. • Obtains sheep population data from the U.S. Inventory. • Uses volatile solids (VS) rates for breeding swine, poultry, and horses that vary slightly by year.
Agricultural Soil Management	• Assumes organic fertilizer is not consumed in Hawaii based on the Association of American Plant Food Control Officials (AAPFCO) Commercial Fertilizer reports. • Calculates emissions from sugarcane, pineapple, sweet potatoes, ginger root, and taro. • Obtains corn for grain production data from the USDA Census of Agriculture.	• Estimates state-level organic fertilizer consumption by applying the percentage of national fertilizer consumption that is organic fertilizer to total state-level fertilizer consumption. • Does not calculate emissions from sugarcane, pineapple, sweet potatoes, ginger root, or taro. • Obtains crop production data from USDA NASS Surveys. USDA NASS Surveys do not include corn for grain production data for Hawaii.
Field Burning of Agricultural Residues	• Assumes the fraction of sugarcane residue burned is 95 percent based on Ashman (2008).	• Assumes that the fraction of Hawaii sugarcane residue burned is zero.
Urea Application	• Extrapolates urea fertilization consumption to 2015 based on the historical five-year trend.	• Uses 2014 data from AAPFCO (2017) as a proxy for 2015 urea fertilization.
Agricultural Soil Carbon	• None.	• None.
Forest Fires	• Obtains forest area burned data from the Hawaii Department of Land and Natural Resources.	• Does not include default data of forest area burned.
Landfilled Yard Trimmings	• Hawaii population data were obtained from the State of Hawaii Data Book. • Extrapolates waste generation to 2015 based on the historical five-year trend.	• Hawaii population data were obtained from U.S. Census 2017. • Uses 2014 waste generation data as a proxy for 2015.
Urban Trees	• Uses carbon sequestration rates from the City and County of Honolulu's *Municipal Forest Resource Analysis* (Vargas et al. 2007).	• Uses carbon sequestration rates for Hawaiian urban trees based on Nowak et al. (2013).

Forest Carbon	• Uses carbon flux estimates calculated by the Tier 1 Gain Loss Method outlined by the 2006 IPCC Guidelines.	• Does not include carbon flux estimates for Hawaii.
N_2O from Settlement Soils	• Does not estimate because Hawaii-specific consumption of synthetic fertilizers for settlement applications is not available.	• Assumes one percent of synthetic fertilizer consumption is used on settlement soils.

* The value downloaded by ICF from USDA NASS in 2017 (i.e., 68,800 beef cows) differs slightly from the beef cow population used in the SIT (i.e., 69,800 beef cows).

Waste

For the Waste sector, the methodology used by ICF and SIT to calculate emissions from landfills and wastewater treatment are similar, while the activity data differs. The SIT does not provide estimates of emissions from composting. A description of the key differences in methodology and data sources used by ICF and the SIT to estimate emissions for the Waste sector are presented in Table J-10.

Table J-10: Key Differences in Methodology and Data Sources for the Waste Sector

Source	ICF Inventory	SIT
Landfills	• Data on the tons of waste landfilled per year were provided by the Hawaii DOH, Solid Waste Branch. • Volumes of landfill gas recovered for flaring and energy were obtained from EPA's GHGRP. • Historical MSW generation and disposal volumes were calculated using population data from the State of Hawaii Data Book.	• Estimates state-level waste disposal by allocating national waste data based on population. • Flaring data is based on information from the U.S. GHG Inventory.
Composting	• Estimated based on the U.S. national average per capita composting rate from the U.S. GHG Inventory.	• Does not estimate emissions from composting.
Wastewater Treatment	• Data on non-National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants, including flow rate and BOD5 are provided by Hawaii DOH, Wastewater Branch. • Population data from the State of Hawaii Data Book were used to calculate wastewater treatment volumes. • The number of households on septic systems were calculated using data from the U.S. Census Bureau and Hawaii DOH, Wastewater Branch.	• Uses data from EPA and BioCycle.

Methodology Comparison - 2020 and 2025 Emission Projections

This section compares the methodology used by ICF/UHERO and the Projection Tool to develop the 2020 and 2025 inventory projections. The methodologies differ significantly between the ICF/UHERO and Projection Tool estimates. A description of the key differences in methodology used by ICF/UHERO and the Projection Tool to project emissions for each sector are presented in Table J-11. A more detailed description of the methodology and data sources used by ICF/UHERO can be found in Appendix H.

Table J-11: Key Differences in Methodology Used to Project Emissions

Sector	ICF/UHERO	Projection Tool
Energy	• For energy industries, emissions were projected based on the HEI PSIP and KIUC GHG Reduction Plan. • For transportation, emissions were projected based on estimates of future vehicle miles traveled and fuel efficiency by vehicle type. • For residential energy use, commercial energy use, industrial energy use, domestic aviation, incineration of waste, oil and natural gas systems, emissions were projected using UHERO's Macroeconomic Forecast.	• Forecasts regional energy consumption data based on EIA's Annual Energy Outlook 2016. Allocates regional consumption to states based on 2015 state-level consumption taken from EIA's State Energy Data 2017.
IPPU	• Emissions were projected using UHERO's Macroeconomic Forecast.	• Forecasts emissions from Soda Ash Manufacture and Consumption, Iron & Steel Production, and Urea Consumption based on historical trends. • Forecasts emissions from Electric Power Transmission and Distribution Systems and ODS Substitutes based on publicly available forecasts.
AFOLU	• Emissions were projected by forecasting activity data using historic trends and published information on future trends.	• Forecasts emissions based on either historical trends or publicly available forecasts (varies by category). Results differ due to minor differences in how activity data is projected and differences in historical estimates. • Sinks are not estimated.
Waste	• Emissions were projected using UHERO's Macroeconomic Forecast.	• Forecasts activity data based on projected population.