Hawaii Greenhouse Gas Emissions Report for 2016

Final Report

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Prepared for:

Prepared by:

Acknowledgments

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Acronyms and Abbreviations

AAPFCO	Association of American Plant Food Control Officials
AD	Anaerobic digestion
AEO	Annual Energy Outlook
AFOLU	Agriculture, Forestry, and Other Land Use
BAU	Business-as-usual
bbl	Barrel
Bbtu	Billion British Thermal Units
BE	Burning efficiency
BOD	Biochemical oxygen demand
CAFE	Corporate average fuel economy
CCAP	Coastal Change Analysis Program
CE	Combustion efficiency
CF	Correction factor
CH_4	Methane
CO_2	Carbon dioxide
CS	Carbon storage
DBEDT	Department of Business, Economic Development, and Tourism
DCA	Division of Consumer Advocacy
DCCA	Department of Commerce and Consumer Affairs
DLNR	Department of Land and Natural Resources
DMF	Dry matter fraction
DOC	Department of Commerce
DOH	Department of Health
DOT	Department of Transportation
DP	Diesel Price
DSIRE	Database of State Incentives for Renewables & Efficiency
ED	Electricity demand
EF	Emission Factor
EIA	Energy Information Administration
EIIRP	Energy Industry Information Reporting Program
EP	Electricity price
EPA	U.S. Environmental Protection Agency
EV	Electric vehicle
FE	Fuel Efficiency
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis

GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
GJ	Gigajoules
GSP	Gross state product
GWP	Global Warming Potential
ha	Hectares
HAR	Hawaii Administrative Rule
HDV	Heavy duty vehicles
HECO	Hawaiian Electric Company
HEI	Hawaii Electric Industries
HELCO	Hawaii Electric Light Company
HFCs	Hydrofluorocarbons
HHV	High heat value
H-POWER	Honolulu Program of Waste Energy Recovery
HRS	Hawaii Revised Statues
IBF	International Bunker Fuels
ICAO	International Civil Aviation Organization
ICC	Initial carbon content
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IW	Incinerated waste
kg	Kilogram
KIUC	Kauai Island Utility Cooperative
kWh	Kilowatt hours
LDV	Light duty vehicles
LULUCF	Land use, land use change, and forestry
MC	Moisture content
MCF	Methane conversion factor
MECO	Maui Electric Company
MMT	Million metric tons
MOVES	Motor Vehicle Emission Simulator
MSW	Municipal Solid Waste
MW	Megawatt
N_2O	Nitrous Oxide
NA	Not Applicable
NASF	National Association of State Foresters
NASS	National Agriculture Statistics Service
NE	Not Estimated

NEI	National Emission Inventory
NEU	Non-energy uses
Nex	Nitrogen excretion rate
NO	Not Occurring
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
ODS	Ozone depleting substances
OECD	Organisation for Economic Co-operation and Development
OR	Oxidation rate
PDF	Probability density function
PFCs	Perfluorocarbons
PIMAR	Petroleum Industry Monitoring, Analysis, and Reporting
PSIP	Power Supply Improvement Plan
PUC	Public Utilities Commission
QA/QC	Quality Assurance/Quality Control
RDF	Refuse-derived fuel
SEDS	State Energy Data System
SF_6	Sulfur hexafluoride
SIT	State Inventory Tool
SNAP	Significant New Alternatives Policy
TAM	Typical animal mass
TFHF	Trees for Honolulu's Future
TJ	Terajoule
TVA	Tennessee Valley Authority
UHERO	University of Hawaii Economic Research Organization
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture
USFS	United States Forest Service
USGS	U.S. 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, 2007, 2010, and 2015 emission estimates;[1] inventory estimates for 2016; 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 lower than net GHG emissions in 1990. These estimates and projections will be reviewed and updated, and presented along with GHG estimates for 2017 in the forthcoming inventory and projection report. Therefore, while this report finds that Hawaii is currently on track to meet the 2020 target, this finding will be reassessed in the forthcoming report.

Background

Greenhouse gases 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.

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, 2015, and 2016 from the following four sectors: Energy,

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[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.
[2] Anthropogenic greenhouse gas emissions are those that originate from human activity.

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, 2007, 2010, and 2015 and newly developed estimates for 2016. 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 2018a). 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: 1990-2016*, 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

Uncertainty is a component of each calculated result; thus, some degree of uncertainty in GHG estimates is associated with all emission inventories. This uncertainty (e.g., systematic error) can be attributed to several factors such as incomplete data, uncertainty in the activity data collected, the use of average or default emission factors, 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 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 and CO_2 emissions from agricultural soil carbon), emission estimates typically have greater uncertainty.

The intent of an uncertainty analysis is not to dispute the validity of the inventory estimates—which are developed using the best available activity data, emission factors, and methodologies available—but rather to guide prioritization of improvements to the accuracy of future inventories (EPA 2018a). For this report, quantitative uncertainty estimates for statewide emissions were developed using the IPCC

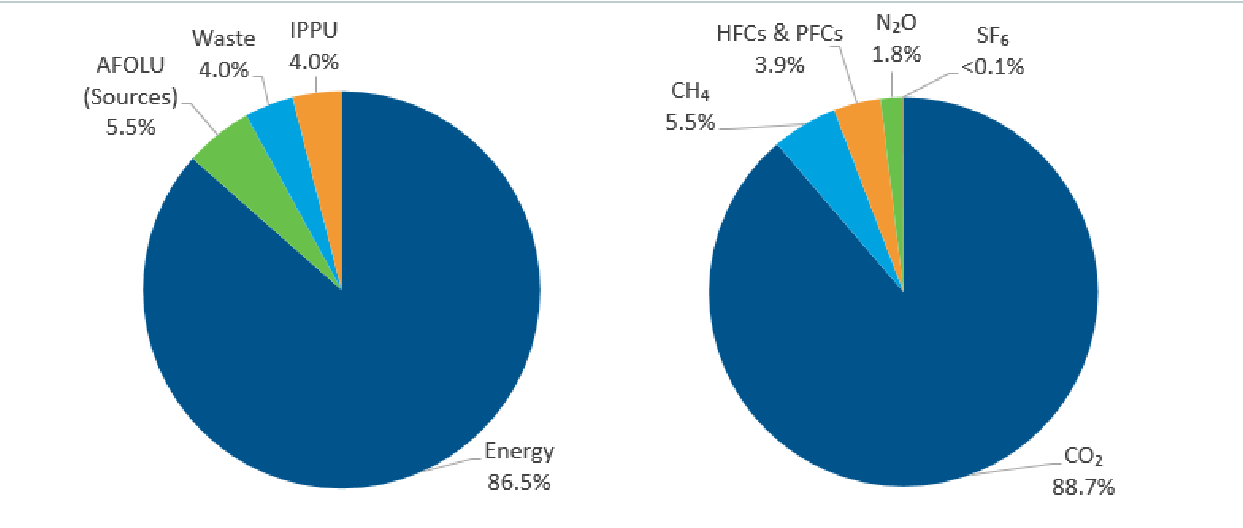
[3] The review team included representatives from the Department of Business, Economic Development and Tourism (DBEDT), the Division of Consumer Advocacy (DCA), the Department of Land and Natural Resources (DLNR), Hawaii Public Utilities Commission (PUC), Smart Trees Pacific, University of Hawaii Cooperative Extension, and the U.S. Department of Agriculture (USDA).

Approach 2 uncertainty estimation methodology, which is considered the more robust approach of the two approaches provided by IPCC. Uncertainties in the emission sources from the AFOLU sector are driving the overall uncertainty for total emissions and emissions sources and sinks from the AFOLU sector are driving the overall uncertainty for net emissions.

Emission Results

In 2016, total GHG emissions in Hawaii were 19.58 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). Net emissions, which take into account carbon sinks, were 13.07 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 (6 percent), the IPPU sector (4 percent), and the Waste sector (4 percent). Carbon dioxide was the largest single contributor to statewide GHG emissions in 2016, accounting for roughly 89 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). Methane is the second largest contributor (6 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 2016 by sector and gas.

Figure ES-1: Hawaii 2016 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 19 percent between 1990 and 2007 before falling 20 percent between 2007 and 2010 and another 3 percent between 2010 and 2015. Although emissions increased by less than 1 percent between 2015 and 2016, total emissions in 2016 were roughly 8 percent lower than 1990 levels. Net emissions were lower by roughly 11 percent in 2016 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, 2015, and 2016)

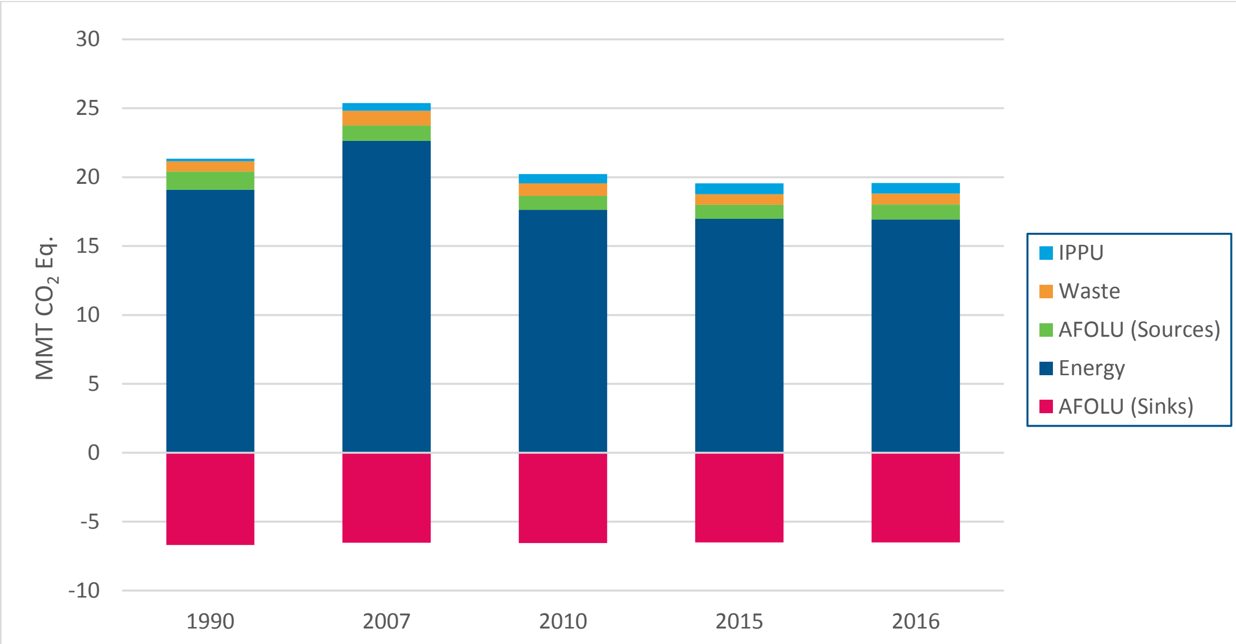


Table ES-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010, 2015, and 2016 (MMT CO_2 Eq.)

Sector/Category	1990	2007	2010	2015	2016
Energy[a]	19.09	22.65	17.62	16.97	16.94
IPPU	0.17	0.55	0.66	0.77	0.78
AFOLU (Sources)	1.31	1.12	1.02	1.03	1.08
AFOLU (Sinks)	(6.70)	(6.52)	(6.55)	(6.50)	(6.51)
Waste	0.75	1.05	0.92	0.77	0.78
Total Emissions (Excluding Sinks)	**21.33**	**25.37**	**20.22**	**19.54**	**19.58**
Net Emissions (Including Sinks)	**14.63**	**18.85**	**13.67**	**13.04**	**13.07**
Aviation[b]	3.79	4.11	3.16	3.99	3.84
Net Emissions (Including Sinks, Excluding Aviation)[b]	**10.84**	**14.73**	**10.51**	**9.04**	**9.23**

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

[b] Domestic aviation and military 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 88 percent of the emissions increase from 1990 to 2007 and 99 percent of reductions between 2007 and 2016. Relative to 1990, emissions from the Energy sector in 2016 were lower by 11 percent. Transportation emissions—which increased between 1990 and 2007, decreased between 2007 and 2010, and then increased again between 2010 and 2016—accounted for the largest share of Energy sector emissions in almost all inventory years (in 2010 stationary combustion accounted for the largest share of Energy sector emissions). Stationary combustion emissions—which increased between 1990 and 2007, and then decreased from 2007 to 2016—is the second largest share. This trend is largely driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial emissions.

Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2016, falling by about 3 percent and 26 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 41 percent from 2007 to 2016. Relative to 1990, emissions from the IPPU sector in 2016 were more than three times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances (ODS).[4] Carbon removals from AFOLU sinks have remained relatively flat since 1990, decreasing by less than 3 percent between 1990 and 2016.

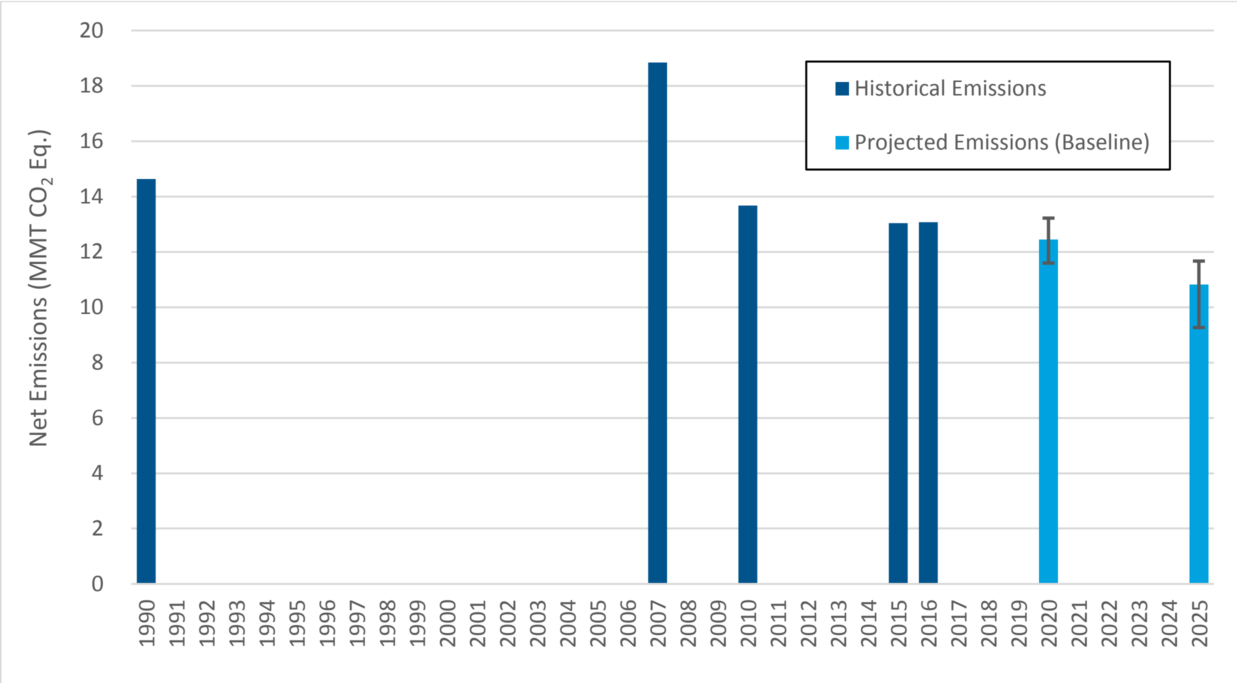
Emission Projections

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, DBEDT's *Population and Economic Projections for the State of Hawaii to 2045* (DBEDT 2018e) was primarily used to project GHG emissions for 2020 and 2025, using the 2016 statewide GHG inventory as a starting point. For other smaller emission sources and sinks, emissions were largely projected by forecasting activity data using historical trends and published information available on future trends, and applying the same calculation methodology used to estimate 2016 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. For these sources, the team additionally quantitatively assessed three major points of uncertainty within the GHG emissions forecast for 2020 and 2025 by projecting emissions under three alternative scenarios.

Total GHG emissions are projected to be 19.02 MMT CO_2 Eq. in 2020 and 17.45 MMT CO_2 Eq. in 2025. Net emissions, which take into account carbon sinks, are projected to be 12.45 MMT CO_2 Eq. in 2020 and 10.81 MMT CO_2 Eq. in 2025. Relative to 2016, total emissions are projected to decrease by 3 percent by 2020 and 11 percent by 2025. Over the same period, net emissions are projected to decrease by 5 percent and 17 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 shows net GHG emissions for each historical and projected inventory year. Projections of statewide emissions and sinks by sector for 2020 and 2025 are summarized in Table ES-3.

[4] 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 J.

Figure ES-3: Hawaii Net GHG Emissions by Year (Including Sinks)



Note: The uncertainty bars represent the range of emissions projected under the alternative scenarios.

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

Sector	2020	2025
Energy[a]	16.31	14.58
IPPU	0.85	0.99
AFOLU (Sources)	1.01	0.96
AFOLU (Sinks)	(6.57)	(6.64)
Waste	0.84	0.92
Total Emissions (Excluding Sinks)	**19.02**	**17.45**
Net Emissions (Including Sinks)	**12.45**	**10.81**
Aviation[b]	4.08	4.38
Net Emissions (Including Sinks, Excluding Aviation)[b]	**8.37**	**6.43**

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

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

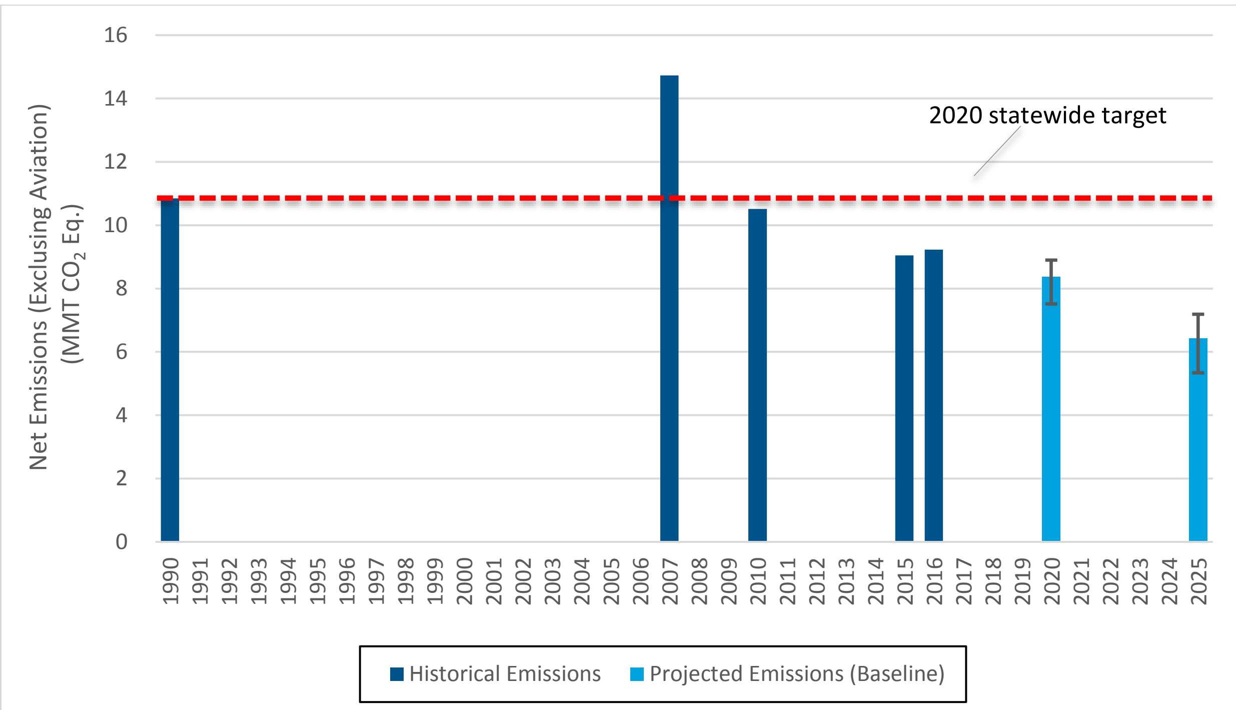
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Hawaii GHG Goal Progress

Excluding aviation, 1990 statewide emissions were estimated to be 10.84 MMT CO_2 Eq., which represents the 2020 emission target (statewide emissions must be at or below this amount). Net GHG emissions in 2016 (excluding aviation) were approximately 15 percent lower than the 2020 statewide goal (1990 levels). 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 and the 2020 statewide target, which is equal to 1990 emissions levels.

As net emissions excluding aviation are projected to be 8.37 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 historical and projected emission estimates (described in detail within this report). The development of the 2017 inventory report, which will include the review and update to the estimates presented in this report as well as ongoing 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: The uncertainty bars represent the range of emissions projected under the alternative scenarios.

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, 2007, 2010, and 2015 emission estimates;[5] inventory estimates for 2016; 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 currently projected to be lower than net GHG emissions in 1990. These estimates and projections will be reviewed and updated, and presented along with GHG estimates for 2017 in a forthcoming inventory and projection report. Therefore, while this report finds that Hawaii is currently on track to meet the 2020 target, this finding will be reassessed in the forthcoming 2017 report.

1.1. Background

Greenhouse gases 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

[5] 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.

The Climate Impact of Black Carbon

Beyond GHGs, other emissions are known to contribute to climate change. For example, black carbon is an aerosol that forms during incomplete combustion of certain fossil fuels (primarily coal and diesel) and biomass (primarily fuel wood and crop waste). Current research suggests that black carbon has a positive radiative forcing by heating the Earth's atmosphere and causing surface warming when deposited on ice and snow (EPA 2018a, IPCC 2013). Black carbon also influences cloud development, but the direction and magnitude of this forcing is an area of active research (EPA 2018a). There is no single accepted method for summarizing the range of effects of black carbon emissions on the climate or representing these effects and impacts in terms of carbon dioxide equivalent; significant scientific uncertainties remain regarding black carbon's total climate effect (IPCC 2013). Although literature increasingly recognizes black carbon as a major heat source for the planet (Ramanathan and Carmichael 2008, Bond et al. 2013), it is not within the scope of a GHG inventory to quantify black carbon climate impacts.

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, 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, which are continually improved over time to reflect advances in the field of GHG accounting, 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, 2015, and 2016 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.

Impacts from Updates to Previous Inventory Estimates on Progress towards GHG Reduction Goal

In the 2015 inventory report, net emissions excluding aviation in 2015 were estimated to be less than 1 percent higher than 1990 levels, which represents the 2020 statewide goal. The updated estimates presented in this inventory report find that net emissions excluding aviation in 2015 were 19 percent lower than 1990 levels. As discussed further in Appendix B, the use of EIA's SEDS data instead of the data collected by DBEDT is the main driver of this change. A close review of the datasets against other available data was undertaken, which found higher confidence in the SEDS data. Appendix C and the text box in Section 1.4 below provide additional information on the key findings of the comparative analysis that was undertaken.

This inventory was developed in accordance with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[6] to ensure completeness and allow for comparability of results with other inventories. The inventory accounts for GHG emissions and removals that take place within the physical boundary of the state. While Hawaii imports a range of goods and products that contribute to the generation of GHG emissions outside of the state, these emissions are outside the scope of this inventory and therefore are not reflected in this report. For emissions that are within the scope of this report, 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, 2007, 2010, and 2015, and newly developed estimates for 2016. The 1990, 2007, 2010, and 2015 estimates were updated to account for updated activity data and methods, and to

[6] 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.

ensure time-series consistency across all inventory years.[7] Two key changes from the 2015 inventory report include (1) the use of the Energy Information Administration's (EIA) State Energy Data System (SEDS) instead of data collected by the Hawaii Department of Business, Economic Development, and Tourism (DBEDT) as the primary source of fuel consumption data to calculate emissions from the Energy sector, and (2) the use of Hawaii-specific net carbon sequestration rates obtained from the U.S. Geological Survey (USGS), instead of using default values from IPCC to calculate sinks from forest carbon. Appendix B summarizes changes in historical emission estimates relative to the 2015 inventory report and provides a discussion on the implications of these changes on total and net emissions over time. These and other updates that impacted emission estimates are also discussed on a source-by-source basis in the subsequent sections of this report.

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, as described in Section 1.4. 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 2018a).

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: 1990-2016* (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 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

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[7] This report also includes updated emission projections for 2020 and 2025, which take into account updated historical emission estimates as well as the best available information on projections of economic activities and the status of policies and programs that impact the intensity of GHG emissions. See Section 7.6 for additional discussion on the changes to the projections relative to the previous inventory report.

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. This was ensured by referencing data sources used in recent analyses and reports of similar detail and complexity (e.g., the U.S. Inventory), reassessing the relevancy and accuracy of data inputs used to develop previous inventory reports, and conducting targeted data comparisons across multiple data sources (see the text box above).

Comparative Analysis of Fuel Consumption Data

As part of the effort to inform which data set to use as the source of fuel consumption data to estimate emissions from the Energy sector, ICF conducted a comparative analysis of available consumption data, including data obtained from EIA SEDS, data collected by DBEDT, and data reported under EPA's GHGRP. Consumption of diesel fuel, residual fuel, motor gasoline, and jet fuel, which collectively represent roughly 90% of fossil-fuel consumption in Hawaii, were compared. Based on this analysis, SEDS was determined, at this point in time, to be the best dataset available across all inventory years. However, as discussed throughout this report, further review and validation of the data could lead to future revisions to these estimates. Appendix C provides additional information on the key findings of the comparative analysis that was undertaken.

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. Prior to the finalization of this report, a multi-level review process was undertaken to ensure the accuracy of all results that were transcribed from the workbooks into this report. This review involved (1) updating all links within the workbooks to ensure they link to the latest version of each spreadsheet, (2) reviewing each workbook for #REF errors, (3) cross walking all numbers and figures in the workbooks against the information presented in this report, (4) confirming the descriptions provided in the text of this report are consistent with the data presented in the tables and figures within the report, and (5) and confirming statistics that are cited in multiple sections of this report are consistent throughout the document.

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. Appendix C discusses the results of this comparative analysis in more detail. ICF also used EPA's State Inventory and Projection Tool to estimate GHG emissions and sinks for Hawaii using default values and compared the output against the 2016 inventory and the inventory projections for 2020 and 2025. The results of this comparison are presented and discussed in Appendix L. In addition, the results were reviewed by representatives from the Department of Health (DOH) as well as a group of other government entities.[8] 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

Uncertainty is a component of each calculated result; thus, some degree of uncertainty in GHG estimates is associated with all emission inventories. This uncertainty (e.g., systematic error) can be attributed to several factors such as incomplete data, uncertainty in the activity data collected, the use of average or default emission factors, 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 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 and CO_2 emissions from agricultural soil carbon), emission estimates typically have greater uncertainty.

The intent of an uncertainty analysis is not to dispute the validity of the inventory estimates—which were developed using the best available activity data, emission factors, and methodologies available—but rather to guide prioritization of improvements to the accuracy of future inventories (EPA 2018a). Overall, it is important to recognize that some level of uncertainty exists with all GHG estimates and the data used to generate such estimates, and these uncertainties vary between sector, source, and gas.

For this report, uncertainty estimates for statewide emissions were developed using the IPCC Approach 2 uncertainty estimation methodology, which is considered the more robust approach of the two approaches provided by IPCC. Overall and sector-level uncertainty estimates are summarized below in Table 1-2. Uncertainties in the emission sources from the AFOLU sector are driving the overall uncertainty for total emissions and emissions sources and sinks from the AFOLU sector are driving the overall uncertainty for net emissions.

Source category-level uncertainty results and a discussion of specific factors affecting the uncertainty associated with the GHG emission estimates for each emission source and sink category are provided in the subsequent sections of this report.[9] Appendix D provides additional detail on the methodology used to develop the quantitative uncertainty results as well as a discussion on limitations of the analysis. The appendix also includes a summary of the input assumptions used in the analysis and the detailed uncertainty results. The information presented in these sections should be evaluated as potential focus

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[8] The review team included representatives from DBEDT, PUC, DCA, DLNR, Smart Trees Pacific, University of Hawaii Cooperative Extension, and USDA.

[9] Uncertainty was quantified for each emission source and sink category. Uncertainty by Stationary Combustion economic sector and Transportation end-use sector were not quantified as part of this analysis. Instead, uncertainties by economic sector and end-use sector are discussed qualitatively in Section 3.

areas for improvement for the 2017 inventory report, which will reflect updates to the emission estimates presented in this report as well as a quantitative assessment of uncertainties for 2017.

Table 1-2: Overall Estimated Quantitative Uncertainty (MMT CO_2 Eq. and Percent)

Sector	2016 Emission Estimate	Uncertainty Range Relative to Emission Estimate[a]				Mean[b]	Standard Deviation[b]
		(MMT CO_2 Eq.)		(%)		(MMT CO_2 Eq.)	
	(MMT CO_2 Eq.)	Lower Bound[c]	Upper Bound[c]	Lower Bound	Upper Bound		
Energy	16.94	16.57	17.52	-2%	+3%	17.04	0.24
Energy (Excl. Aviation)	13.10	12.85	13.55	-2%	+3%	13.20	0.18
IPPU	0.78	0.76	0.83	-2%	+6%	0.79	0.02
AFOLU (Sources)	1.08	(0.64)	2.67	-159%	+146%	1.03	0.86
AFOLU (Sinks)	(6.51)	(8.49)	(4.04)	+30%	-38%	(6.26)	1.14
Waste	0.78	0.55	0.95	-30%	+21%	0.76	0.10
Total Emissions	**19.58**	**17.84**	**21.37**	**-9%**	**+9%**	**19.62**	**0.90**
Net Emissions	**13.07**	**10.50**	**16.24**	**-20%**	**+24%**	**13.36**	**1.47**
Net Emissions (Excl. Aviation)	**9.23**	**6.65**	**12.32**	**-28%**	**+33%**	**9.51**	**1.45**

[a] The uncertainty estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the upper bound corresponding to 97.5th percentile.

[b] Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.

[c] The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.

1.6. Organization of Report

The remainder of this report is organized as follows:

- **Chapter 2: Emission Results** – Summarizes 2016 inventory results for the state of Hawaii, trends in GHG emissions and sinks across the inventory years since 1990, and emissions by county.
- **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 under a baseline and three alternate scenarios.
- **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.
- **Chapter 9: References –** Lists the sources of data and other information used in the development of this report.

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: Updates to the Historical Emission Estimates Presented in the 2015 Inventory Report** – Summarizes changes in emission estimates relative to the 2015 inventory report and provides a discussion on the implications of these changes on total and net emissions over time.
- **Appendix C: Energy Data Comparative Analysis** – Presents the results of a comparative analysis of available fuel consumption data.
- **Appendix D: Uncertainty** – Provides a summary of the methodology used to develop the quantitative uncertainty results as well as a discussion on limitations of the uncertainty analysis.
- **Appendix E: County Emissions Methodology** – Summarizes the methodology used to quantify Hawaii's GHG emissions by county.
- **Appendix F: HAR Facility Data** – Summarizes annual GHG emissions from HAR affected facilities for 2010 to 2015 and projections for 2020 and 2025.
- **Appendix G: Activity Data** – Summarizes by sector the activity data used to develop the inventory presented in this report.
- **Appendix H: Emission Factors** – Summarizes by sector the emission factors used to develop the inventory presented in this report.
- **Appendix I: Areas for Improvement** – Summarizes areas for improvement, ranked by priority.
- **Appendix J: ODS Emissions** – Summarizes for informational purposes estimated emissions from ozone depleting substances (ODS) for the state of Hawaii.
- **Appendix K: 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 L: 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.

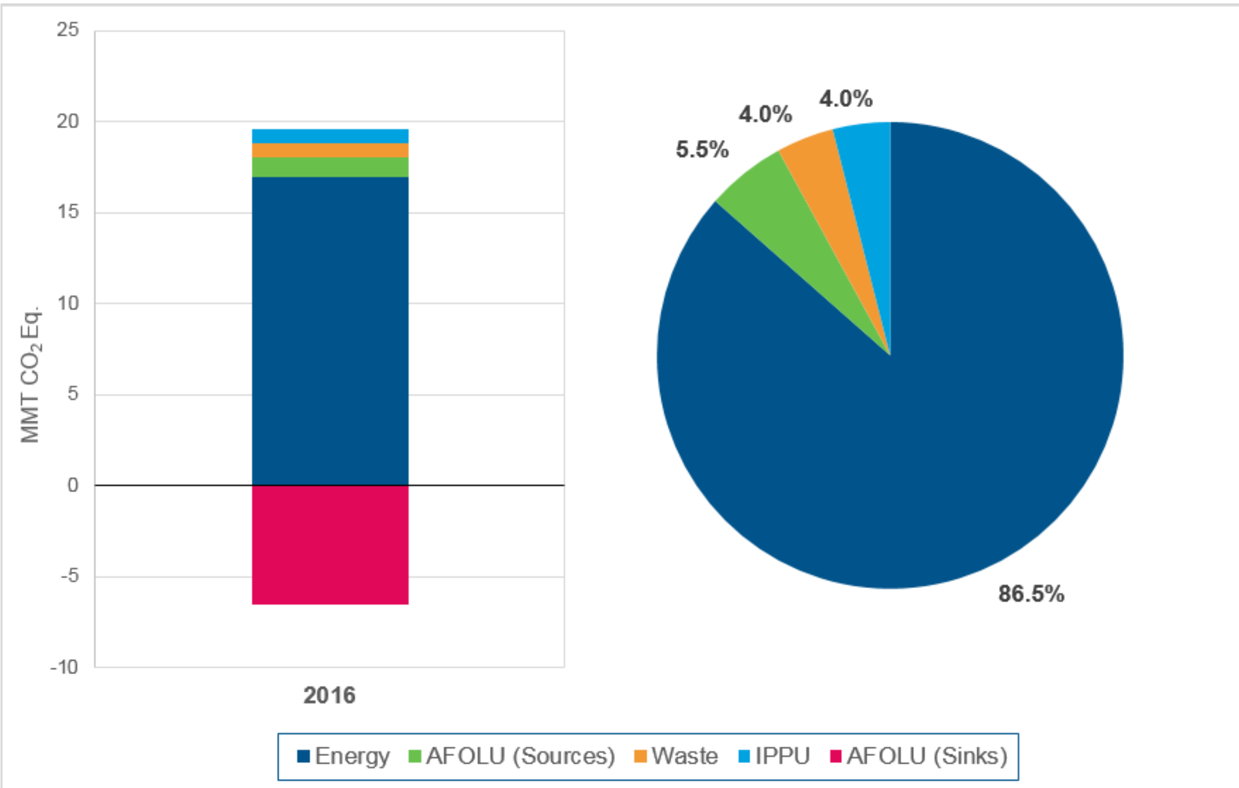
2. Emission Results

This section summarizes 2016 inventory results for the state of Hawaii, trends in GHG emissions and sinks across the inventory years since 1990, and emissions by county.

2.1. Overview of 2016 Emissions

In 2016, total GHG emissions in Hawaii were 19.59 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 13.08 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 (6 percent), the Waste sector (4 percent), and the IPPU sector (4 percent). Figure 2-1 shows emissions for 2016 by sector.

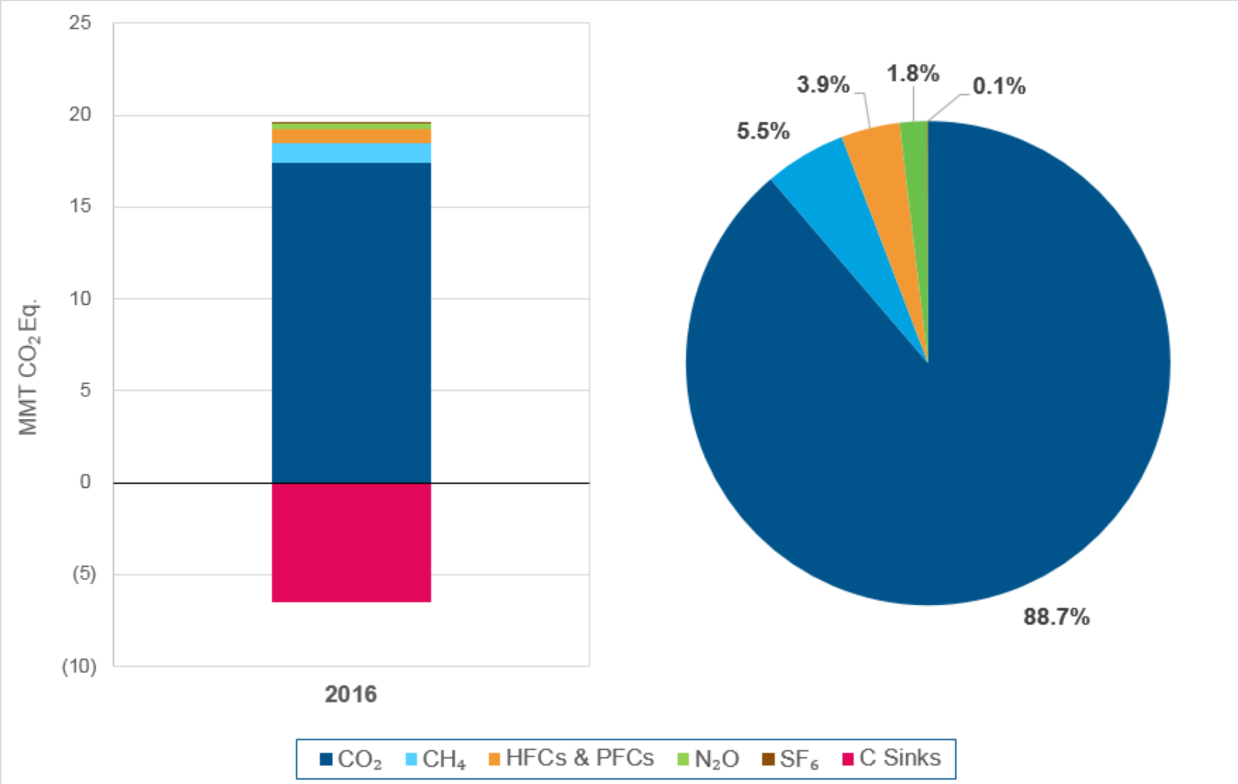
Figure 2-1: Hawaii 2016 GHG Emissions by Sector



Notes: Totals may not sum due to independent rounding. Percentages represent the percent of total emissions excluding sinks.

Carbon dioxide was the largest single contributor to statewide GHG emissions in 2016, accounting for roughly 89 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), nitrous oxide (2 percent), and sulfur hexafluoride (less than 0.1 percent). Figure 2-2 shows emissions for 2016 by gas.

Figure 2-2: Hawaii 2016 GHG Emissions by Gas



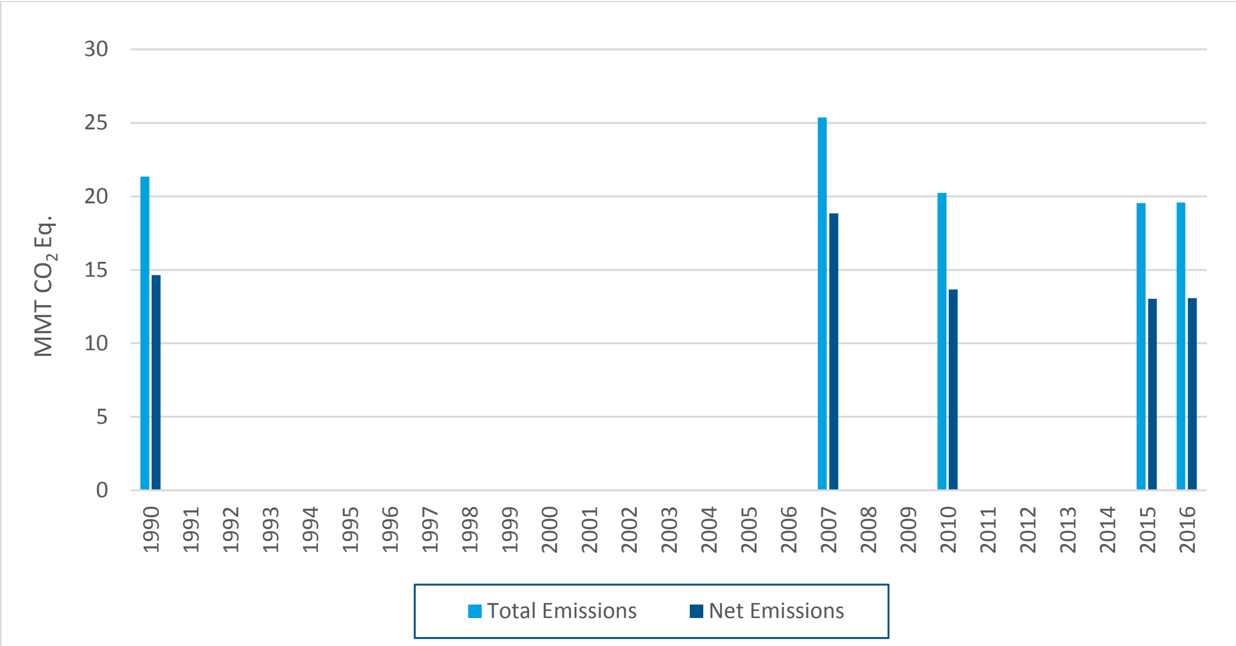
Note: Totals may not sum due to independent rounding.

2.2. Emission Trends

Total GHG emissions in Hawaii grew by 19 percent between 1990 and 2007 before falling 20 percent between 2007 and 2010 and another 3 percent between 2010 and 2015.[10] Although emissions increased by less than 1 percent between 2015 and 2016, total emissions in 2016 were roughly 8 percent lower than 1990 levels. Net emissions were lower by roughly 11 percent in 2016 relative to 1990. Figure 2-3 below shows total and net GHG emissions for each inventory year.

[10] The historical trend in total emissions from 1990 through 2010 is consistent with the trend seen at the national level. Specifically, between 1990 and 2007, U.S. emissions increased by roughly 17 percent before falling 6 percent between 2007 and 2010 (EPA 2012). The decrease in U.S. emissions from 2007 to 2010 was largely driven by increasing energy prices coupled with the economic downturn during this period (EPA 2012). Similarly, in Hawaii, the average cost of electricity (cents/kWh) increased by 18 percent between 2007 and 2010 (EIA 2019a).

Figure 2-3: Hawaii Total and Net GHG Emissions by Year



Emissions by Sector

In all inventory years, emissions from the Energy sector accounted for the largest portion (more than 85 percent) of total emissions in Hawaii. Figure 2-4 below shows emissions for each inventory year by sector. Emission by source and year are also summarized in Table 2-1.

Figure 2-4: Hawaii GHG Emissions by Sector (1990, 2007, 2010, 2015, and 2016)

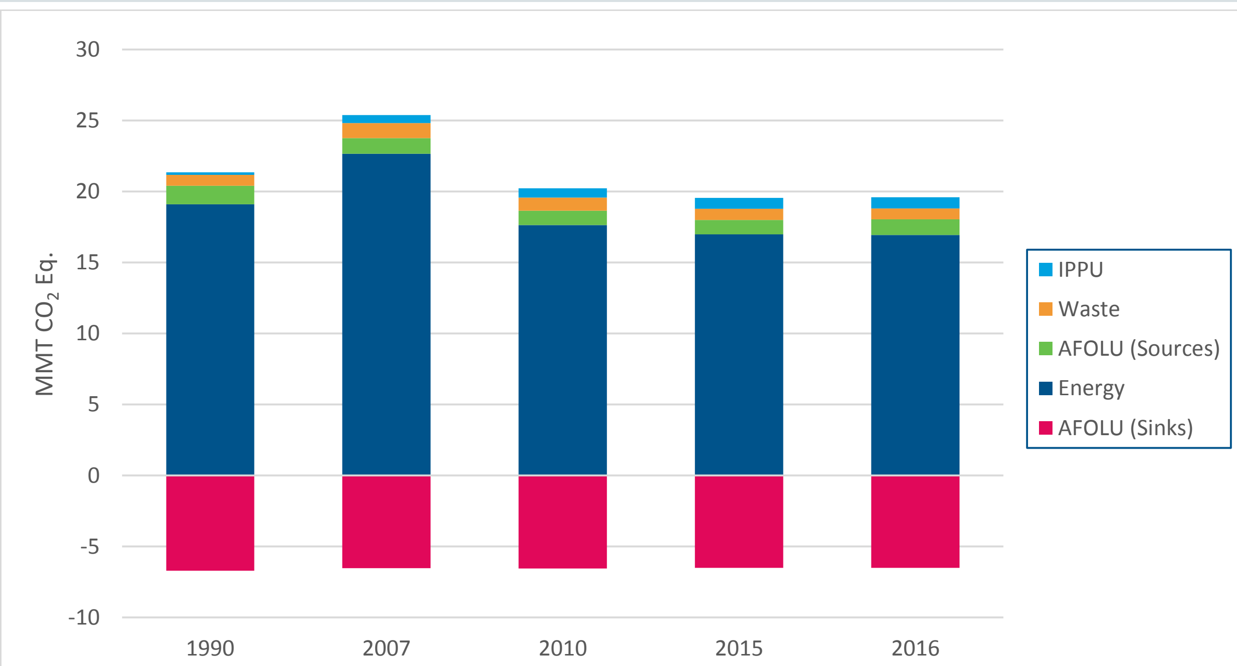


Table 2-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010, 2015 and 2016 (MMT CO_2 Eq.)

Sector/Category	1990	2007	2010	2015	2016
Energy	**19.09**	**22.65**	**17.62**	**16.97**	**16.94**
Stationary Combustion	8.81	9.35	8.82	7.94	7.79
Transportation	9.84	12.91	8.41	8.64	8.69
Incineration of Waste[a]	0.18	0.15	0.19	0.20	0.27
Oil and Natural Gas Systems	0.27	0.24	0.20	0.19	0.19
International Bunker Fuels[b]	*1.53*	*1.22*	*1.31*	*1.65*	*1.54*
CO_2 from Wood Biomass and Biofuel Consumption[b]	*2.43*	*0.87*	*1.27*	*1.47*	*1.53*
IPPU	**0.17**	**0.55**	**0.66**	**0.77**	**0.78**
Cement Production	0.10	NO	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01	0.01
Substitution of Ozone Depleting Substances	+	0.54	0.65	0.76	0.77
AFOLU (Sources)	**1.31**	**1.12**	**1.02**	**1.03**	**1.08**
Enteric Fermentation	0.32	0.29	0.27	0.24	0.25
Manure Management	0.15	0.05	0.04	0.04	0.04
Agricultural Soil Management	0.17	0.16	0.16	0.16	0.16
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01	0.01
Urea Application	+	+	+	+	+
Agricultural Soil Carbon	0.57	0.48	0.53	0.56	0.55
Forest Fires	0.08	0.12	0.01	0.02	0.07
AFOLU (Sinks)	**(6.70)**	**(6.52)**	**(6.55)**	**(6.50)**	**(6.51)**
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)
Urban Trees	(0.28)	(0.35)	(0.32)	(0.33)	(0.33)
Forest Carbon	(6.30)	(6.13)	(6.18)	(6.12)	(6.13)
Waste	**0.75**	**1.05**	**0.92**	**0.77**	**0.78**
Landfills	0.65	0.92	0.84	0.69	0.69
Composting	+	0.02	0.01	0.02	0.02
Wastewater Treatment	0.10	0.12	0.07	0.07	0.07
Total Emissions (Excluding Sinks)	**21.33**	**25.37**	**20.22**	**19.54**	**19.58**
Net Emissions (Including Sinks)	**14.63**	**18.85**	**13.67**	**13.04**	**13.07**
Aviation[c]	3.79	4.11	3.16	3.99	3.84
Net Emissions (Including Sinks, Excluding Aviation)[c]	**10.84**	**14.73**	**10.51**	**9.04**	**9.23**

+ 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 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 and military 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 88 percent of the emissions increase from 1990 to 2007 and 99 percent of reductions between 2007 and 2016. Energy emissions grew by 19 percent between 1990 and 2007 before falling by 23 percent between 2007 and 2010, 4 percent between 2010 and 2015, and another 0.2 percent between 2015 and 2016. Relative to 1990, emissions from the Energy sector in 2016 were lower by 11 percent. Transportation emissions—which increased by 31 percent between 1990 and 2007, decreased by 35 percent between 2007 and 2010, and then increased by 3 percent between 2010 and 2016—accounted for the largest share of Energy sector emissions in almost all inventory years (in 2010 stationary combustion accounted for the largest share of Energy sector emissions). The trend in transportation emissions is largely driven by the trend in ground transportation and domestic aviation emissions, which collectively represented 62 percent of transportation emissions in 1990 and 83 percent of transportation emissions in 2016. Even so, the overall decrease in domestic marine, military aviation, and military (non-aviation) emissions between 1990 and 2016 more than offset the overall increase in domestic aviation and ground transportation emissions during this period. Stationary combustion emissions—which increased by 6 percent between 1990 and 2007, and then decreased by 17 percent from 2007 to 2016—is the second largest share. This trend is largely driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial emissions.

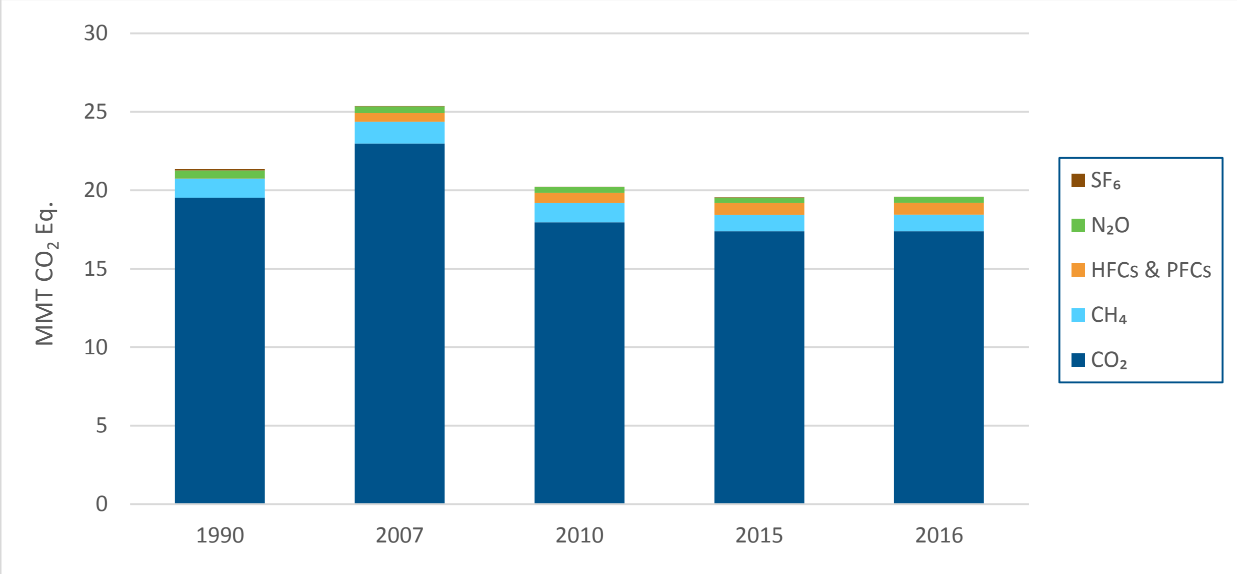
Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2016, falling by about 3 percent and 26 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 41 percent from 2007 to 2016. Relative to 1990, emissions from the IPPU sector in 2016 were more than three times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances (ODS).[11] Carbon removals from AFOLU sinks have remained relatively flat since 1990, decreasing by less than 1 percent between 1990 and 2016.

Emissions by Gas

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 2016. Methane and emissions also increased between 1990 and 2007 and decreased between 2007 and 2016. Emissions of HFCs and PFCs grew substantially from 1990 to 2016, while SF_6 emissions decreased over the same period. Emissions of N_2O similarly decreased between 1990 and 2015 but increased between 2015 and 2016, largely due to forest fires. Figure 2-5 shows emissions for each inventory year by gas.

[11] 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 J.

Figure 2-5: Hawaii GHG Emissions by Gas (1990, 2007, 2010, 2015, and 2016)

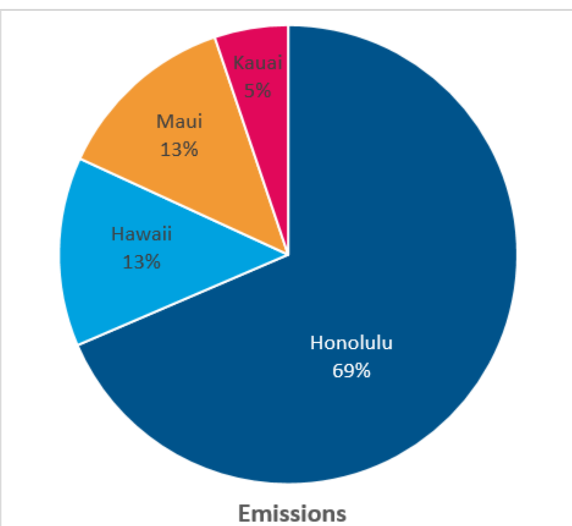


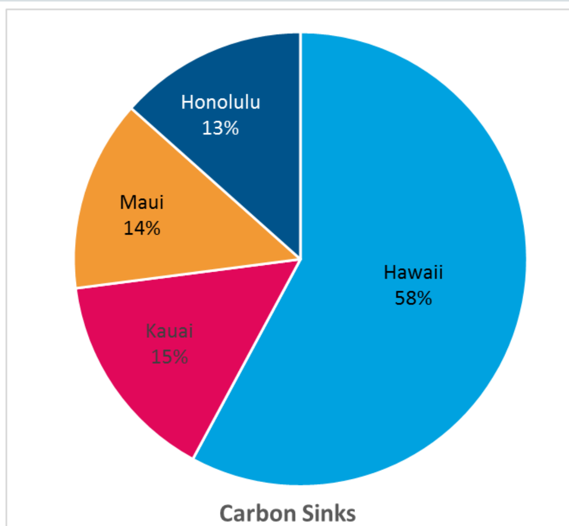
2.3. Emissions by County

In 2016, Honolulu County accounted for the largest share of GHG emissions (69 percent), followed by Hawaii County (13 percent), Maui County[12] (13 percent), and Kauai County (5 percent). Hawaii County accounted for the largest share of carbon removals from AFOLU sinks in 2016 (58 percent), followed by Kauai County (15 percent), Maui County (14 percent), and Honolulu County (13 percent).

Figure 2-6 shows the breakout of emissions and carbon removals (sinks) by county in 2016.

Figure 2-6: 2016 GHG Emissions and Carbon Removals by County (MMT CO_2 Eq.)





[12] Maui County includes emissions from Kalawao County.

Emissions from the Energy sector accounted for the largest portion of emissions from each county in all inventory years. In 2016, emissions from the Energy sector accounted for 92 percent of emissions from Honolulu County, 83 percent of emissions from Maui County, 76 percent of emissions from Kauai County, and 64 percent of emissions from Hawaii County. Emissions from AFOLU sources accounted for the second largest portion of emissions from all counties except Honolulu County, in which emissions from the IPPU and Waste sectors accounted for a larger share of emissions. Figure 2-7 shows 2016 emissions by sector and county. Figure 2-8 shows net emissions by county and year. Emissions by sector and year for each county are summarized in Table 2-2.

The methodology used to develop these estimates varies by emissions source, depending on data availability. For some sources, county-level activity data were available to build bottom-up county level emissions estimates. For other sources, only state-level activity data were available, requiring emissions to be allocated to each county using proxy information such as population and VMT data. Appendix E summarizes the methodology used to quantify Hawaii's GHG emissions by county.

Figure 2-7: Hawaii 2016 GHG Emissions by Sector and County

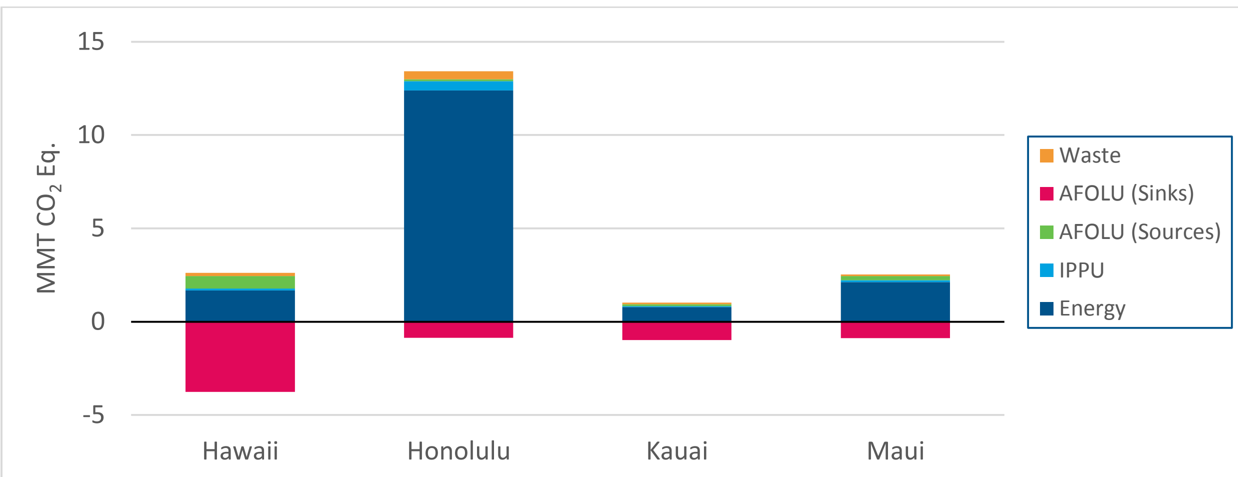


Figure 2-8 Net GHG Emissions by County (1990, 2007, 2010, 2015, and 2016)

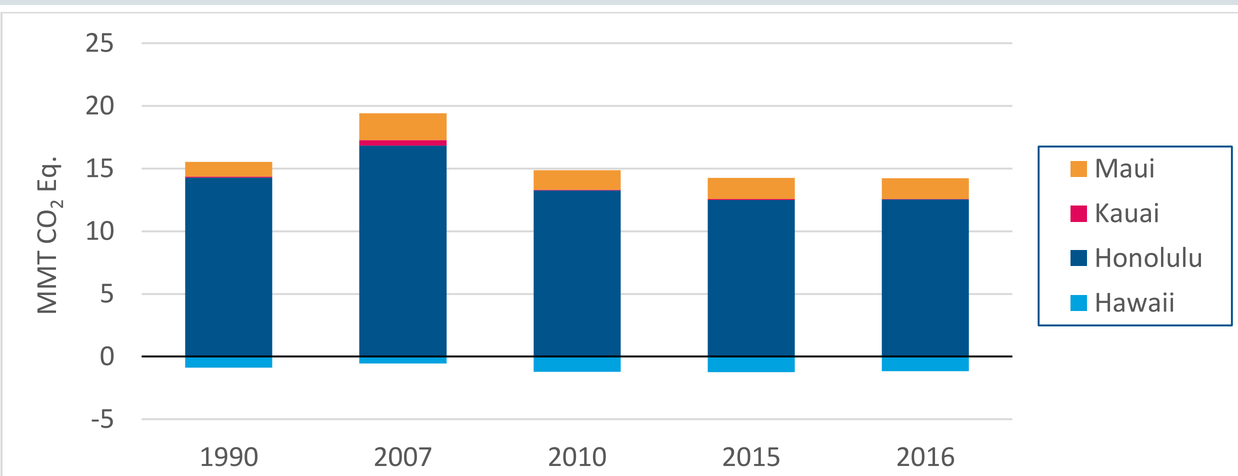


Table 2-2: GHG Emissions by Sector and County for 1990, 2007, 2010, 2015 and 2016 (MMT CO_2 Eq.)

Sector	1990	2007	2010	2015	2016
Honolulu County					
Energy	14.32	16.62	13.02	12.35	12.39
IPPU	0.16	0.36	0.44	0.50	0.51
AFOLU (Sources)	0.19	0.09	0.08	0.08	0.09
AFOLU (Sinks)	(0.96)	(0.88)	(0.83)	(0.86)	(0.87)
Waste	0.57	0.65	0.57	0.43	0.43
Total Emissions	**15.25**	**17.72**	**14.10**	**13.36**	**13.42**
Net Emissions	**14.29**	**16.84**	**13.27**	**12.50**	**12.54**
Hawaii County					
Energy	1.92	2.34	1.67	1.64	1.67
IPPU	0.01	0.08	0.10	0.11	0.11
AFOLU (Sources)	0.74	0.71	0.64	0.63	0.67
AFOLU (Sinks)	(3.64)	(3.85)	(3.78)	(3.77)	(3.77)
Waste	0.08	0.16	0.17	0.16	0.17
Total Emissions	**2.75**	**3.30**	**2.57**	**2.54**	**2.61**
Net Emissions	**(0.89)**	**(0.56)**	**(1.20)**	**(1.23)**	**(1.16)**
Maui County					
Energy	1.89	2.57	2.14	2.17	2.11
IPPU	0.01	0.08	0.09	0.11	0.11
AFOLU (Sources)	0.27	0.21	0.21	0.21	0.22
AFOLU (Sinks)	(1.06)	(0.89)	(0.98)	(0.89)	(0.89)
Waste	0.06	0.16	0.11	0.10	0.10
Total Emissions	**2.23**	**3.02**	**2.54**	**2.59**	**2.54**
Net Emissions	**1.16**	**2.12**	**1.56**	**1.70**	**1.65**
Kauai County					
Energy	0.96	1.12	0.79	0.82	0.78
IPPU	+	0.03	0.04	0.05	0.05
AFOLU (Sources)	0.11	0.10	0.09	0.10	0.11
AFOLU (Sinks)	(1.03)	(0.90)	(0.96)	(0.98)	(0.98)
Waste	0.03	0.08	0.08	0.08	0.09
Total Emissions	**1.11**	**1.33**	**1.01**	**1.04**	**1.02**
Net Emissions	**0.08**	**0.43**	**0.05**	**0.06**	**0.03**

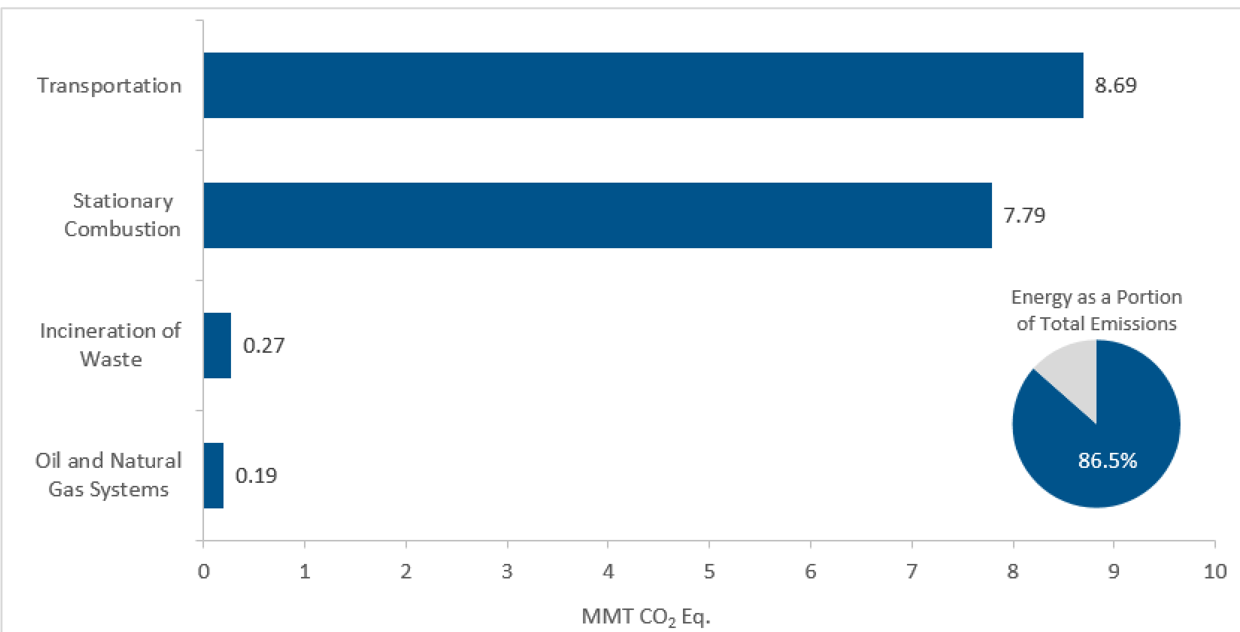
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.
+ Does not exceed 0.005 MMT CO_2 Eq.

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).[13] 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 2016, emissions from the Energy sector were 16.94 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 (51 percent), followed closely by stationary combustion (46 percent). Emissions from waste incineration and oil and natural gas systems comprised a relatively small portion of Energy sector emissions (3 percent). Figure 3-1 and show emissions from the Energy sector by source for 2016.

Figure 3-1: 2016 Energy Emissions by Source



[13] 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 2016 were lower by roughly 11 percent. Figure 3-3 below shows Energy sector emissions by source category for each inventory year. In almost all inventory years, transportation accounted for the largest share of emissions, followed closely by stationary combustion (in 2010, stationary combustion accounted for the largest share of emissions). The trend in transportation emissions, which increased significantly from 1990 to 2007, decreased from 2007 to 2010, and then increased slightly from 2010 to 2016, is largely driven by the trend in ground transportation and domestic aviation emissions, which collectively represented 62 percent of transportation emissions in 1990 and 83 percent of transportation emissions in 2016. Even so, the overall decrease in domestic marine, military aviation, and military (non-aviation) emissions between 1990 and 2016 more than offset the overall increase in domestic aviation and ground transportation emissions during this period. The trend in stationary combustion emissions, which increased between 1990 and 2007, and then decreased from 2007 to 2016, is largely driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial emissions. Emissions by source and year are also summarized in Table 3-1.

Figure 3-2: 2016 Energy Emissions by Source

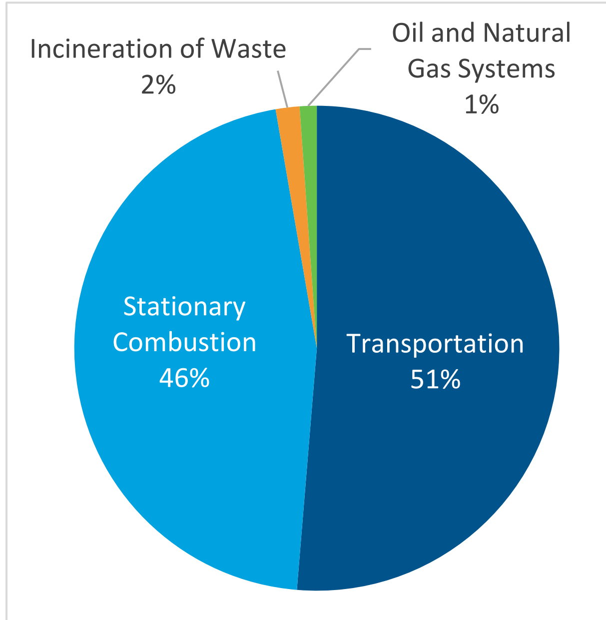


Figure 3-3: Energy Sector Emissions by Source and Year

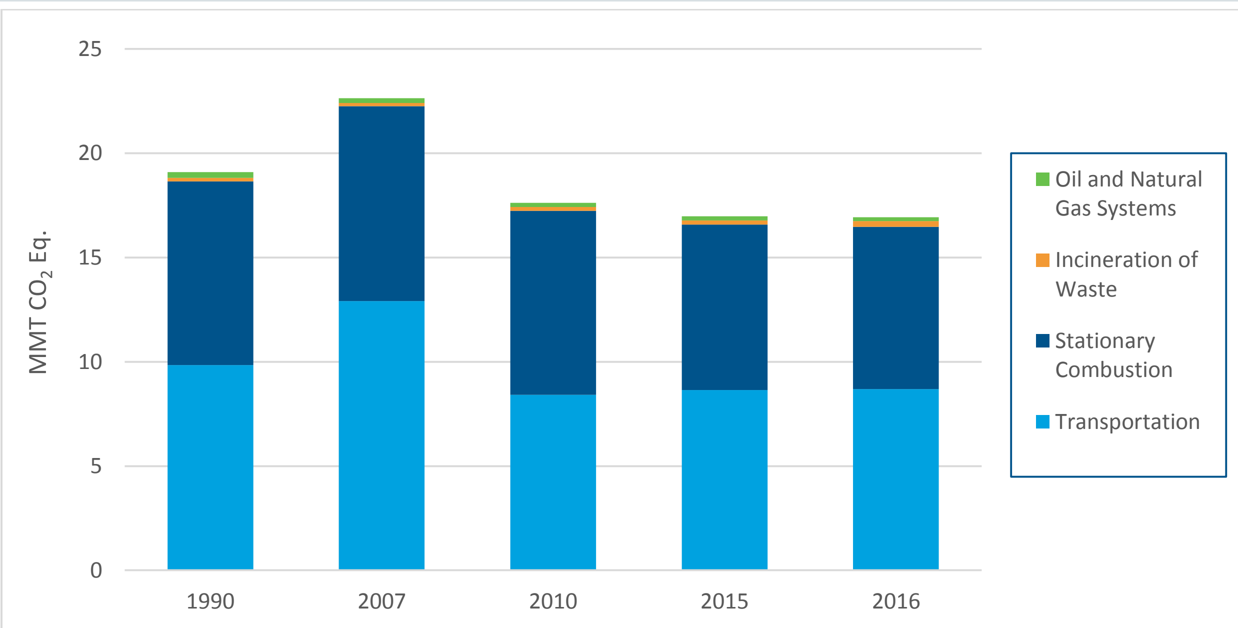


Table 3-1: GHG Emissions from the Energy Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016
Stationary Combustion[a]	**8.81**	**9.35**	**8.82**	**7.94**	**7.79**
Energy Industries[b]	6.66	8.29	7.79	6.88	6.83
Residential	0.05	0.06	0.09	0.06	0.08
Commercial	0.78	0.30	0.37	0.47	0.45
Industrial	1.32	0.70	0.57	0.52	0.43
Transportation[a]	**9.84**	**12.91**	**8.41**	**8.64**	**8.69**
Ground	3.72	5.12	4.15	4.04	4.05
Domestic Marine	1.58	2.90	0.60	0.56	0.64
Domestic Aviation	2.41	3.48	2.67	3.33	3.20
Military Aviation	1.38	0.63	0.49	0.66	0.64
Military Non-Aviation	0.76	0.77	0.50	0.05	0.16
Incineration of Waste	**0.18**	**0.15**	**0.19**	**0.20**	**0.27**
Oil and Natural Gas Systems	**0.27**	**0.24**	**0.20**	**0.19**	**0.19**
International Bunker Fuels[c]	***1.53***	***1.22***	***1.31***	***1.65***	***1.54***
International Marine	*0.12*	*0.05*	*0.40*	*0.10*	*0.06*
International Aviation	*1.41*	*1.17*	*0.92*	*1.55*	*1.48*
CO_2 from Wood Biomass and Biofuel Consumption[c]	***2.43***	***0.87***	***1.27***	***1.47***	***1.53***
Total	**19.09**	**22.65**	**17.62**	**16.97**	**16.94**

+ 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. Facility-level data for Hawaii Administrative Rule (HAR) affected facilities are provided in Appendix F.[14,15] Activity data and emission factors used in the analysis are summarized in Appendix G and Appendix H, respectively. A consolidated list of areas for improvement, ranked by priority, is provide in Appendix I.

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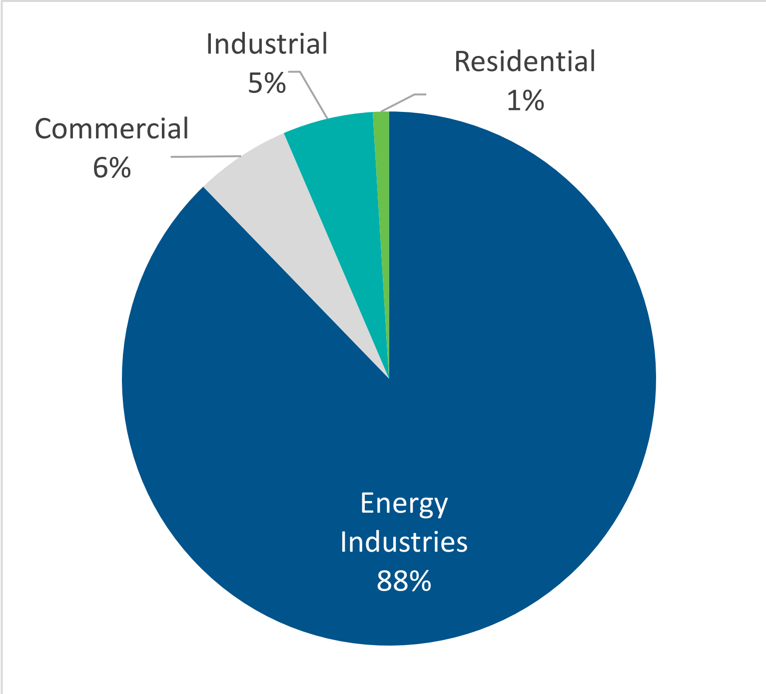
[14] HAR affected facilities refers to large existing stationary sources with potential GHG emissions at or above 100,000 tons per year. Hawaii Administrative Rules, Chapter 11-60.1, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.

[15] The sector subtotals presented in Appendix F, which are largely based on GHGRP facility-level data, differ from the estimates by end-use sector presented in this inventory report, which are based mainly on SEDS sector-specific fuel consumption data. The differences are a result of differences in how SEDS allocates its data by end-use sector. Specifically, diesel consumption at the refineries is reported by SEDS under the industrial sector. Additionally, emissions from the consumption of naphtha, which is used as a feedstock to produce synthetic natural gas, are reported by SEDS as natural gas consumption under the industrial sector.

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

Figure 3-4: 2016 Stationary Combustion Emissions by Economic Sector



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[16], residential[17], commercial[18], and industrial[19]), based on where the fuel is combusted. In 2016, emissions from stationary combustion in Hawaii were 7.79 MMT CO_2 Eq., accounting for 46 percent of Energy sector emissions. The vast majority of these emissions are from energy industries (88 percent), which includes both electric power plants and petroleum refineries. The commercial sector accounted for the next largest portion of stationary combustion emissions (6 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 2016.

[16] Energy industries consist of all industries involved in the production and sale of energy to the public, particularly petroleum, gas, coal, and renewable power plants. The electric power sector is a subset of the broader energy industries sector and consists of electricity and combined heat and power (CHP) plants whose primary business is to sell electricity or heat to the public (EIA 2019).

[17] The residential sector consists of living quarters for private households. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances (EIA 2019).

[18] The commercial sector consists of service-providing facilities and equipment used by businesses; federal, state, and local governments; and other private and public organizations. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running equipment. This sector also includes generators that produce electricity and/or useful thermal output primarily to support the activities of the above-mentioned commercial establishments (EIA 2019).

[19] The industrial sector consists of all facilities and equipment used for producing, processing, or assembling goods. Overall energy use in this sector is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting (EIA 2019).

Relative to 1990, emissions from stationary combustion in 2016 were lower by roughly 12 percent. This trend is largely driven by emissions from energy industries, which increased from 1990 to 2007 and then decreased from 2007 to 2016. Emissions from the industrial sector consistently decreased from 1990 to 2016. Emissions from the residential and commercial sectors followed an inconsistent trend. Emissions from the residential sector increased from 1990 to 2010, decreased from 2010 to 2015, and then increased from 2015 to 2016. Emissions from the commercial sector decreased from 1990 to 2007, increased from 2007 to 2015, and then decreased from 2015 to 2016. Figure 3-5 presents emissions from stationary combustion in Hawaii by economic sector for 1990, 2007, 2010, 2015, and 2016. Table 3-2 summarizes emissions from stationary combustion in Hawaii by economic sector and gas for 1990, 2007, 2010, 2015, and 2016.

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

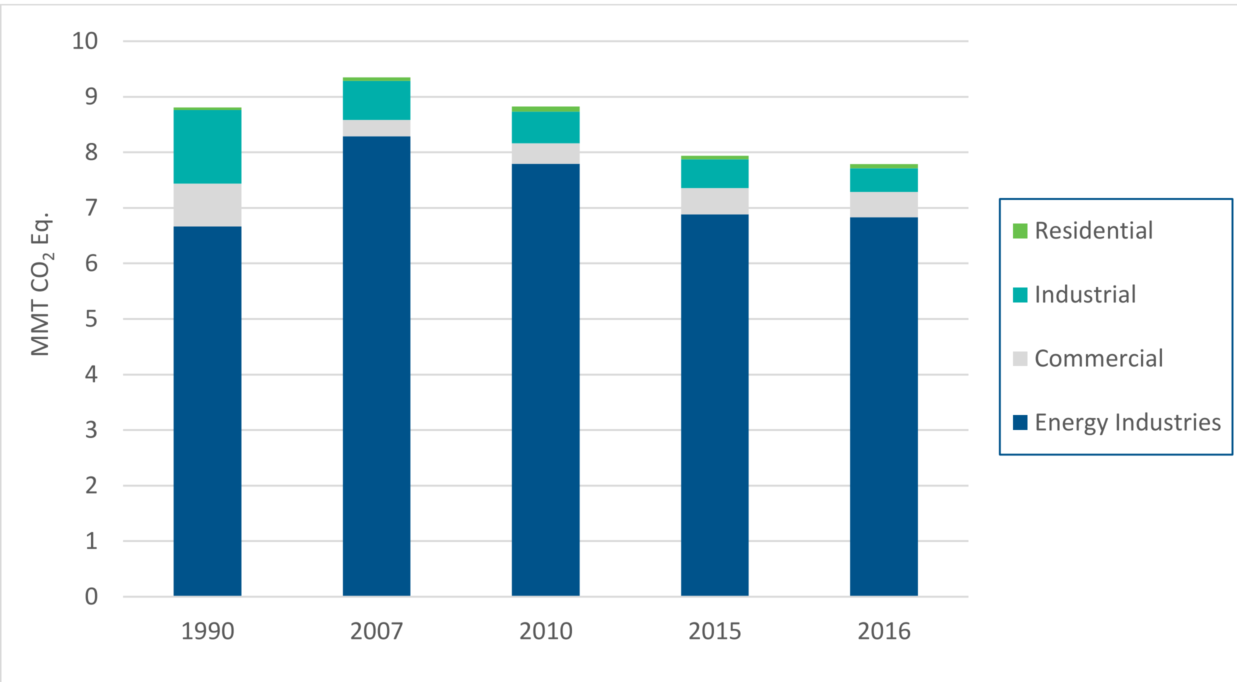


Table 3-2: GHG Emissions from Stationary Combustion by Economic Sector and Gas (MMT CO_2 Eq.)

Economic Sector/Gas	1990	2007	2010	2015	2016
Energy Industries	**6.66**	**8.29**	**7.79**	**6.88**	**6.83**
CO_2	6.63	8.26	7.76	6.86	6.81
CH_4	0.01	0.01	0.01	0.01	0.01
N_2O	0.02	0.02	0.02	0.02	0.02
Residential	**0.05**	**0.06**	**0.09**	**0.06**	**0.08**
CO_2	0.05	0.06	0.09	0.06	0.07
CH_4	+	+	+	+	+
N_2O	+	+	+	+	+
Commercial	**0.78**	**0.30**	**0.37**	**0.47**	**0.45**
CO_2	0.77	0.28	0.34	0.44	0.42
CH_4	+	0.02	0.02	0.02	0.03
N_2O	+	+	+	+	0.01
Industrial	**1.32**	**0.70**	**0.57**	**0.52**	**0.43**
CO_2	1.29	0.69	0.56	0.51	0.42
CH_4	0.01	+	+	+	+
N_2O	0.02	0.01	0.01	0.01	+
Total	**8.81**	**9.35**	**8.82**	**7.94**	**7.79**

+ 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 2018a). Methane and N_2O emission factors were obtained from the *2006 IPCC Guidelines* (IPCC 2006) for fossil fuels and wood biomass, and the U.S. Inventory (EPA 2018a) for ethanol.

Fuel consumption data by end-use sector were obtained from EIA's State Energy Data System (SEDS) (EIA 2018a) for all years.[20] For 1990, an adjustment was made to the SEDS data to remove residual fuel and diesel fuel consumption from the Kalaeloa Facility based on the facility's 1990 Annual Emissions Report and communication with the plant manager (HECO 1991; McFall 2019).[21] For some fuel types, consumption data were not available in SEDS and were obtained from additional data sources. Specifically, fuel gas consumption at refineries were collected by the Hawaii Department of Business, Economic Development, and Tourism (DBEDT 2008a) for 2007.[22] For 2010, 2015, and 2016, CO_2, CH_4, and N_2O emissions from fuel gas consumption at refineries were obtained directly from EPA's GHGRP (EPA 2018b). Methane and N_2O emissions from biodiesel consumption at the Hawaiian Electric Company (HECO) and the Maui Electric Company (MECO) were also obtained directly from EPA's GHGRP (EPA 2018b) for 2015 and 2016.[23]

Changes in Estimates since the Previous Inventory Report

In the 2015 inventory report, data collected by DBEDT were used as the primary source of fuel consumption data to estimate stationary combustion emissions. To protect the confidentiality of the data, in accordance with HRS Chapter 486J, fuel consumption data collected by DBEDT for 2010 and 2015 was aggregated across fuel categories and end-use sectors. Based on further input from DBEDT[24] as well as the results of a comparative analysis of available energy consumption data, for this inventory report, EIA's SEDS was used as the primary source of fuel consumption data, instead of data from DBEDT. SEDS data was used for all inventory years to ensure consistency across the entire time series, to use a source that has undergone extensive review and verification, and to use data from the same

[20] Motor gasoline consumption obtained from EIA (2018a) includes blended ethanol. Pure ethanol consumption obtained from EIA (2018a) was subtracted from motor gasoline prior to estimating emissions.

[21] The inaccurate inclusion of fuel consumption from Kalaeloa in 1990 SEDS data was confirmed in EIA Form-867, which feeds into SEDS (EIA 2019b). The facility annual emissions report also shows a small amount of butane and syngas consumption, which are reflected in the 1990 estimates.

[22] 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.

[23] Carbon dioxide emissions from Wood Biomass and Biofuels Consumption are reported in Section 2.6.

[24] Based on additional communications between DBEDT and ICF, DBEDT clarified that the data collected under the Energy Industry Information Reporting Program (EIIRP), which were previously used to support the development of the emission estimates for 2010 and 2015, as presented in the 2015 inventory report, are not used or verified by DBEDT. Rather, DBEDT relies on fuel consumption data from EIA when conducting analyses.

source that DBEDT uses for its own analyses. See Appendix C for a summary of the comparative analysis of available energy consumption data from SEDS and DBEDT. The resulting changes in historical emission estimates are presented in Table 3-3. Additional discussion on the change in emission estimates relative to the 2015 inventory report is found in Appendix B.

Table 3-3: Change in Emissions from Stationary Combustion Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
Energy Industries				
2015 Inventory Report (MMT CO_2 Eq.)	6.80	8.78	8.48	7.06
This Inventory Report (MMT CO_2 Eq.)	6.66	8.29	7.79	6.88
Percent Change	-2.0%	-5.7%	-8.1%	-2.6%
Residential				
2015 Inventory Report (MMT CO_2 Eq.)	0.03	0.04	0.08	0.08
This Inventory Report (MMT CO_2 Eq.)	0.05	0.06	0.09	0.06
Percent Change	48.2%	38.5%	7.1%	-16.4%
Commercial				
2015 Inventory Report (MMT CO_2 Eq.)	0.38	0.24	0.51	0.84
This Inventory Report (MMT CO_2 Eq.)	0.78	0.30	0.37	0.47
Percent Change	103.8%	24.9%	-27.6%	-43.6%
Industrial				
2015 Inventory Report (MMT CO_2 Eq.)	0.70	0.19	0.84	0.40
This Inventory Report (MMT CO_2 Eq.)	1.32	0.70	0.57	0.52
Percent Change	90.3%	272.7%	-31.8%	27.6%
Total				
2015 Inventory Report (MMT CO_2 Eq.)	7.91	9.26	9.91	8.38
This Inventory Report (MMT CO_2 Eq.)	8.81	9.35	8.82	7.94
Percent Change	11.4%	1.0%	-11.0%	-5.4%

Uncertainties

Uncertainties associated with stationary consumption estimates include the following:

- The differences between the SEDS consumption data and the data collected by DBEDT, as highlighted in Appendix C, indicate potential areas of uncertainty. In compiling this report, a significant effort was made to validate these datasets. As a result of this analysis, there was higher confidence in the accuracy of the EIA SEDS dataset across inventory years; thus, this data now underpins the energy consumption estimates (with some adjustments). This will be an area for continued assessment.
- Differences between residual fuel consumption in EIA SEDS dataset and EPA’s GHGRP for 2016.
- Emissions from fuel gas consumption at refineries were only available from EPA’s GHGRP starting in 2010. Data on fuel gas consumption at refineries in 2007 were collected by DBEDT. As

DBEDT is the conduit of this data but not the source, there is additional uncertainty associated with this data.

- Data on biodiesel consumption were not available for 1990 and 2007. As a result, CH_4 and N_2O emissions from biodiesel for 1990 and 2007 are not reflected in this analysis.
- Emissions from fuel gas and biodiesel consumption in the energy industries sector for 2010, 2015, and 2016 that were obtained from EPA's GHGRP (EPA 2018b) do not include emissions from facilities that are below the reporting threshold of 25,000 MT CO_2 Eq. per year.
- Uncertainty with respect to specific plant data. For example, due to calibration issues on emissions monitoring equipment at the AES Hawaii facility that were reported to GHGRP, AES Hawaii emissions were recalculated based on SEDS energy industries coal consumption data and a site-specific emission factor provided by DOH. Additionally, due to inaccuracies in how 1990 fuel consumption was allocated to various fuels and end-use sectors at the Kalaeoloa Cogeneration Plant, the SEDS data was adjusted to correctly apportion fuel consumption.

To estimate uncertainty associated with emissions from stationary combustion, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on IPCC (2006) and expert judgment. Uncertainty ranges for activity data were developed using the *2006 IPCC Guidelines* due to lack of available information from EIA. The *2006 IPCC Guidelines* provide default uncertainty bounds for activity data based on the type of energy data system from which the activity data were obtained. Because SEDS is a robust national dataset based on data from thousands of industry-specific surveys, these data were assumed to fall under the "Well developed statistical systems: Surveys" category for all fuel types except coal and residual fuel consumption. The highest range of uncertainties were used for this analysis. For coal fuel consumption, expert judgement determined that a higher uncertainty range should be applied to account for recalculating AES Hawaii emissions based on SEDS energy industries coal consumption data and a site-specific emission factor provided by DOH, as noted above. For residual fuel consumption, expert judgement determined that a higher uncertainty range should be applied to account for differences between residual fuel consumption in EIA SEDS dataset and EPA's GHGRP for 2016. These values may change as additional analysis is conducted in the future.

The following parameters contributed the most to the quantified uncertainty estimates: (1) residual fuel consumption in the energy industries sector, (2) the CO_2 emission factor for coal consumption in the energy industries sector, (3) the CO_2 emission factor for residual fuel consumption in the energy industries sector, (4) coal consumption in the energy industries sector, and (5) non-energy consumption of asphalt and road oil in the industrial sector. The results of the quantitative uncertainty analysis are summarized in Table 3-4. GHG emissions from stationary combustion were estimated to be between 7.59 and 8.11 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 3 percent below and 4 percent above the emission estimate of 7.79 MMT CO_2 Eq.

Table 3-4: Quantitative Uncertainty Estimates for Emissions from Stationary Combustion

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
7.79	7.59	8.11	-3%	+4%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Areas for improvement associated with stationary consumption estimates include the following:

- Further review and verification of the SEDS fuel consumption data should be explored, depending in part on the availability of additional data. For example, Hawaii Senate Bill SB1241, which will allow DBEDT to share the EIIRP data with DOH for the purposes of regulating GHG emissions, was signed into law on June 7, 2019. Therefore, additional year by year trend analyses from 2010 onwards could be performed for fuel types and sectors to compare the EIIRP data against SEDS and other sources such as GHGRP. In addition, to further assess fuel consumption estimates for 1990 and 2007, a closer review of year-over-year trends in the SEDS data by fuel type and end-use sector could be explored to identify possible anomalies in the data.
- Emissions from non-energy uses (NEU) of fuels[25] are assumed to be captured within the Industrial Processes sector calculations. Future analyses could confirm this assumption, estimate emissions from the consumption of fossil fuel feedstocks for NEU, and include these emissions under the Energy sector.
- If data becomes available, the following emissions could be estimated:
    - CO_2 emissions from biodiesel consumption for 1990 and 2007, and
    - CO_2 emissions from biodiesel consumption at energy industries facilities that fall below the reporting threshold for EPA's GHGRP for 2010, 2015, and 2016.

3.2. Transportation (IPCC Source Category 1A3)

Emissions from transportation result from the combustion of fuel for ground, domestic marine, domestic aviation, military aviation, and military (non-aviation) transportation. Ground transportation includes passenger cars, light trucks, motorcycles, and heavy-duty vehicles (i.e., trucks and buses). In 2016, emissions from transportation activities in Hawaii were 8.69 MMT CO_2 Eq., accounting for 51 percent of Energy sector emissions. Ground transportation accounted for the largest portion of transportation emissions (47 percent) followed by domestic aviation (37 percent), domestic marine (7 percent), military aviation (7 percent), and military non-aviation (2 percent). Figure 3-6 shows the

[25] Non-energy uses of fuels include use of fossil fuel feedstocks for industrial and transportation applications that do not involve combustion, including production of lubricants, asphalt, and road oil.

breakout of transportation emissions by end-use sector for 2016.

Relative to 1990, emissions from transportation in 2016 were lower by roughly 12 percent. While emissions from ground and domestic aviation transportation increased between 1990 and 2016, emissions from domestic marine and military transportation decreased during the same time period. Figure 3-7 presents emissions from transportation in Hawaii by end-use sector for 1990, 2007, 2010, 2015, and 2016. Table 3-5 summarizes emissions from transportation in Hawaii by end-use sector and gas for 1990, 2007, 2010, 2015, and 2016.

Figure 3-6: 2016 Transportation Emissions by End-Use Sector

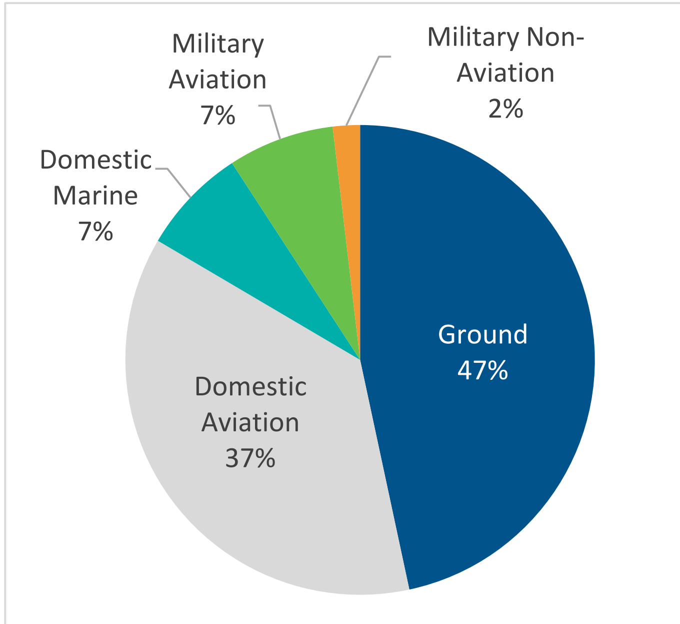


Figure 3-7: Transportation Emissions by End-Use Sector and Year (MMT CO_2 Eq.)

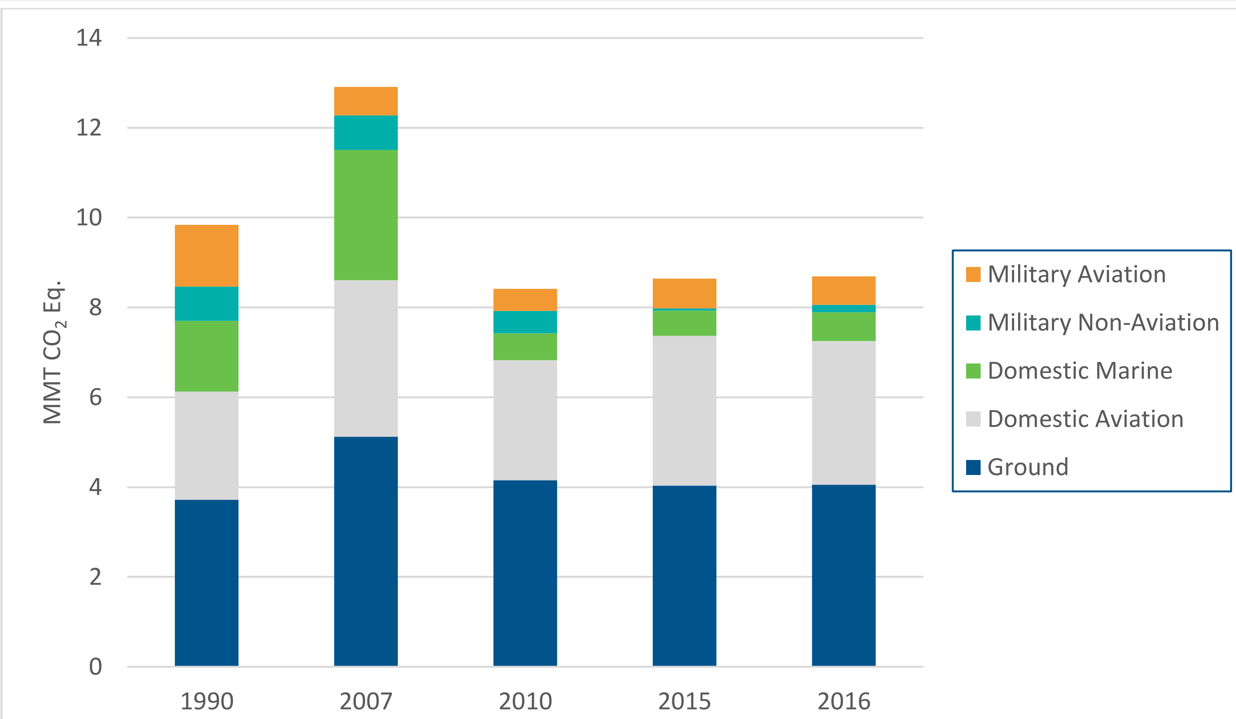


Table 3-5: GHG Emissions from Transportation by End-Use Sector and Gas (MMT CO_2 Eq.)

End-Use Sector/Gas	1990	2007	2010	2015	2016
Ground	**3.72**	**5.12**	**4.15**	**4.04**	**4.05**
CO_2	3.55	5.01	4.07	3.99	4.00
CH_4	0.02	0.01	0.01	+	+
N_2O	0.14	0.10	0.08	0.05	0.04
Domestic Marine	**1.58**	**2.90**	**0.60**	**0.56**	**0.64**
CO_2	1.55	2.86	0.59	0.55	0.63
CH_4	+	+	+	+	+
N_2O	0.02	0.04	0.01	0.01	0.01
Domestic Aviation	**2.41**	**3.48**	**2.67**	**3.33**	**3.20**
CO_2	2.39	3.45	2.65	3.30	3.17
CH_4	+	+	+	+	+
N_2O	0.02	0.03	0.02	0.03	0.03
Military Aviation	**1.38**	**0.63**	**0.49**	**0.66**	**0.64**
CO_2	1.37	0.63	0.48	0.66	0.63
CH_4	+	+	+	+	+
N_2O	0.01	0.01	+	0.01	0.01
Military Non-Aviation	**0.76**	**0.77**	**0.50**	**0.05**	**0.16**
CO_2	0.75	0.76	0.49	0.05	0.16
CH_4	+	+	+	+	+
N_2O	0.01	0.01	+	+	+
Total	**9.84**	**12.91**	**8.41**	**8.64**	**8.69**

+ 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 for transportation were obtained from EIA's SEDS (EIA 2018a) for all years.[26] These data were available at an aggregate level by fuel type. Disaggregated transportation data collected by DBEDT (2008a) for 2007 were used to allocate transportation fuel consumption from EIA (2018a) for diesel fuel, motor gasoline, propane, residual fuel, and natural gas into marine and ground transportation for each fuel type.[27] All aviation gasoline and jet fuel kerosene are assumed to be used for aviation.

Aviation gasoline, naphtha-type jet fuel, diesel fuel, and residual fuel consumption for military were obtained from EIA (2019c) for all years. Aviation gasoline and naphtha-type jet fuel were assumed to be consumed for aviation purposes, while diesel and residual fuel were assumed to be consumed for non-aviation purposes. These values were subtracted from the aggregate transportation aviation gasoline, diesel fuel, and residual fuel consumption data from EIA (2018a) prior to estimating emissions for the other subcategories.[28]

For 1990 and 2007, kerosene-type jet fuel consumption data for military were collected by DBEDT (2008a). These values were subtracted from the aggregate transportation jet fuel consumption data from EIA (2018a) prior to estimating emissions for these years. For 2010, 2015, and 2016, the aggregate

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[26] Diesel fuel consumption data obtained from EIA (2018a) includes blended biodiesel. Pure biodiesel consumption data collected by DBEDT (2018a and 2018b) were used for 2010, 2015, and 2016. Some of this fuel is assumed to be consumed by the energy industries sector based on emissions reported under EPA's GHGRP (EPA 2018b). The remaining fuel was assumed to be consumed by the ground transportation sector. This amount was subtracted from total diesel fuel consumption for ground transportation prior to estimating emissions. For 1990 and 2007, biodiesel consumption is assumed to be zero due to a lack of available data.

[27] To protect the confidentiality of the data, in accordance with HRS Chapter 486J, disaggregated transportation data by fuel type and end-use sector is unavailable for the 2010, 2015, and 2016 inventory years. See the Transportation Uncertainties section below for further discussion on the impact of this assumption.

[28] EIA SEDS (2018a) does not include any naphtha consumption for Hawaii, so naphtha-type jet fuel consumption in 1990 obtained from EIA (2018b) was assumed to be excluded from SEDS.

transportation jet fuel consumption data from EIA (2018a) were allocated to military transportation and non-military transportation using the 2007 data breakout.

Biodiesel consumption data for transportation were not directly available in SEDS.[29] Therefore, biodiesel consumption data collected by DBEDT (2018a and 2018b) were used for 2010, 2015, and 2016.[30,31]

For all years, aviation and marine fuel consumption were categorized as either domestic or international consumption for the purposes of estimating emissions from international bunker fuels. The methodology and uncertainties associated with the methodology used to apportion aviation and marine fuel consumption into domestic or international consumption 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:

$$CH_4 \text{ and } N_2O \text{ Emissions} = VMT \times EF_t$$

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, 2015, and 2016, 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; 2015; 2016). The distribution of annual VMT by vehicle type for each functional class for the state of Hawaii, which was also obtained from FHWA (2010; 2015; 2016),[32] 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 as control technologies and emission factors by vehicle type for all years, were obtained from the U.S. Inventory (EPA 2018a).

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[29] SEDS includes all biodiesel blended into distillate fuel oil in the consumption total for distillate fuel oil.
[30] 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.
[31] Biodiesel consumption data for 1990 and 2007 were not provided by DBEDT; therefore, emissions from biodiesel for 1990 and 2007 are not estimated.
[32] The distribution of annual VMT by vehicle type was not available for 2016, so 2015 data were used as a proxy.

Calculating CH_4 and N_2O emissions from non-highway vehicles

Methane and N_2O emissions from non-highway vehicles[33] 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.

Calculating CH_4 and N_2O emissions from alternative fuel vehicles

Methane and N_2O emissions from alternative fuel (i.e., biodiesel and ethanol) vehicles were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:

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

where,

Fuel Consumption	= total amount of biodiesel or ethanol combusted (Bbtu)
EF_{fuel}	= emission factor of CH_4 and N_2O by fuel type (kg CH_4 or N_2O/Bbtu)

Methane and N_2O emission factors were taken from the U.S. Inventory (EPA 2018a) for ethanol and biodiesel.

Changes in Estimates since the Previous Inventory Report

In the 2015 inventory report, data collected by DBEDT were used as the primary source of fuel consumption data to estimate transportation emissions. To protect the confidentiality of the data, in accordance with HRS Chapter 486J, fuel consumption data collected by DBEDT for 2010 and 2015 were aggregated across fuel categories and end-use sectors. Based on further input from DBEDT[34] as well as the results of a comparative analysis of available energy consumption data (see Appendix C), for this

[33] 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.

[34] Based on additional communications between DBEDT and ICF, DBEDT clarified that the data collected under EIIRP, which were previously used to support the development of the emission estimates for 2010 and 2015 in the 2015 inventory report, are not used or verified by DBEDT. Rather, DBEDT relies on fuel consumption data from EIA when conducting analyses.

inventory report, EIA's SEDS (EIA 2018a) was instead used as the primary source of fuel consumption data to estimate transportation emissions for all years. DBEDT data are still used for some inventory years to disaggregate fuel consumption data from EIA into ground and marine transportation, to disaggregate the jet fuel consumption from EIA into military or non-military, and for biodiesel consumption. In addition, military emissions were further disaggregated into military aviation and military non-aviation emissions. The changes in historical emission estimates are presented in Table 3-6. See Appendix B for additional discussion on the change in emission estimates relative to the 2015 inventory report.

Table 3-6: Change in Emissions from Transportation Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
Ground				
2015 Inventory Report (MMT CO_2 Eq.)	3.40	4.97	5.28	5.64
This Inventory Report (MMT CO_2 Eq.)	3.72	5.12	4.15	4.04
Percent Change	9.4%	3.2%	-21.4%	-28.5%
Domestic Marine				
2015 Inventory Report (MMT CO_2 Eq.)	1.82	1.79	0.91	0.39
This Inventory Report (MMT CO_2 Eq.)	1.58	2.90	0.60	0.56
Percent Change	-13.6%	62.3%	-33.9%	42.6%
Domestic Aviation				
2015 Inventory Report (MMT CO_2 Eq.)	4.66	4.42	2.87	3.23
This Inventory Report (MMT CO_2 Eq.)	2.41	3.48	2.67	3.33
Percent Change	-48.2%	-21.2%	-6.7%	3.2%
Military[a]				
2015 Inventory Report (MMT CO_2 Eq.)	1.38	1.02	1.10	0.53
This Inventory Report (MMT CO_2 Eq.)	2.14	1.40	0.98	0.71
Percent Change	55.2%	37.2%	-10.7%	35.7%
Total				
2015 Inventory Report (MMT CO_2 Eq.)	11.26	12.19	10.16	9.79
This Inventory Report (MMT CO_2 Eq.)	9.84	12.91	8.41	8.64
Percent Change	-12.6%	5.9%	-17.2%	-11.7%

[a] In the 2015 inventory report, military emissions were presented as a single end-use sector. Therefore, military aviation and military non-aviation emissions were combined for the purposes of comparison.

Uncertainties

Uncertainties associated with transportation estimates include the following:

- The differences between the SEDS consumption data and the data collected by DBEDT, as highlighted in Appendix C, indicate potential areas of uncertainty. In compiling this report, a significant effort was made to validate these datasets. As a result of this analysis, there was higher confidence in the accuracy of the EIA SEDS dataset across inventory years; thus, this data now underpins the energy consumption estimates (with some adjustments). This will be an area for continued assessment.

- Data collected by DBEDT for 2007 were used to disaggregate fuel consumption data from EIA into ground and marine transportation for 1990, 2007, 2010, 2015 and 2016. There is uncertainty associated with the disaggregation of the DBEDT-collected data by fuel type and end-use sector. For example, when applying this method, marine-based diesel fuel consumption is estimated to decrease by more than 60 percent from 2010 to 2016, which does not align with the activities of the overall economy. This incongruity may be a result of applying the allocations implied by the 2007 data collected by DBEDT to 2010, 2015, and 2016 diesel fuel consumption from EIA in the absence of more recent disaggregated data. However, since this uncertainty is only applicable to the apportioning of data, uncertainty surrounding the overall emission estimates for the transportation sector are unaffected. Also, since the data collected by DBEDT are not used to apportion aviation sector consumption, net emissions excluding aviation is not impacted by this uncertainty.
- Commercial jet fuel consumption grew by 22 percent from 2010 to 2016, which is more than double the growth in gross state product (GSP) over the same period.
- Kerosene-type jet fuel consumption for military were not available from EIA. For 1990 and 2007, the analysis used kerosene-type jet fuel consumption data for military as collected by DBEDT. The data collected by DBEDT were used to disaggregate the jet fuel consumption from EIA into military or non-military for 2010, 2015, and 2016. There is uncertainty associated with the disaggregation of the DBEDT-collected data by fuel type and end-use sector; however, since this uncertainty is only applicable to the apportioning of data, uncertainty surrounding the overall emission estimates for the transportation sector are unaffected.
- Biodiesel consumption was not available from EIA. Data collected by DBEDT were used for 2010, 2015, and 2016, resulting in some uncertainty. Data on biodiesel consumption were not available for 1990 and 2007. As a result, CH_4 and N_2O emissions from biodiesel for 1990 and 2007 are not reflected in this analysis.
- 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).

To estimate uncertainty associated with emissions from transportation, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on IPCC (2006) and expert judgment. Uncertainty ranges for activity data were developed using the *2006 IPCC Guidelines* due to lack of available information from EIA. The *2006 IPCC Guidelines* provide default uncertainty bounds for activity data based on the type of energy data system from which the activity data were obtained. Because SEDS is a robust national dataset based on data from thousands of industry-specific surveys, these data were assumed to fall under the “Well developed statistical systems: Surveys” category. The highest range of uncertainties were used for this analysis. This value may change as additional analysis is conducted in the future.

The following parameters contributed the most to the quantified uncertainty estimates: (1) CO_2 emission factor for jet fuel, (2) jet fuel consumption, (3) motor gasoline consumption, (4) percent of total aviation consumption subtracted for international bunker fuels, and (5) CO_2 emission factor for motor gasoline. The results of the quantitative uncertainty analysis are summarized in Table 3-7. GHG emissions from transportation were estimated to be between 8.34 and 9.12 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 4 percent below and 5 percent above the emission estimate of 8.69 MMT CO_2 Eq.

Table 3-7: Quantitative Uncertainty Estimates for Emissions from Transportation

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
8.69	8.34	9.12	-4%	+5%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Areas for improvement associated with transportation estimates include the following:

- Further review and verification of the SEDS fuel consumption data should be explored, depending in part on the availability of additional data. For example, Hawaii Senate Bill SB1241, which will DBEDT to share the EIIRP data with DOH for the purposes of regulating GHG emissions, was signed into law on June 7, 2019. Therefore, additional year by year trend analyses from 2010 onwards could be performed for fuel types and sectors to compare the EIIRP data against SEDS and other sources such as GHGRP. In addition, to further assess fuel consumption estimates for 1990 and 2007, a closer review of year-over-year trends in the SEDS data by fuel type and end-use sector could be explored to identify possible anomalies in the data.
- For the purposes of verifying current estimates, transportation fuel consumption could alternatively be estimated based on mileage data and registered vehicles in Hawaii. Building on the work that has already been done to calculate CH_4 and N_2O emissions, an annual estimate of transportation fuel consumption could be made using compiled data on VMT by vehicle type, shares of gasoline and diesel vehicles by vehicle type, and vehicle age distribution data for each year. Data on fuel economy characteristics by vehicle type could then be added to estimate fuel consumption volumes and trends, which could then be compared to SEDS and the data collected by DBEDT.
- The U.S. Inventory (EPA 2018a) uses non-road emission factors for CH_4 and N_2O emissions developed based on the *2006 IPCC Guidelines* (IPCC 2006) Tier 3 guidance and EPA's MOVES2014 model. The use of these updated emission factors for off-road vehicles should be considered for future analyses.
- Methane and N_2O emissions from biodiesel consumption for 1990 and 2007 should be incorporated into the totals for this source category if data becomes available.

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 2016, emissions from the incineration of waste in Hawaii were 0.27 MMT CO_2 Eq., accounting for 2 percent of Energy sector emissions.[35] 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 2016 emissions increased due to expansions in H-POWER's processing capacity. Table 3-8 shows emissions from the incineration of waste in Hawaii by gas for 1990, 2007, 2010, 2015, and 2016.

Table 3-8: Emissions from Incineration of Waste by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	0.17	0.15	0.18	0.19	0.26
CH_4	+	+	+	+	+
N_2O	+	+	0.01	0.01	0.01
Total	**0.18**	**0.15**	**0.19**	**0.20**	**0.27**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

2010, 2015, and 2016

Emissions for the H-POWER plant for 2010, 2015, and 2016 were obtained directly from EPA's GHGRP (EPA 2018b). 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
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

[35] Consistent with the U.S. Inventory (EPA 2018a), emissions from waste incineration are reported under the Energy sector because the waste is used to produce energy.

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 2018c).

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).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from waste incineration since the 2015 inventory report.

Uncertainties

To estimate uncertainty associated with emissions from waste incineration, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on the U.S. Inventory (EPA 2018a) and expert judgment. The quantified uncertainty estimated for non-biogenic CO_2 emissions for H-POWER facility contributed the vast majority to the quantified uncertainty estimates. The remaining input variables had a minor impact on the overall uncertainty of this source category.

The results of the quantitative uncertainty analysis are summarized in Table 3-9. GHG emissions from waste incineration were estimated to be between 0.25 and 0.30 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 9 percent below and 13 percent above the emission estimate of 0.27 MMT CO_2 Eq.

Table 3-9: Quantitative Uncertainty Estimates for Emissions from Waste Incineration

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.27	0.25	0.30	-9%	+13%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

No areas for improvement were identified for this source category.

3.4. Oil and Gas Operations (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,[36] operate

[36] 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.

in Hawaii that contribute to these emissions (EIA 2018b). In 2016, 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 2016 were lower by roughly 28 percent. This decrease is attributed to a reduction in crude oil throughput over this time period. Table 3-10 summarizes emissions from oil and natural gas systems in Hawaii by gas for 1990, 2007, 2010, 2015, and 2016.[37]

Table 3-10: Emissions from Oil and Natural Gas Systems by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	0.27	0.24	0.20	0.19	0.19
CH_4	+	+	+	+	+
N_2O	+	+	+	+	+
Total	**0.27**	**0.24**	**0.20**	**0.19**	**0.19**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

2010, 2015, and 2016

Emissions from oil and gas systems for 2010, 2015, and 2016 were taken directly from EPA's GHGRP (EPA 2018b). 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 2018b) 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).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from oil and gas operations since the 2015 inventory report.

Uncertainties

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

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

a proxy for emissions in 1990 and 2007. 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.

To estimate uncertainty associated with emissions from oil and gas operations, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment. The quantified uncertainty estimated for CO_2 emissions for the Island Energy Services Downstream facility contributed the vast majority to the quantified uncertainty estimates. The remaining input variables had a minor impact on the overall uncertainty of this source category.

The results of the quantitative uncertainty analysis are summarized in Table 3-11. GHG emissions from oil and natural were estimated to be between 0.19 and 0.20 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 3 percent below and 3 percent above the emission estimate of 0.19 MMT CO_2 Eq.

Table 3-11: Quantitative Uncertainty Estimates for Emissions from Oil and Natural Gas Systems

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.19	0.19	0.20	-3%	+3%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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 2016 (EPA 2018b), are not currently captured in this inventory. These emissions should be incorporated into future inventory analyses. In addition, improvements to 1990 and 2007 emissions calculations should be made if additional data becomes available.

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

International bunker fuels are defined as fuels used for 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 2016, emissions from international bunker fuels in Hawaii were 1.54 MMT CO_2 Eq., which is 0.4 percent higher than 1990 levels. Table 3-12 summarizes emissions from international bunker fuels in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 3-12: Emissions from International Bunker Fuels by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
International Marine	**0.12**	**0.05**	**0.40**	**0.10**	**0.06**
CO_2	0.12	0.05	0.39	0.10	0.06
CH_4	+	+	+	+	+
N_2O	+	+	+	+	+
International Aviation	**1.41**	**1.17**	**0.92**	**1.55**	**1.48**
CO_2	1.39	1.16	0.91	1.54	1.47
CH_4	NO	NO	NO	NO	NO
N_2O	0.01	0.01	0.01	0.01	0.01
Total	**1.53**	**1.22**	**1.31**	**1.65**	**1.54**

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

Note: Totals may not sum due to independent rounding.

Methodology

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

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

where,

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

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

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

where,

IBF Consumption = total amount of International Bunker Fuel combusted (Bbtu)

EF_{fuel} = emission factor of CH_4 and N_2O by fuel type (MT/Bbtu)

Carbon dioxide emission factors were obtained from the U.S. Inventory (EPA 2018a), while CH_4 and N_2O emission factors were obtained from IPCC (2006). The following sections describe how IBF consumption was derived for aviation and marine bunker fuel.

Aviation Bunker Fuel

Aviation bunker fuel consumption was 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 (DOT 2018). That ratio was multiplied by total non-military jet fuel consumption in Hawaii, as derived from EIA (2018a and 2019c), to calculate aviation international bunker fuel consumption.

$$IBF\ Consumption\ =\ [Jet\ Fuel_T - Jet\ Fuel_M] \times [\frac{Miles_I}{Miles_I +\ Miles_D}]$$

where,

IBF Consumption	= total consumption of International Bunker Fuels from jet fuel (Bbtu)
Jet $Fuel_T$	= total jet fuel consumption from SEDS (Bbtu)
Jet $Fuel_M$	= military jet fuel consumption (Bbtu)
$Miles_I$	= miles flown for international trips originating in Hawaii
$Miles_D$	= miles flown for domestic trips originating in Hawaii

Marine Bunker Fuel

Marine bunker fuel consumption was calculated based on the estimated amount of diesel and residual fuel consumption used for international trips. For all inventory years except 1990, marine bunker fuel consumption for Hawaii was obtained directly from the Census Bureau (DOC 2008 and 2018). 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 2018a).

Changes in Estimates since the Previous Inventory Report

In the 2015 inventory report, data collected by DBEDT were used as the primary source of total jet fuel consumption data, which is a key input to estimating aviation and marine bunker fuel emissions. To protect the confidentiality of the data, in accordance with HRS Chapter 486J, fuel consumption data collected by DBEDT for 2010 and 2015 were aggregated across fuel categories and end-use sectors. Based on further input from DBEDT[38] as well as the results of a comparative analysis of available energy consumption data (see Appendix C), for this inventory report, EIA's SEDS (EIA 2018a) was instead used as the primary source of total statewide jet fuel consumption data, which impacts the estimate of bunker fuel emissions for all years. The resulting changes in historical emission estimates are presented in Table 3-13. The trend in fuel consumption seen in the SEDS data across the inventory years is

[38] Based on additional communications between DBEDT and ICF, DBEDT clarified that the data collected under EIIRP, which were previously used to support the development of the emission estimates for 2010 and 2015, as presented in the 2015 inventory report, are not used or verified by DBEDT. Rather, DBEDT relies on fuel consumption data from EIA when conducting analyses.

consistent with the trend in miles flown over the same time period as presented in the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database (DOT 2018).

Table 3-13: Change in Emissions from International Bunker Fuels Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	2.95	1.54	1.38	1.61
This Inventory Report (MMT CO_2 Eq.)	1.53	1.22	1.31	1.65
Percent Change	-48.1%	-20.7%	-4.8%	2.9%

Uncertainties

Uncertainties associated with international bunker fuel estimates include the following:

- The differences between the SEDS consumption data and the data collected by DBEDT, as highlighted in Appendix C, indicate potential areas of uncertainty. In compiling this report, a significant effort was made to validate these datasets. As a result of this analysis, there was higher confidence in the accuracy of the EIA SEDS dataset across inventory years; thus, this data now underpins the energy consumption estimates (with some adjustments). This will be an area for continued assessment.
- There is some uncertainty associated with estimating jet fuel consumption for international trips based on the international flight to total flight mileage ratio from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database (DOT 2018). This approach was used because data on actual 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 Census Bureau (DOC 2008 and 2018) 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 2018a).
- For this analysis, all 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.

To estimate uncertainty associated with emissions from international bunker fuels, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on IPCC (2006) and expert judgment. Uncertainty ranges for activity data were developed using the *2006 IPCC Guidelines* due to lack of available information from EIA. The *2006 IPCC Guidelines* provide default uncertainty bounds for activity data based on the type of energy data system from which the activity data were obtained. Because SEDS is a robust national dataset based on data from thousands of industry-specific surveys, these data were assumed to fall under the "Well developed statistical systems: Surveys" category. The highest range of uncertainties were used for this analysis. This value may change as additional analysis is conducted in the future.

The following parameters contributed the most to the quantified uncertainty estimates: (1) percent of total aviation consumption for international bunker fuels, (2) jet fuel consumption, and (3) CO_2 emission factor for jet fuel. The results of the quantitative uncertainty analysis are summarized in Table 3-14. GHG emissions from international bunker fuels were estimated to be between 1.36 and 1.73 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 11 percent below and 12 percent above the emission estimate of 1.54 MMT CO_2 Eq.

Table 3-14: Quantitative Uncertainty Estimates for Emissions from International Bunker Fuels

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1.54	1.36	1.73	-11%	+12%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Areas for improvement associated with international bunker fuel estimates include the following:

- Further review and verification of the SEDS fuel consumption data should be explored, depending in part on the availability of additional data. For example, Hawaii Senate Bill SB1241, which will allow DBEDT to share the EIIRP data with DOH for the purposes of regulating GHG emissions, was signed into law on June 7, 2019. Therefore, additional year by year trend analyses from 2010 onwards could be performed for fuel types and sectors to compare the EIIRP data against SEDS and other sources such as GHGRP. In addition, to further assess fuel consumption estimates for 1990 and 2007, a closer review of year-over-year trends in the SEDS data by fuel type and end-use sector could be explored to identify possible anomalies in the data.
- Additional analysis could be done on the existing domestic and international flight mileage data to better allocate fuel consumption estimates. Specifically, data on the distance and aircraft type by journey obtained from the DOT (2018) could be used to improve estimates by differentiating the fuel efficiency of each aircraft type, accounting for the fact that long haul flights tend to be more fuel efficient on a per mile basis.
- If data becomes available, actual data on jet fuel consumption for international trips originating in Hawaii, as well as data by specific aircraft type, number of individual flights, and movement data could be used in emissions calculations for this source category.
- If data becomes available, marine bunker fuel consumption data for 1990 should be incorporated into emissions calculations for this source category.

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

Ethanol, biodiesel, and other types of biomass release CO_2 emissions when combusted.[39,40] 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 2016, CO_2 emissions from wood biomass and biofuel consumption in Hawaii were 1.53 MMT CO_2 Eq. Table 3-15 summarizes CO_2 emissions from wood biomass and biofuel consumption in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 3-15: Emissions from Wood Biomass and Biofuel Consumption by Gas (MMT CO_2 Eq.)

Gas	1990[a]	2007[a]	2010	2015	2016
CO_2	2.43	0.87	1.27	1.47	1.53

+ Does not exceed 0.005 MMT CO_2 Eq.
[a] Emissions from biodiesel were not estimated for 1990 and 2007 due to a lack of available data. Emissions reported for 1990 and 2007 reflect emissions from ethanol and solid biomass 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)

Ethanol and solid biomass consumption data were obtained from SEDS (EIA 2018a) for all years. Pure biodiesel consumption data were not available in SEDS.[41] Therefore, biodiesel consumption data

[39] Ethanol is blended with motor gasoline at oil refineries. Hawaii began blending ethanol into its motor gasoline supply in 2006.
[40] 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.
[41] SEDS includes all biodiesel blended into distillate fuel oil in the consumption total for distillate fuel oil.

collected by DBEDT (2018a and 2018b) were used for 2010, 2015, and 2016.[42,43] Ethanol, biodiesel, and solid biomass CO_2 combustion emission factors were obtained from the U.S. Inventory (EPA 2018a).

Changes in Estimates since the Previous Inventory Report

In the 2015 inventory report, ethanol consumption data collected by DBEDT were used for all years. Solid biomass consumption data were not available from DBEDT, so carbon dioxide emissions from solid biomass consumption were obtained directly from EPA's GHGRP for 2010, 2015, and 2016. Emissions from solid biomass consumption were not estimated for 1990 and 2007. For this inventory report, ethanol and solid biomass consumption data for all inventory years were obtained from EIA (2018a). The resulting changes in historical emission estimates are presented in Table 3-16.

Table 3-16: Change in CO_2 Emissions from Wood Biomass and Biofuel Consumption Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	NE	0.16	1.22	1.45
This Inventory Report (MMT CO_2 Eq.)	2.43	0.87	1.27	1.47
Percent Change	NA	450.2%	4.1%	1.3%

NE (emissions are Not Estimated); NA (estimates are Not Applicable).

Uncertainties

Uncertainties associated with CO_2 emissions from wood biomass and biofuel consumption include the following:

- Biodiesel consumption was not available from EIA. Transportation sector biodiesel consumption data collected by DBEDT were used for 2010, 2015, and 2016. There is uncertainty associated with the disaggregation of the DBEDT-collected data by fuel type and end-use sector; however, since this uncertainty is only applicable to the apportioning of data, uncertainty surrounding the overall emission estimates for the transportation sector are unaffected. Data on biodiesel consumption were not available for 1990 and 2007. As a result, CO_2 emissions from biodiesel for 1990 and 2007 are not reflected in this analysis.
- Emissions from biodiesel consumption in the energy industries sector for 2010, 2015, and 2016 that were obtained from EPA's GHGRP (EPA 2018b) do not include emissions from facilities that are below the reporting threshold of 25,000 MT CO_2 Eq. per year.

To estimate uncertainty associated with CO_2 emissions from wood biomass and biofuel consumption, uncertainties associated with all input variables were assessed. Uncertainty was estimated

[42] 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.
[43] Biodiesel consumption data for 1990 and 2007 were not available from DBEDT; therefore, emissions from biodiesel for 1990 and 2007 are not estimated.

quantitatively around each input variable based on IPCC (2006) and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) commercial wood and wood waste consumption, and (2) H-Power plant biogenic CO_2 emissions. The results of the quantitative uncertainty analysis are summarized in Table 3-17. Carbon dioxide emissions from wood biomass and biofuel consumption were estimated to be between 1.40 and 1.66 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 8 percent below and 9 percent above the emission estimate of 1.53 MMT CO_2 Eq.

Table 3-17: Quantitative Uncertainty Estimates for Emissions from Wood Biomass and Biofuel Consumption

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1.53	1.40	1.66	-8%	+9%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

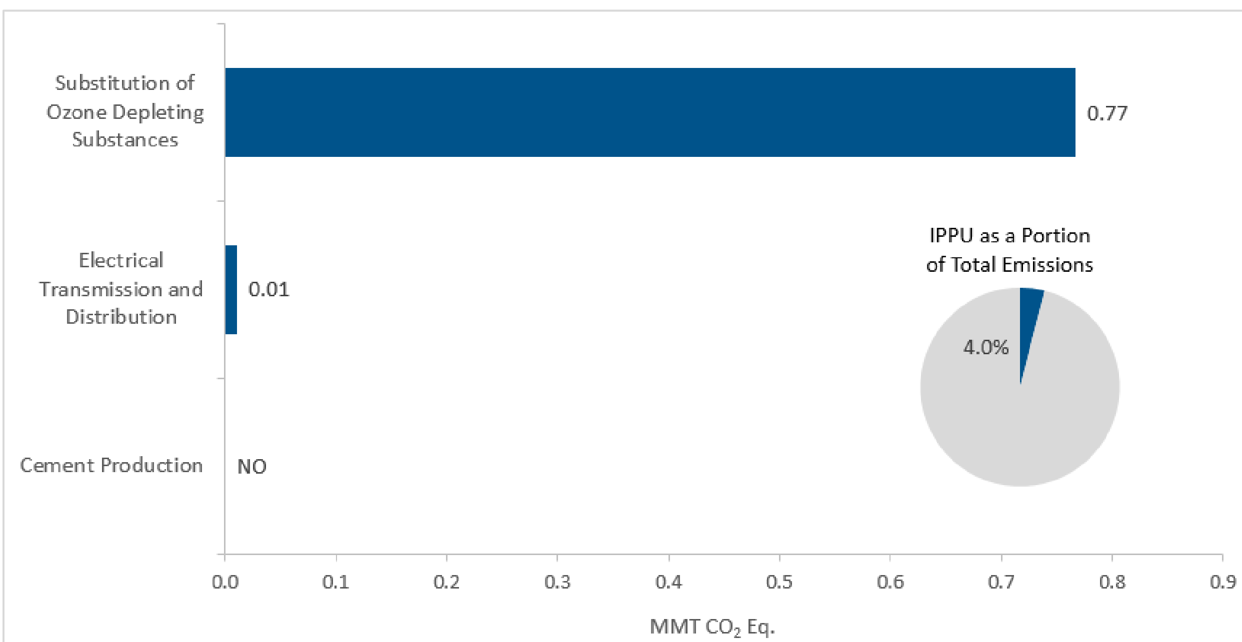
For all inventory years, it was assumed that biogas generated at wastewater treatment plants in Hawaii was not captured and converted to renewable natural gas. However, in 2017 Hawaii Gas announced a project to install equipment to capture biogas at the Honouliuli Wastewater Treatment Plant and convert it to renewable natural gas (Hawaii Free Press 2018). If and when this project is completed, future inventories will account for the amount of CH_4 emissions from wastewater treatment that is captured and combusted for energy. In addition, if data becomes available, the following emissions will be incorporated into the totals for this source category: CO_2 emissions from biodiesel consumption for 1990 and 2007; and CO_2 emissions from biodiesel consumption at energy industries facilities that fall below the reporting threshold for EPA’s GHGRP for 2010, 2015, and 2016.

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).[44]

In 2016, emissions from the IPPU sector were 0.78 MMT CO_2 Eq., accounting for 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 2016 were zero. Figure 4-1 and Figure 4-2 show emissions from the IPPU sector by source for 2016.

Figure 4-1: 2016 IPPU Emissions by Source (MMT CO_2 Eq.)



[44] 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 2016 were more than 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 2018a). 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 2018a). 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: 2016 IPPU Emissions by Source

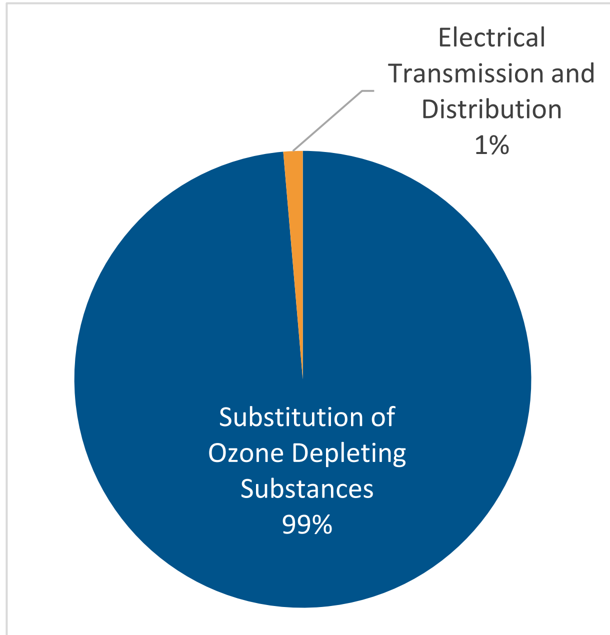


Figure 4-3: IPPU Emissions by Source and Year

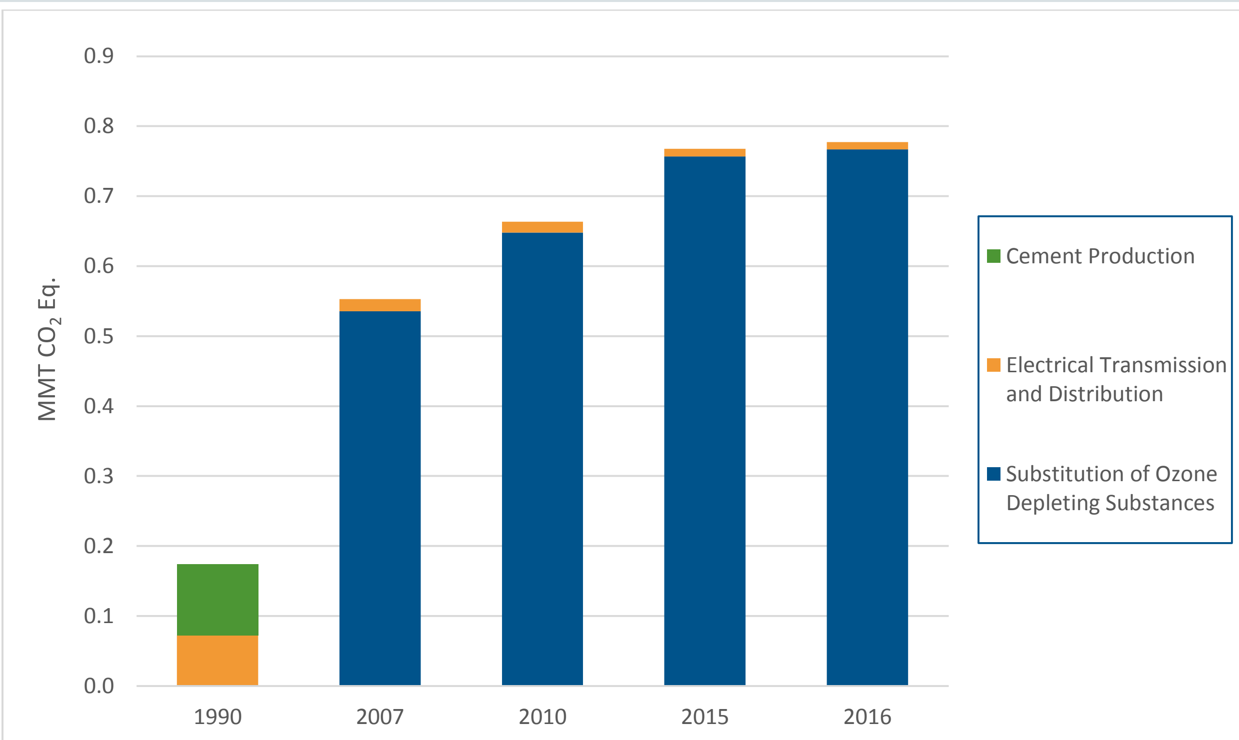


Table 4-1: GHG Emissions from the IPPU Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016
Cement Production	0.10	NO	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01	0.01
Substitution of Ozone Depleting Substances	+	0.54	0.65	0.76	0.77
Total	**0.17**	**0.55**	**0.66**	**0.77**	**0.78**

+ 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 G and Appendix H, respectively. A consolidated list of areas for improvement, ranked by priority, is provide in Appendix I.

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 2016, emissions from cement production in Hawaii were zero. Table 4-2 summarizes emissions from cement production in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
CO_2	0.10	NO	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:

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

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

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from cement production since the 2015 inventory report.

Uncertainties

The uncertainties around emissions from cement production were not quantitatively assessed because there is currently no cement production in the state.

Areas for Improvement

No 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 2016, 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 2016 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 2018a). Table 4-3 summarizes emissions from electrical transmission and distribution systems in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
SF_6	0.07	0.02	0.02	0.01	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 2018a). National electricity sales data come from the U.S. Department of Energy, Energy Information Administration (EIA 2018c). Hawaii electricity sales data come from the State of Hawaii Data Book (DBEDT 2018c).

Changes in Estimates since the Previous Inventory Report

Electricity sales data for both Hawaii and the United States were updated based on the most recent available data, as published by EIA (2018c) and DBEDT (2018c). U.S. emissions data was also updated based on updated values published by EPA (2018a). The resulting changes in historical emissions estimates are presented in Table 4-4.

Table 4-4: Change in Emissions from Electrical Transmission and Distribution Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01
This Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01
Percent Change	+	-0.4%	0.3%	3.6%

+ Does not exceed 0.05%

Uncertainties

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). These model uncertainties were not assessed as part of the quantitative uncertainty analysis.

To estimate uncertainty associated with emissions from electrical transmission and distribution, uncertainties associated with three quantities were assessed: (1) Hawaii electricity sales, (2) U.S. electricity sales, and (3) U.S. SF_6 electricity transmission and distribution emissions. Uncertainty was estimated quantitatively around each input variable based on expert judgment. Each input variable contributed relatively evenly to the overall uncertainty of the emissions estimate.

The results of the quantitative uncertainty analysis are summarized in Table 4-5. GHG emissions from electrical transmission and distribution systems were estimated to be between 0.008 MMT CO_2 Eq. and 0.014 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 23 percent below and 28 percent above the emission estimate of 0.011 MMT CO_2 Eq.

Table 4-5: Quantitative Uncertainty Estimates for Emissions from Electrical Transmission and Distribution

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.011	0.008	0.014	-23%	+28%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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 2016, emissions from ODS substitutes in Hawaii were 0.77 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 (EPA 2018a). Table 4-6 summarizes emissions from HFCs and PFCs that are used as substitutes of ODS in Hawaii for 1990, 2007, 2010, 2015, and 2016. While not included in the inventory totals, estimated emissions from ODS in Hawaii are presented in Appendix J.[45]

Table 4-6: Emissions from Substitutes of ODS by Gas (MMT CO_2 Eq.)

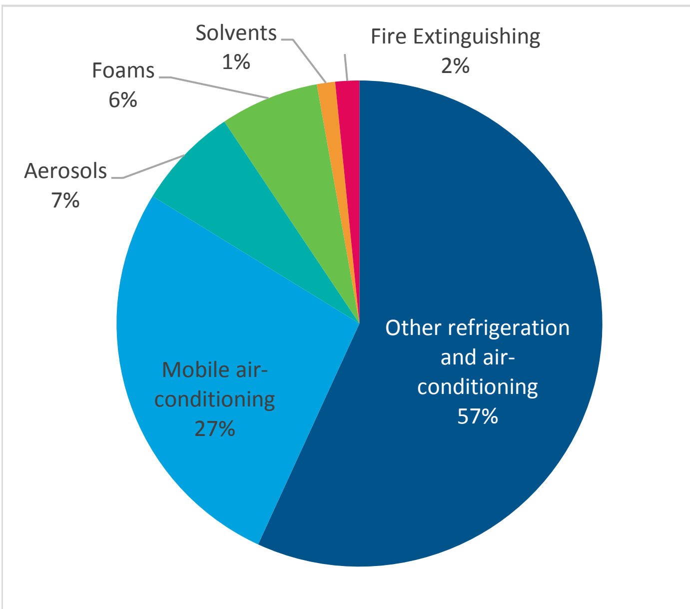
Gas	1990	2007	2010	2015	2016
HFC/PFC	+	0.54	0.65	0.76	0.77

+ 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: 2016 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

45 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 J.

different end-use categories, and applies HFC and PFC leak rates to estimate annual emissions. In the U.S. Inventory (EPA 2018a), 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 2018a) to Hawaii based on the ratio of Hawaii vehicle registrations from the State of Hawaii Data Book (DBEDT 2018d) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2017). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2018a) were apportioned to Hawaii based on the ratio of Hawaii population from DBEDT (2018c) to U.S. population from the U.S. Census Bureau (2018).

Changes in Estimates since the Previous Inventory Report

Population data for the United States was updated based on the most recent available data, as published by the U.S. Census Bureau (2018). U.S. emissions data were also updated based on updated values published by EPA (2018a). Specifically, U.S. emissions estimates were updated based on a peer review of the Vintaging Model that is used to calculate emissions from substitutes of ODS. These updates included revisions to various assumptions and the addition of new end-uses representing refrigerated food processing and dispensing equipment and heavy-duty vehicle air conditioners. The industrial process refrigeration end-use was updated to adjust for HCFC-123 phase-out requirements under the Montreal Protocol and based on direction seen in the industry (EPA 2018a). The resulting changes in historical emissions estimates are presented in Table 4-7.

Table 4-7: Change in Emissions from Substitutes of ODS Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	+	0.53	0.66	0.82
This Inventory Report (MMT CO_2 Eq.)	+	0.54	0.65	0.76
Percent Change	4.8%	1.7%	-1.2%	-7.9%

+ Does not exceed 0.005 MMT CO_2 Eq.

Uncertainties

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 2018d). 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. These model uncertainties were not assessed as part of the quantitative uncertainty analysis.

To estimate uncertainty associated with emissions from substitutes of ODS, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) U.S. emissions from substitutes of ODS from refrigeration and air conditioning, (2) U.S. emissions from substitutes of ODS from aerosols, and (3) U.S. emissions from substitutes of ODS from foams.

The results of the quantitative uncertainty analysis are summarized in Table 4-8. GHG emissions from substitutes of ODS were estimated to be between 0.75 and 0.82 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 2 percent below and 7 percent above the emission estimate of 0.77 MMT CO_2 Eq.

Table 4-8: Quantitative Uncertainty Estimates for Emissions from Substitutes of ODS

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.77	0.75	0.82	-2%	+7%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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.

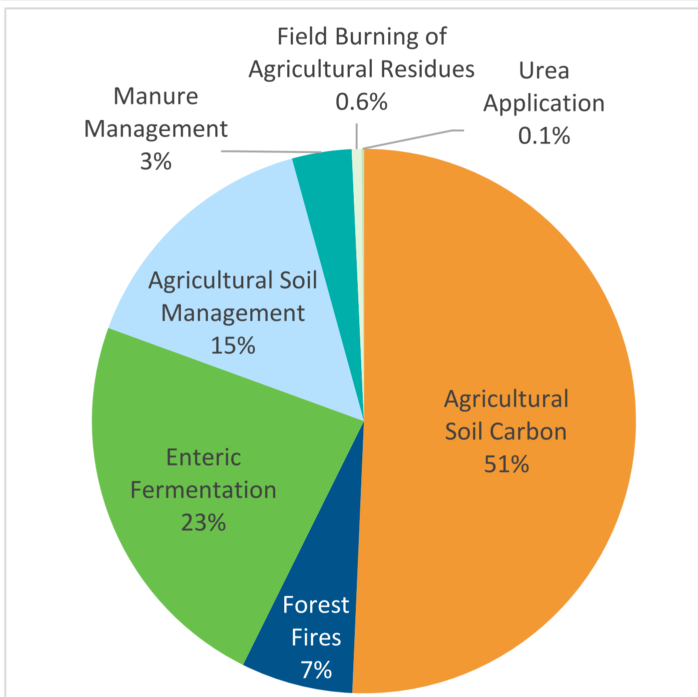
5. Agriculture, Forestry and Other Land Uses (AFOLU)

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:[46] 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.

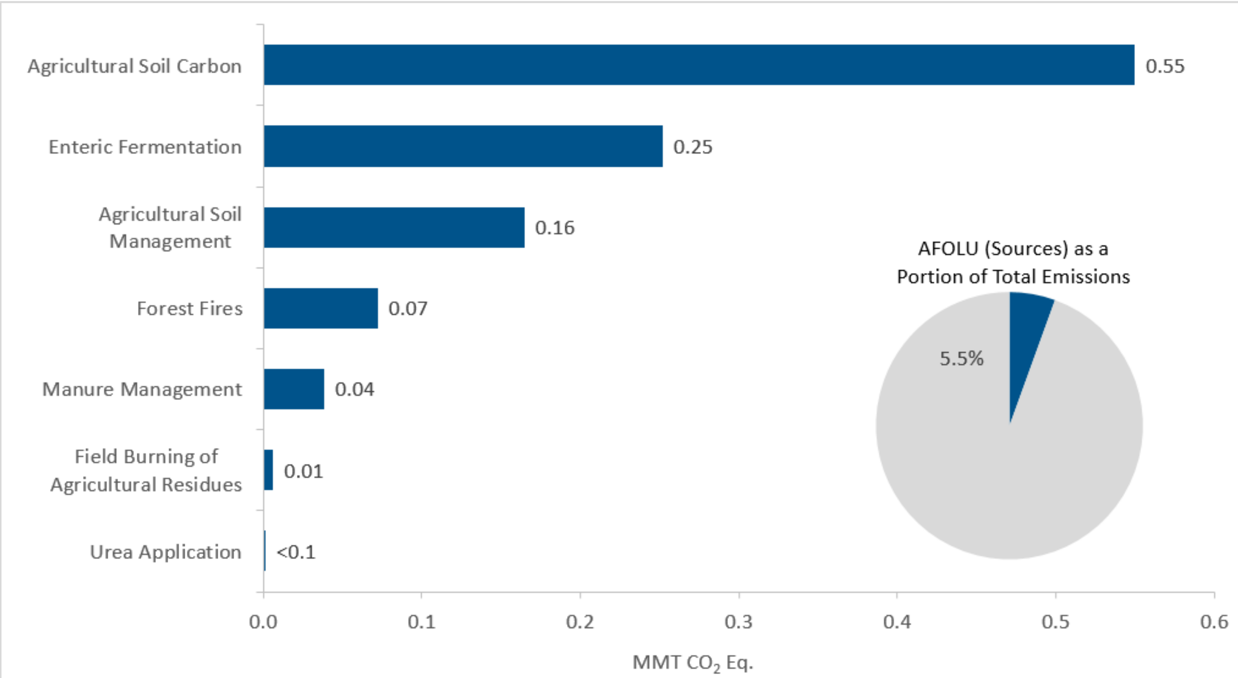
In 2016, total emissions (excluding sinks) from the AFOLU sector were 1.08 MMT CO_2 Eq., accounting for 6 percent of total Hawaii emissions. Agricultural soil carbon accounted for the largest share of AFOLU emissions, followed by enteric fermentation, agricultural soil management, forest fires, manure 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 2016.

Figure 5-1: 2016 AFOLU Emissions by Source



[46] 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: 2016 AFOLU Emissions by Source (MMT CO_2 Eq.)



Carbon sinks were 6.51 MMT CO_2 Eq. in 2016. Therefore, the AFOLU sector resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 5.43 MMT CO_2 Eq. in 2016. 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 2016.

Relative to 1990, emissions from AFOLU sources in 2016 were lower by roughly 17 percent. Carbon removals from AFOLU sinks in 2016 were lower by roughly 3 percent relative to 1990 sinks. As a result, net removals from AFOLU increased by 1 percent in 2016 compared to 1990 (i.e., this sector "removes" 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: 2016 AFOLU Removals by Carbon Sink

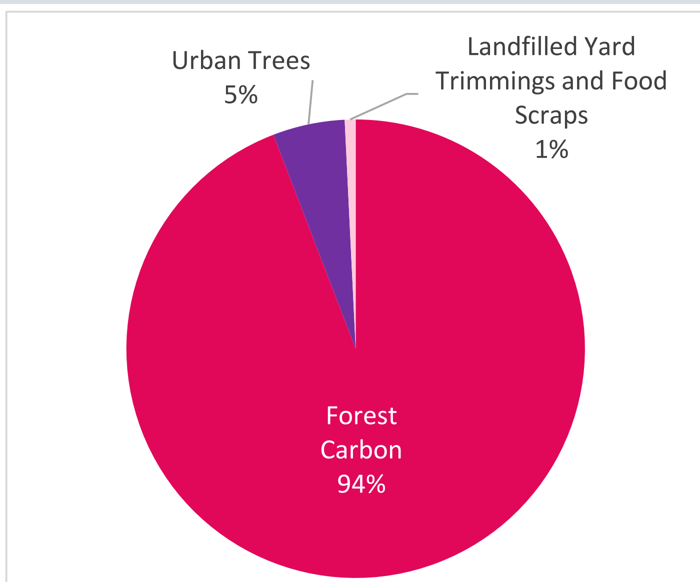


Figure 5-4: AFOLU Emissions and Removals by Source and Sink Category and Year

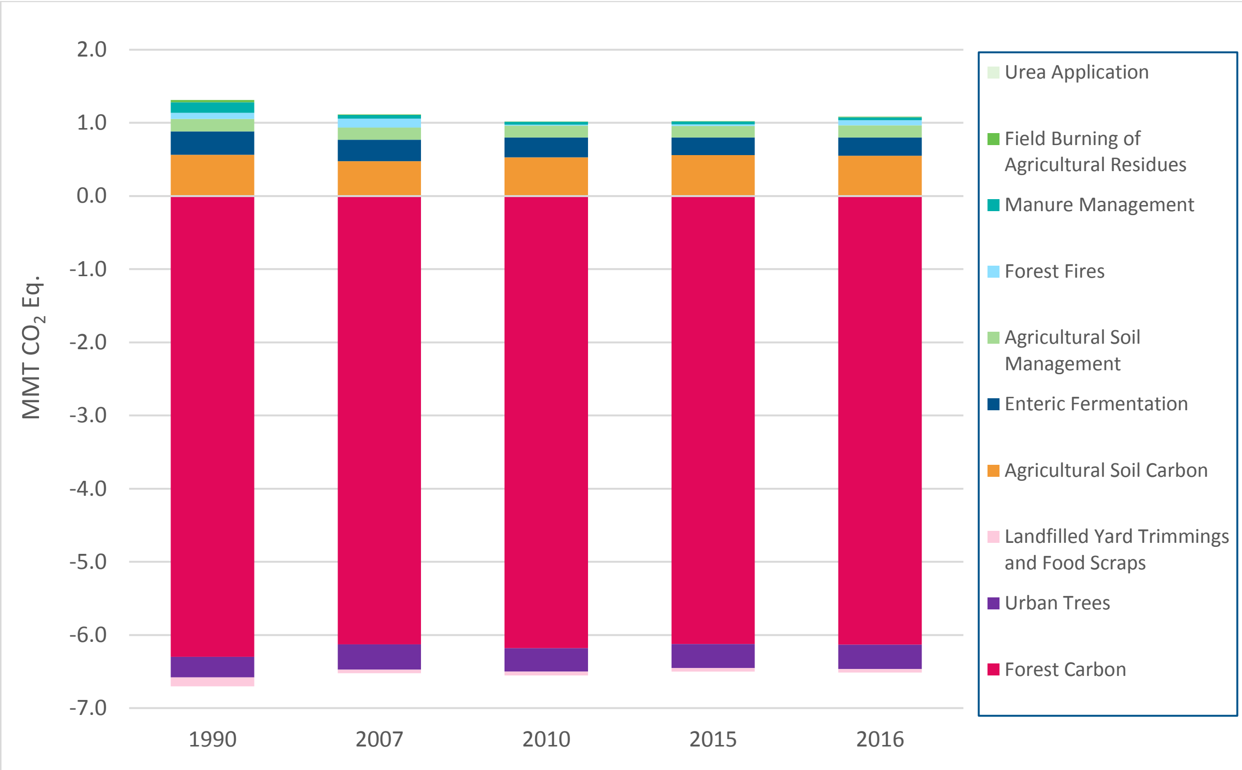


Table 5-1: GHG Emissions from the AFOLU Sector by Category (MMT CO_2 Eq.)

Category	1990	2007	2010	2015	2016
Agriculture	**0.67**	**0.52**	**0.48**	**0.44**	**0.46**
Enteric Fermentation	0.32	0.29	0.27	0.24	0.25
Manure Management	0.15	0.05	0.04	0.04	0.04
Agricultural Soil Management	0.17	0.16	0.16	0.16	0.16
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01	0.01
Urea Application	+	+	+	+	+
Land Use, Land-Use Change, and Forestry	**(6.05)**	**(5.92)**	**(6.01)**	**(5.92)**	**(5.89)**
Agricultural Soil Carbon	0.57	0.48	0.53	0.56	0.55
Forest Fires	0.08	0.12	0.01	0.02	0.07
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)
Urban Trees	(0.28)	(0.35)	(0.32)	(0.33)	(0.33)
Forest Carbon	(6.30)	(6.13)	(6.18)	(6.12)	(6.13)
Total (Sources)	**1.31**	**1.12**	**1.02**	**1.03**	**1.08**
Total (Sinks)	**(6.70)**	**(6.52)**	**(6.55)**	**(6.50)**	**(6.51)**
Total Net Emissions	**(5.39)**	**(5.40)**	**(5.53)**	**(5.48)**	**(5.43)**

+ 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 G and Appendix H, respectively. A consolidated list of areas for improvement, ranked by priority, is provide in Appendix I.

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 2018a). This source includes CH_4 emissions from dairy and beef cattle, sheep, goats, swine, and horses. In 2016, CH_4 emissions from enteric fermentation were 0.25 MMT CO_2 Eq., accounting for 18 percent of AFOLU sector emissions. Table 5-2 summarizes emissions from enteric fermentation in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
CH_4	0.32	0.29	0.27	0.24	0.25

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 2018a and 2018b). 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, 2015, and 2016 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 2018a).[47] Constant emission factors for sheep, goats, horses, and swine were also obtained from the U.S. Inventory (EPA 2018a).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from enteric fermentation since the 2015 inventory report.

Uncertainties

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, 2015, and 2016.
- 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 2018a). 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 averaged using emission factors of multiple animal types.
- 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, due to the difficulty in estimating the diet characteristics for grazing members of this animal group (EPA 2018a). In addition, the emission factors for non-cattle animal types, also obtained from the U.S. Inventory, are not specific to Hawaii.

To estimate uncertainty associated with emissions from enteric fermentation, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment and IPCC (2006). The following parameters contributed the most to the quantified uncertainty estimates: (1) enteric emission factor for beef cows (2) beef cow population data, and (3) enteric emission factor for beef replacement heifers. The quantified uncertainty estimated for the enteric emission factor for beef cows contributed the vast majority to the quantified uncertainty estimates, while the remaining input variables contributed relatively evenly to the overall uncertainty of the emissions estimate.

The results of the quantitative uncertainty analysis are summarized in Table 5-3. GHG emissions from enteric fermentation were estimated to be between 0.21 and 0.29 MMT CO_2 Eq. at the 95 percent

[47] 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.

confidence level. This confidence level indicates a range of approximately 15 percent below and 15 percent above the emission estimate of 0.25 MMT CO_2 Eq.

Table 5-3: Quantitative Uncertainty Estimates for Emissions from Enteric Fermentation

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.25	0.21	0.29	-15%	+15%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Further research into the accuracy of interpolated and extrapolated animal population data as well as aligning animal groupings with those used in the U.S. Inventory may be considered in future analyses. In addition, updated and/or Hawaii-specific enteric emission factors should be incorporated into future analyses if data becomes available.

5.2. Manure Management (IPCC Source Category 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 2018a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. In 2016, emissions from manure management were 0.04 MMT CO_2 Eq., accounting for 3 percent of AFOLU sector emissions. Table 5-4 summarizes emissions from manure management in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
CH_4	0.11	0.04	0.03	0.03	0.03
N_2O	0.03	0.01	0.01	0.01	0.01
Total	**0.15**	**0.05**	**0.04**	**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_0	= 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 2018a, 2018b, 2018c), with the exception of chicken population data for 2015 and 2016, 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, 2015, and 2016 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 2018a). Weighted methane conversion factors (MCFs) for all cattle types, sheep, goats and horses were obtained from the U.S. Inventory (EPA 2018a), while swine and chicken MCFs were taken from the EPA's State Inventory Tool (EPA 2018e). Volatile solids (VS) excretion rates were obtained from the U.S. Inventory (EPA 2018a), with the exception of VS rates for horses, which were taken from EPA's State Inventory Tool (EPA 2018e).

To develop N_2O emissions from manure management, nitrogen excretion (Nex) rates for all cattle types were obtained from the U.S. Inventory (EPA 2018a), while non-cattle Nex rates were obtained from

EPA's State Inventory Tool (EPA 2018e). The distributions of waste by animal in different waste management systems (WMS) were obtained from the U.S. Inventory (EPA 2018a). 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).

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, weighted MCFs for cattle were updated for the full time series based on EPA (2018a). The resulting changes in historical emissions estimates, which are not visibly significant, are presented in Table 5-5.

Table 5-5: Change in Emissions from Manure Management Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.15	0.05	0.04	0.04
This Inventory Report (MMT CO_2 Eq.)	0.15	0.05	0.04	0.04
Percent Change	-0.5%	-3.9%	-6.4%	-6.0%

Uncertainties

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, 2015, and 2016. Similarly, chicken population data, which are only available through 2010, were extrapolated to obtain estimates for 2015 and 2016.
- 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 2018a). 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 averaged using emission factors of multiple animal types.
- 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_0 data used to estimate emissions from manure management are dated (EPA 2018a).

To estimate uncertainty associated with emissions from manure management, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment and IPCC (2006). The following parameters contributed the most to the quantified uncertainty estimates: (1) the emission factor for dry lot manure management system (2) the methane conversion factor for dairy cows, and (3) the maximum methane producing capacity for animal waste (B_0) for dairy cows.

The results of the quantitative uncertainty analysis are summarized in Table 5-6. GHG emissions from manure management were estimated to be between 0.03 and 0.05 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 26 percent below and 31 percent above the emission estimate of 0.04 MMT CO_2 Eq.

Table 5-6: Quantitative Uncertainty Estimates for Emissions from Manure Management

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.04	0.03	0.05	-26%	+31%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Further research into the accuracy of interpolated and extrapolated animal population data, the availability of animal population data that are disaggregated by weight, and aligning animal groupings with the U.S. Inventory may be considered in future analyses. Additionally, 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 2018a). 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 2016, emissions from agricultural soil management were 0.16 MMT CO_2 Eq., accounting for 12 percent of AFOLU sector emissions. Table 5-7 summarizes emissions from agricultural soil management in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
N_2O	0.17	0.16	0.16	0.16	0.16

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}	= aboveground residue dry matter (Mg/hectares)
A	= crop area (hectares)
N_{AG}	= N content of aboveground residue (kg N/dry matter)
N_{BG}	= N content of belowground residues (kg N/dry matter)
R_{BG-BIO}	= Ratio of belowground 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 2018d). 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, 2015, and 2016 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012 data. Pineapple crop production and crop acreage were not available for 2007 or 2012, so pineapple data for 2010, 2015, and 2016 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, 2015, and 2016 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 2018a).

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 and 2016 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 2018a, 2018b, 2018c), with the exception of chicken population data for 2015 and 2016, 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, 2015, and 2016 were interpolated and extrapolated based on 1987, 1992, 2007 and 2012 data.

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, total synthetic fertilizer consumption estimates in 2013 and 2014 were updated based on the most recent version of the *Commercial Fertilizers* report. This revision slightly increased 2015 emissions, which are based on the last five years of data. In addition, the methodology used to apportion 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) was corrected to consistently apply a calendar year consumption ratio (based on historical fertilizer consumption patterns) to the 2008 through 2016 fertilizer sales.[48] Previously, the ratio was only applied to 1990 through 2007 fertilizer sales while calendar year fertilizer consumption for later years were extrapolated based on historical estimates. The resulting changes in historical emissions estimates are presented in Table 5-8.

Table 5-8: Change in Emissions from Agricultural Soil Management Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.17	0.16	0.15	0.14
This Inventory Report (MMT CO_2 Eq.)	0.17	0.16	0.16	0.16
Percent Change	4.6%	3.7%	6.6%	12.8%

[48] Based on historical fertilizer consumption patterns, 65 percent of consumption in a fertilizer year is assumed to occur during January through June of the current calendar year. The remaining 35 percent of consumption in a fertilizer year is assumed to occur during July through December of the previous calendar year (EPA 2018a).

Uncertainties

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 2018a). 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 2016. Similarly, chicken population data, which are only available through 2010, were extrapolated to obtain estimates for 2015 and 2016.
- 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 2016 were extrapolated using 1997 and 2002 data.
- There is uncertainty associated with the extrapolation of synthetic fertilizer N application data to 2016 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).
- Crop residue factors were obtained from sources published over 10 years ago and may not accurately reflect current practices.
- 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.

To estimate uncertainty associated with emissions from agricultural soil management, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on the U.S. Inventory (EPA 2017), IPCC (2006), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) the emission factor for nitrogen additions from synthetic nitrogen applied, organic fertilizer applied, and crop residues; (2) the emission factor for nitrogen inputs from manure from cattle, poultry and pigs; and (3) volatile solids rate of beef cows on pasture.

The results of the quantitative uncertainty analysis are summarized in Table 5-9. GHG emissions from agricultural soil management were estimated to be between 0.12 and 0.32 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 28 percent below and 93 percent above the emission estimate of 0.16 MMT CO_2 Eq.

Table 5-9: Quantitative Uncertainty Estimates for Emissions from Agricultural Soil Management

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a] (MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.16	0.12	0.32	-28%	+93%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Further research into the accuracy of interpolated and extrapolated animal population, crop production, and synthetic fertilizer application data may be considered in future analyses. In addition, further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses. As crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly. Finally, 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 2018a).[49] This source includes CH_4 and N_2O emissions from sugarcane burning, which is the only major crop in Hawaii whose residues are regularly burned (Hudson 2008). In 2016, 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 5-10 summarizes emissions from field burning of agricultural residues in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-10: Emissions from Field Burning of Agricultural Residues Emissions by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CH_4	0.03	0.01	+	+	0.01
N_2O	+	+	+	+	+
Total	**0.03**	**0.01**	**0.01**	**0.01**	**0.01**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

[49] 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).

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 2018a). 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_{5}-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 2018d). 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).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from field burning of agricultural residues since the 2015 inventory report.

Uncertainties

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 are assumed to be zero. In addition, crop residue factors were obtained from sources published over 10 years ago and may not accurately reflect current practices.

To estimate uncertainty associated with emissions from field burning of agricultural residues, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) the methane emissions ratio of field burning of agricultural residues, (2) the residue to crop ratio of sugarcane, and (3) fraction of residue burned for sugarcane. The quantified uncertainty estimated for the methane emissions ratio of sugarcane contributed the vast majority to the quantified uncertainty estimates.

The results of the quantitative uncertainty analysis are summarized in Table 5-11. GHG emissions from field burning of agricultural residues were estimated to be between 0.004 and 0.009 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 37 percent below and 40 percent above the emission estimate of 0.006 MMT CO_2 Eq.

Table 5-11: Quantitative Uncertainty Estimates for Emissions from Field Burning of Agricultural Residues

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.006	0.004	0.009	-37%	+40%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

If information on the field burning of crop residues from other crops, besides sugarcane, becomes available, this information should be incorporated into future inventory analyses. In addition, as crop residue 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 2016, emissions from urea application were 0.002 MMT CO_2 Eq., accounting for less than 1 percent of AFOLU sector emissions. Table 5-12 summarizes emissions from urea application in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-12: Emissions from Urea Application by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
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).[50] 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 and 2016 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.

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, total urea fertilizer consumption in 2013 and 2014 was updated based on the most recent version of the *Commercial Fertilizers* report (AAPFCO 2017). This revision slightly decreased 2015 emissions, which are based on the last five years of data. The resulting changes in historical emissions estimates, which are not visibly significant, are presented in Table 5-13.

Table 5-13: Change in Emissions from Urea Application Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	+	+	+	+
This Inventory Report (MMT CO_2 Eq.)	+	+	+	+
Percent Change	0%	0%	0%	-6.3%

+ Does not exceed 0.005 MMT CO_2 Eq.

[50] 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.

Uncertainties

There is uncertainty associated with the extrapolation of urea fertilizer application data to 2016 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).

To estimate uncertainty associated with emissions from urea application, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) emission factor for urea, (2) the share of annual fertilizer application between January and June, and (3) the share of annual fertilizer application between July and December. The quantified uncertainty estimated for the emission factor for urea contributed the vast majority to the quantified uncertainty estimates.

The results of the quantitative uncertainty analysis are summarized in Table 5-14. GHG emissions from urea application were estimated to be between 0.001 and 0.002 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 44 percent below and 4 percent above the emission estimate of 0.002 MMT CO_2 Eq.

Table 5-14: Quantitative Uncertainty Estimates for Emissions from Urea Application

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
+	+	+	-44%	+4%

+ Does not exceed 0.005 MMT CO_2 Eq.

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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 2018a). 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 2016, emissions from agricultural soils were 0.55 MMT CO_2 Eq., accounting for 39 percent of AFOLU sector emissions. Table 5-15 summarizes emissions from agricultural soils in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-15: Emissions from Agricultural Soil Carbon by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	0.57	0.48	0.53	0.56	0.55

Methodology

Emission estimates from Hawaii's agricultural soils for 1990 through 2015 were taken directly from the U.S. Inventory (EPA 2017).[51] 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 2017).

State-level emission estimates from agricultural soils were not available in the 1990-2016 U.S. Inventory (EPA 2018a). Therefore, emissions from Hawaii's agricultural soils in 2016 were projected from 2015 data 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 2016 estimates.

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from agricultural soil carbon since the 2015 inventory report.

Uncertainties

According to the U.S. Inventory, areas of uncertainty include changes in certain carbon pools (biomass, dead wood, and litter), which are only estimated for forest land converted to cropland or grassland and not estimated for other land types converted to cropland or grassland (EPA 2017). In addition, state-level emission estimates from agricultural soils were not available for 2016. The methodology used to project 2015 emissions from agricultural soil carbon to 2016 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).

To estimate uncertainty associated with emissions from agricultural soil carbon, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on EPA (2017) and Selmants et al. (2017). The following parameters contributed the most

[51] 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 2018a).

to the quantified uncertainty estimates: (1) carbon stock changes in organic soils in grassland, (2) carbon stock changes in mineral soils in grassland, and (3) carbon stock changes in organic soils in cropland.

The results of the quantitative uncertainty analysis are summarized in Table 5-16. GHG emissions from agricultural soil carbon were estimated to be between -1.25 and 2.10 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 327 percent below and 281 percent above the emission estimate of 0.55 MMT CO_2 Eq.

Table 5-16: Quantitative Uncertainty Estimates for Emissions from Agricultural Soil Carbon

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.55	(1.25)	2.10	-327%	+281%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

EPA continues to investigate improvements in estimating changes in additional carbon pools for other land types converted to cropland or grassland. These improvements, once implemented, should be reflected in future analyses. Additionally, 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). Other examples of initiatives include a 35 percent tree canopy goal by 2035, which was championed by Trees for Honolulu's Future (TFHF) and adopted by the City and County of Honolulu (City & County of Honolulu 2019). The tree canopy goal also has sub-goals of planting 100,000 new trees by 2025 in Oahu (TFHF 2018). Further research into emissions reductions from improved agricultural soil management practices may be considered in future analyses.

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).[52] In 2016, emission from forest fires were 0.07 MMT CO_2 Eq., accounting for 7 percent of AFOLU sector emissions. Table 5-17 summarizes emissions from forest fires in Hawaii from 1990, 2007, 2010, 2015, and 2016.

[52] 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 and because prescribed burning is not a common practice in Hawaii. Emissions from this activity are expected to be marginal.

Table 5-17: Emissions from Forest Fires by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	0.07	0.11	0.01	0.02	0.06
CH_4	0.01	0.01	+	+	+
N_2O	+	0.01	+	+	+
Total	**0.08**	**0.12**	**0.01**	**0.02**	**0.07**

Note: Totals may not sum due to independent rounding.

Methodology

The IPCC (2006) Tier 2 methodology was used to calculate GHG emissions from forest fires according to the following equation:

$$Emissions = \sum_i A_i \times G_{ef,i}$$

where,

A_i = area burned by forest type i, hectares (ha)
$G_{ef,i}$ = emission factor by forest type i, tonnes C/ha
i = forest type (forest or shrubland in Hawaii)

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, 2015, and 2016 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, 2017). 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 2018d). The estimate of wildland area was obtained, in million acres, for years 1998 and 2002 from the National Association of State Foresters (NASF 1998 and 2002) and 2010, 2015, and 2016 from the DLNR (2011, 2016, 2017). 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 2018d). 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, 2015, and 2016. Unmanaged forests are not included in this analysis per IPCC guidelines because the majority of anthropogenic GHG emissions occur on managed land (IPCC 2006).

Since Hawaii's forest is comprised of both forest and shrubland, total area burned was separated into area of forest burned and area of shrubland burned. The annual percent of area burned that is forest or shrubland was obtained from USGS (Selmants et al. 2017), and then was applied to the total forest/shrubland area burned to obtain the area burned by forest type. The annual percent of area burned that is forest or shrubland for 2002 through 2011 is taken directly from USGS (Selmants et al. 2017), while 1990 through 2001 and 2012 through 2016 are estimated based on the mean of the annual percent of area burned by forest type between 2002 and 2011.

Hawaii-specific CO_2 emission factors by forest type were then applied to area burned by forest type to estimate CO_2 emissions. CO_2 emission factors by forest type were based on an average of C emissions by forest type and moisture scenario from USGS (Selmants et al. 2017). Emission factors for CH_4 and N_2O emissions were obtained from IPCC (2006).

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, the methodology for the entire time series was updated to multiply area burned by Hawaii-specific CO_2 emission factors obtained from USGS (Selmants et al. 2017). In addition, the ratio of forest to shrubland area was updated for the entire time series based on annual percent of area burned by vegetation class (forest/shrubland) obtained from USGS (Selmants et al. 2017). Previously, IPCC (2006) default combustion factors for tropical forest and shrubland were weighted using a ratio of Hawaii forest to shrubland area, which 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 USGS (Selmants et al. 2017). In addition, previously, emissions were based on the mass of fuel available for combustion (i.e., carbon density) and a default CO_2 emission factor from IPCC (2006).

The resulting changes in historical emissions estimates are presented in Table 5-18. These lower emission estimates are more in line with the fact that the majority of wildfires in Hawaii occur in grasslands and shrublands, not forested areas. The current emission estimates are also more in line with the forest/shrubland fire emission estimates in Chapter 5 of Selmants et al. (2017), which employs Hawaii-specific emission factors.

Table 5-18: Change in Emissions from Forest Fires Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.38	0.57	0.19	0.11
This Inventory Report (MMT CO_2 Eq.)	0.08	0.12	0.01	0.02
Percent Change	-79.0%	-78.4%	-92.8%	-79.6%

Uncertainties

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 estimated 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.

- The percent of area burned that is forest or shrubland is also a source of uncertainty for 1990, 2015, and 2016, because the percentages used for these years are based on the average percent of area burned by forest type for 2002 through 2011 (Selmants et al. 2017).
- According to USFS (2019b), emissions from prescribed fires are expected to be marginal, because prescribed burning is not common in Hawaii. However, emission estimates from prescribed fires in Hawaii that are published by EPA's National Emission Inventory (NEI) program indicate that emissions from prescribed fires in Hawaii were 0.12 MMT CO_2 Eq. in 2011 and 1.92 MMT CO_2 Eq. in 2014.[53] The NEI additionally does not report any emissions from wildfires in Hawaii during these years. Given that prescribed fires are not common in Hawaii and that the NEI data for prescribed fires are inconsistent with the wildfire data obtained from DLNR, NEI data were not used to estimate emissions from forest fires in this report.

To estimate uncertainty associated with emissions from forest fires, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on USFS (2019a), IPCC (2006), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) combustion efficiency of forest, (2) combustion efficiency of shrubland, and (3) annual forest area burned.

The results of the quantitative uncertainty analysis are summarized in Table 5-19. GHG emissions from forest fires were estimated to be between 0.05 and 0.09 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 27 percent below and 31 percent above the emission estimate of 0.07 MMT CO_2 Eq.

Table 5-19: Quantitative Uncertainty Estimates for Emissions from Forest Fires

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.07	0.05	0.09	-27%	+31%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Areas for improvement associated with forest fires estimates include the following:

- Further investigation into alternative sources for historical wildfire acres burned and prescribed fire acres burned may be considered in future analyses.
- Coordination with EPA to understand the cause for the discrepancy between emission estimates presented in this report and NEI prescribed fire emissions may be considered.

[53] Available online at: https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data.

- Additional data for percent of area burned by forest type for each year in the time series should also be incorporated into future analyses if they become available.

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 2016, landfilled yard trimmings sequestered 0.05 MMT CO_2 Eq., accounting for 1 percent of carbon sinks. Table 5-20 summarizes changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-20: CO_2 Flux from Landfilled Yard Trimmings (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	(0.12)	(0.05)	(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 using a methodology consistent with the EPA's State Inventory Tool (EPA 2018f). 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 are 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 2018f) 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 2018f), were used to calculate the national-level estimates. Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2018d).

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, waste generation and incineration data were updated based on the most recent version of EPA's *Advancing Sustainable Materials Management* Fact Sheet, as referenced in EPA's State Inventory Tool (EPA 2018f). The resulting changes in historical sink estimates, which are not visibly significant, are presented in Table 5-21.

Table 5-21: Change in Sinks from Landfilled Yard Trimmings and Food Scraps Relative to the 2015 Inventory Report

Sink Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)
This Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)
Percent Change	0%	+	0.6%	2.1%

+ Does not exceed 0.05%

Uncertainties

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.

To estimate uncertainty associated with carbon sequestration in landfilled yard trimmings and food scraps, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) yard trimming generation in 2015, (2) the proportion of carbon stored permanently in food scraps, and (3) yard trimming generation in 2014. The quantified uncertainty estimated for yard trimming generation in 2015 and the proportion of carbon stored permanently in food scraps contributed the vast majority to the quantified uncertainty estimates, while the remaining input variables contributed relatively evenly to the overall uncertainty of the sink estimate.

The results of the quantitative uncertainty analysis are summarized in Table 5-22. Sinks from landfilled yard trimmings and food scraps were estimated to be between -0.09 and -0.02 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 72 percent below and 51 percent above the sink estimate of -0.05 MMT CO_2 Eq.

Table 5-22: Quantitative Uncertainty Estimates for Sinks from Landfilled Yard Trimmings and Food Scraps

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(0.05)	(0.09)	(0.02)	+72%	-51%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Further research into Hawaii trends in diverting yard trimmings and food scraps from landfills, as well as yard trimmings and food scraps sequestration rates that incorporate Hawaii's climate 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 2018d). In 2016, urban trees sequestered 0.41 MMT CO_2 Eq., accounting for 6 percent of carbon sinks. Table 5-23 summarizes carbon flux from urban trees in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-23: CO_2 Flux from Urban Trees (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	(0.28)	(0.35)	(0.32)	(0.33)	(0.33)

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 2018a) 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.[54] State-level urban area estimates were adapted from the U.S. Census (1990a) 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 2011. After 2011, 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 2011 estimate of urban area to estimate urban area in 2015 and 2016. Nowak and Greenfield (2012) developed a study to determine percent tree cover by state. According to Nowak et al. (2012), 39.9 percent of urban areas in Hawaii were covered by trees circa 2005. The percent tree cover of 39.9 percent was applied to Hawaii for years 1990 through 2005.

After 2005, a time series for percent tree cover of Honolulu was established based on available statistics. According to the Tree Canopy Report for Honolulu (MacFaden et al. 2016), based on high-resolution aerial imagery and LiDAR, 23 percent of Honolulu was covered by tree canopy in 2013 and Honolulu experienced a net loss of tree canopy of 4.8 percent between 2010 and 2013. The 2005 estimate from Nowak et al. (2012) and the 2010 through 2013 Honolulu-specific estimates from MacFaden et al. (2016)

[54] 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 2018a).

were used to linearly interpolate percent tree cover of Honolulu for years 2006 through 2009. Percent tree cover of Honolulu in years 2014 through 2016 were proxied to 2013 at 23 percent.

A time series for percent tree cover after 2005 was also established for the rest of the urban areas in Hawaii based on available statistics. In 2018, Nowak and Greenfield published two studies with updated percent tree cover statistics by state. According to these studies, 41.7 percent of urban areas in Hawaii were covered by trees circa 2015 (Nowak et al. 2018a), and Hawaii's urban tree cover increased by an average of 0.1 percent each year between 2009 and 2015 (Nowak et al. 2018b). The 2005 estimate from Nowak et al. (2012) and the 2009 through 2015 estimates from Nowak et al. (2018a and 2018b) were used to linearly interpolate percent tree cover for urban areas, except Honolulu, for years 2006 through 2008. Percent tree cover for urban areas, except Honolulu, in year 2016 was proxied to 2015 at 41.7 percent.

With a time series of total urban tree cover for Hawaii, the Hawaii-specific sequestration factor (MT C/km^2 tree cover) was applied to the area in each year to calculate total C sequestration by urban trees (MT C/year).

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, percent tree cover was updated based on more recent data from the MacFaden et al. (2016) and Nowak et al. (2018a and 2018b). Previously, percent tree cover was a static estimate based on 2005 data that did not consider changes in the percent tree cover over time. A time series for percent tree cover was established, specific to Honolulu and to urban areas except for Honolulu, based on 2005 data as well as more recent data. The resulting changes in historical sink estimates are presented in Table 5-24.

Table 5-24: Change in Sinks from Urban Trees Relative to the 2015 Inventory Report

Sink Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	(0.28)	(0.37)	(0.38)	(0.40)
This Inventory Report (MMT CO_2 Eq.)	(0.28)	(0.35)	(0.32)	(0.33)
Percent Change	+	-5.3%	-15.4%	-19.4%

+ Does not exceed 0.05%

Uncertainties

Uncertainties associated with urban tree CO_2 flux estimates include the following:

- 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.
- The methodology used to estimate urban area in 2015 and 2016 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). This methodology does not consider potential changes in the rate of urbanization over time.

- Although percent tree cover has been updated to show variations over time, some uncertainty is still associated with tree cover in 1990, 2007, and 2016. Percent tree cover for these years was either proxied or interpolated based on data for surrounding years.

To estimate uncertainty associated with sinks from urban trees, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on Nowak et al. (2005, 2012, 2018a, and 2018b), Selmants et al. (2017), U.S. Census (2012), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) annual carbon sequestration in Honolulu urban trees, (2) total canopy cover in Honolulu, and (3) the percent of urban area in Hawaii covered by trees. The quantified uncertainty estimated for annual carbon sequestration and canopy cover in Honolulu, which are used to estimate the annual net sequestration rates in urban trees in Hawaii, contributed the vast majority to the quantified uncertainty estimates. The remaining input variables contributed relatively evenly to the overall uncertainty of the sink estimate.

The results of the quantitative uncertainty analysis are summarized in Table 5-25. Sinks from urban trees were estimated to be between -0.42 and -0.26 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 26 percent below and 21 percent above the sink estimate of -0.33 MMT CO_2 Eq.

Table 5-25: Quantitative Uncertainty Estimates for Sinks from Urban Trees

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(0.33)	(0.42)	(0.26)	+26%	-21%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Further research into urban tree sequestration rates by county or island may be considered in future analyses. 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). Other examples of initiatives include a 35 percent tree canopy goal by 2035, which was championed by TFHF and adopted by the City and County of Honolulu (City & County of Honolulu 2019). The tree canopy goal also has sub-goals of planting 100,000 new trees by 2025 in Oahu (TFHF 2018). Further research into 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.[55] In 2016, forests and shrubland sequestered 6.13 MMT CO_2 Eq., accounting for 93 percent of carbon sinks. Table 5-26 summarizes carbon flux from forests and shrubland in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 5-26: CO_2 Flux from Forest Carbon (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CO_2	(6.30)	(6.13)	(6.18)	(6.12)	(6.13)

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 annual net C sequestration per unit area. The Gain Loss method calculates annual increase in carbon stocks using the following equation:

$$Forest\ CO_2\ Flux = \sum_i (A_i \times S_{Net,i}) \times \frac{44}{12}$$

where,

A	= forest land area, hectares
$S_{Net,i}$	= net C sequestration rate, tonnes of C/hectare/year
44/12	= conversion of carbon to CO_2
i	= forest type (forest or shrubland in Hawaii)

Managed forestland acreage data were obtained from the State of Hawaii Data Book (DBEDT 2018d). 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, 2015, and 2016.

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).

[55] 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.

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 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 and 2016. 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).

Average net C sequestration rates by forest type in Hawaii from 2004 through 2013 were obtained from USGS (Selmants et al. 2017). These estimates were used as a proxy for 1990, 2015, and 2016. To obtain annual net C flux, the total of net sequestration rates for native and invaded mesic-wet forest, dry forest, and alien tree plantations was applied to forest area, while the net sequestration rate for shrubland was applied to shrubland area.

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, net sequestration rates for the entire time series were updated to Hawaii-specific values from USGS (Selmants et al. 2017). The USGS net sequestration rates are based on Hawaii-specific biomass and soil organic carbon data, aboveground carbon density maps, and climate data (Selmants et al. 2017). Previously, default biomass growth rates and ratios of belowground to aboveground biomass for tropical Asia from IPCC (2006) were used to estimate annual net sequestration in forests and shrubland. The USGS net sequestration rates for forest are comparable to the IPCC default factors used in the 2015 inventory report. In contrast, USGS shrubland sequestration rates are higher than the IPCC default factors that were previously used, and therefore contributed to the majority of the changes in sinks from forest carbon relative to the 2015 inventory report. The resulting changes in historical emissions estimates are presented in Table 5-27. Additional uncertainties associated with the revised factors are discussed below.

Table 5-27: Change in Sinks from Forest Carbon Relative to the 2015 Inventory Report

Emission Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	(2.66)	(2.87)	(3.01)	(3.08)
This Inventory Report (MMT CO_2 Eq.)	(6.30)	(6.13)	(6.18)	(6.12)
Percent Change	136.8%	113.4%	105.3%	98.8%

Uncertainties

The methodology used to estimate carbon flux from forests and shrubland is based on the ratio of forest and shrubland area. The ratio of forest and shrubland area is a source of uncertainty for all inventory years because the ratios are estimated based on land cover data for years 2000 and 2014.

In addition, the net sequestration rate in shrubland is based on a limited amount of published field data on biomass carbon stored in Hawaii shrubland. While the limited data are Hawaii-specific, they may not be fully representative of the variety of shrublands that exist in Hawaii (Selmants et al. 2017).

Finally, this methodology does not consider potential changes in sequestration rates due to the age of the forest ecosystem and forest management practices, particularly for 1990, 2015, and 2016 data, which are proxied to average sequestration rates for 2004 through 2013.

To estimate uncertainty associated with sinks from forest carbon, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on IPCC (2006) and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) annual forest net sequestration rate, (2) private forest land area in Hawaii, and (3) annual shrubland net sequestration rate. The quantified uncertainty estimated for the forest net sequestration rate contributed the vast majority to the quantified uncertainty estimates. The remaining input variables contributed relatively evenly to the overall uncertainty of the sink estimate.

The results of the quantitative uncertainty analysis are summarized in Table 5-28. Sinks from forest carbon were estimated to be between -8.14 and -3.64 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 33 percent below and 41 percent above the sink estimate of -6.13 MMT CO_2 Eq.

Table 5-28: Quantitative Uncertainty Estimates for Sinks from Forest Carbon

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(6.13)	(8.14)	(3.64)	+33%	-41%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Additional land cover data and annually variable net sequestration rates should be incorporated into future analyses if they become available. Further research into the age of Hawaii forests, improved forest management practices, and their emissions reduction potential may also be considered in future analyses.

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).[56]

In 2016, 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 (89 percent), followed by emissions from wastewater treatment (9 percent) and composting (2 percent). Figure 6-1 and Figure 6-2 show emissions from the Waste sector by source for 2016.

Figure 6-1: 2016 Waste Emissions by Source

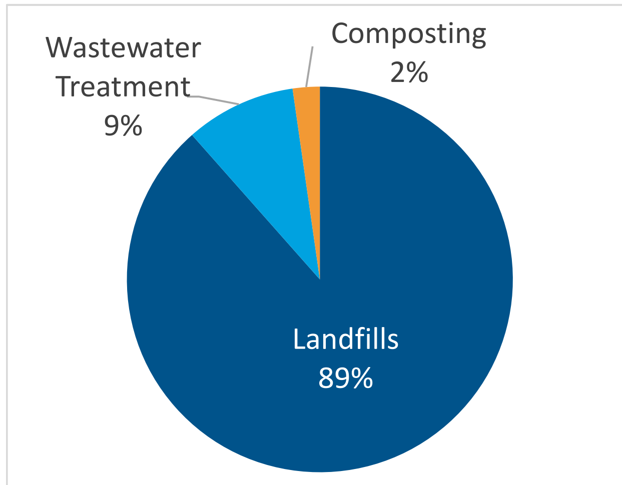
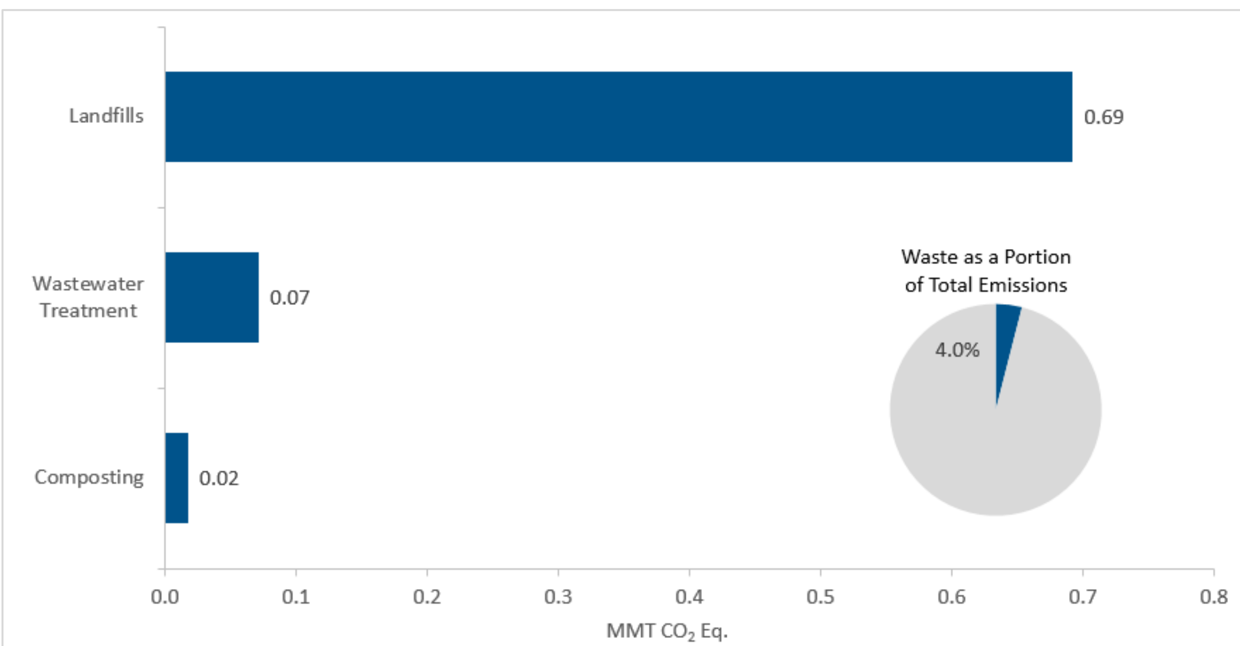


Figure 6-2: 2016 Waste Emissions by Source (MMT CO_2 Eq.)



[56] 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 2016 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 2016 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 Sector Emissions by Source and Year

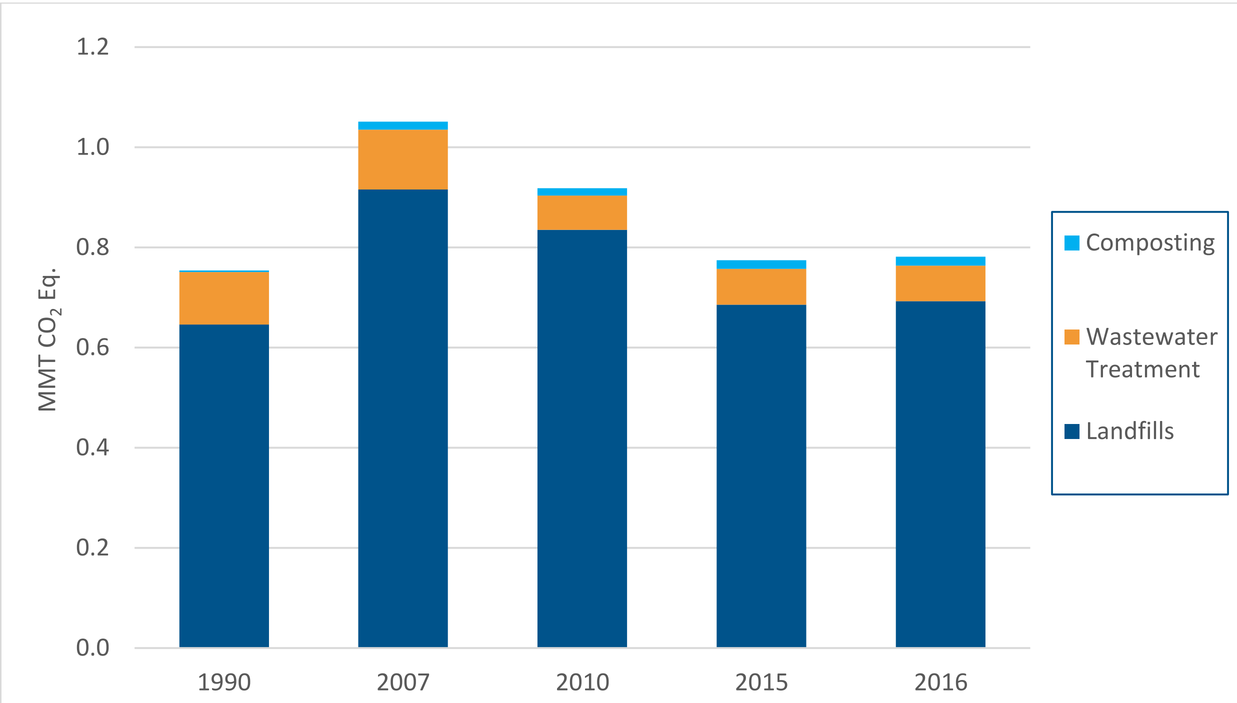


Table 6-1: GHG Emissions from the Waste Sector by Source (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016
Landfills	0.65	0.92	0.84	0.69	0.69
Composting	+	0.02	0.01	0.02	0.02
Wastewater Treatment	0.10	0.12	0.07	0.07	0.07
Total	**0.75**	**1.05**	**0.92**	**0.77**	**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 G and Appendix H, respectively. A consolidated list of areas for improvement, ranked by priority, is provide in Appendix I.

6.1. Landfills (IPCC Source Category 5A1)

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 2018a). Consistent with IPCC (2006), biogenic CO_2 from landfills is not reported under the Waste sector. In 2016, CH_4 emissions from landfills in Hawaii were 0.69 MMT CO_2 Eq., accounting for 89 percent of Waste sector emissions. Relative to 1990, emissions from landfills in 2016 were higher by roughly 7 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 2016. Table 6-2 summarizes CH_4 emissions from landfills in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
CH_4	0.65	0.92	0.84	0.69	0.69

Methodology

Consistent with the methodology used for the U.S. Inventory (EPA 2018a), 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 2016 were provided by the Hawaii Department of Health (DOH), Solid Waste Branch (Hawaii DOH 2017a and Otsu 2008). 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 2018c). Potential CH_4 emissions were then calculated using the following equation:

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

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 2018c). The CH_4 generation rate varies according 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:

$$Landfill\ methane\ emissions = \ Q_{CH_4} * \ (1 - OR) - Flared - Recovered$$

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, 2015, and 2016, volumes of landfill gas recovered for flaring and energy were obtained from EPA's GHGRP (EPA 2018b). 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 2018d), 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 2018c).

Changes in Estimates since the Previous Inventory Report

In the 2015 inventory report, potential emissions for 2011 were inadvertently used to estimate emissions from landfills for 2015. For this inventory report, this error was corrected so that 2015 potential emissions were utilized to calculate total emissions for 2015. The resulting changes in historical emission estimates are presented in Table 6-3.

Table 6-3: Change in Emissions from Landfills Relative to the 2015 Inventory Report

Sink Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.65	0.92	0.84	0.72
This Inventory Report (MMT CO_2 Eq.)	0.65	0.92	0.84	0.69
Percent Change	+	+	+	-4.8%

+ Does not exceed 0.05%

Uncertainties

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 2016. 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 2018c). 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.

To estimate uncertainty associated with emissions from landfills, uncertainties for several quantities were assessed, including: (1) oxidation rates, (2) methane collection efficiency, (3) landfill methane emissions, (4) methane generation potential, (5) methane generation rate constant, (6) Hawaii state population, and (7) landfill disposal rates. Uncertainty was estimated quantitatively around each input variable based on expert judgment, IPCC (2006), and EPA (2018a and 2018b). The following parameters contributed the most to the quantified uncertainty estimates: (1) methane generation potential, (2) methane generation rate constant, and (3) oxidation rates.

The results of the quantitative uncertainty analysis are summarized in Table 6-4. GHG emissions from landfills were estimated to be between 0.46 and 0.85 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 33 percent below and 23 percent above the emission estimate of 0.69 MMT CO_2 Eq.

Table 6-4: Quantitative Uncertainty Estimates for Emissions from Landfills

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.69	0.46	0.85	-33%	+23%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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 5B1)

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 2018a). In 2016, emissions from composting in Hawaii were 0.02 MMT CO_2 Eq., accounting for 2 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 2016 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 6-5 summarizes emissions from composting in Hawaii for 1990, 2007, 2010, 2015, and 2016.

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

Gas	1990	2007	2010	2015	2016
CH_4	+	0.01	0.01	0.01	0.01
N_2O	+	0.01	0.01	0.01	0.01
Total	**+**	**0.02**	**0.01**	**0.02**	**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).

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

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

$$N_2O\ Emissions = M * EF$$

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 2018a). MSW composting volumes for Hawaii were calculated using population data from the State of Hawaii Data Book (DBEDT 2018d). The emission factors for composting were obtained from IPCC (2006). No CH_4 recovery is assumed to occur at composting operations in Hawaii.

Changes in Estimates since the Previous Inventory Report

Relative to the 2015 inventory report, population data for the United States was updated based on the most recent available data, as published by the U.S. Census Bureau (2018). The resulting changes in historical emission estimates are presented in Table 6-6.

Table 6-6: Change in Emissions from Composting Relative to the 2015 Inventory Report

Sink Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	+	0.02	0.01	0.02
This Inventory Report (MMT CO_2 Eq.)	+	0.02	0.01	0.02
Percent Change	0%	0%	+	-0.3%

\+ Does not exceed 0.005 MMT CO_2 Eq. or 0.05%

Uncertainties

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.

To estimate uncertainty associated with emissions from composting, uncertainties for five quantities were assessed: (1) CH_4 emission factor, (2) N_2O emission factor, (3) U.S. waste composted, (4) Hawaii state population, and (5) U.S. population. Uncertainty was estimated quantitatively around each input variable based on expert judgment, IPCC (2006), and EPA (2018a). The following parameters contributed the most to the quantified uncertainty estimates: (1) U.S. waste composted, (2) CH_4 emission factor, and (3) N_2O emission factor.

The results of the quantitative uncertainty analysis are summarized in Table 6-7. GHG emissions from composting were estimated to be between 0.01 and 0.03 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 61 percent below and 98 percent above the emission estimate of 0.02 MMT CO_2 Eq.

Table 6-7: Quantitative Uncertainty Estimates for Emissions from Composting

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.02	0.01	0.03	-61%	+98%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

Hawaii-specific data on composting volumes, if it becomes available, should be incorporated into future inventory analyses.

6.3. Wastewater Treatment (IPCC Source Category 5D)

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 2018a). 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, serving most of the state's population. The remaining wastewater is treated at on-site wastewater systems. In 2016, emissions from wastewater treatment in Hawaii were 0.07 MMT CO_2 Eq., accounting for 9 percent of Waste sector emissions. Relative to 1990, emissions from wastewater treatment in 2016 were lower by 32 percent, down from 14 percent higher than 1990 levels in 2007. Table 6-8 summarizes emissions from wastewater treatment in Hawaii for 1990, 2007, 2010, 2015, and 2016.

Table 6-8: Emissions from Wastewater Treatment by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016
CH_4	0.07	0.08	0.03	0.03	0.03
N_2O	0.04	0.04	0.04	0.05	0.05
Total	**0.10**	**0.12**	**0.07**	**0.07**	**0.07**

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 2018a) and EPA's State Inventory Tools – Wastewater Module (EPA 2018g). 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:

$$CH_4\,Emissions = BOD_5 * EF * AD$$

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:

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

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:

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

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 National Pollutant Discharge Elimination System (NPDES) and non-NPDES wastewater treatment plants, including flow rate and BOD_5, were provided by Hawaii DOH, Wastewater Branch (Pruder 2008, Hawaii DOH 2017b, Hawaii DOH 2018). Where sufficient data 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 2018d), U.S. Census Bureau data (1990b), and Pruder (2008) were used to calculate wastewater treatment volumes and the share of households on septic systems. For 2010, 2015, and 2016, 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, 2015, and 2016. Emission factors were obtained from EPA's State Inventory Tool (EPA 2018g).

Changes in Estimates since the Previous Inventory Report

For the 2015 inventory report, data for Honouliuli Water Recycling Plant were only available for 2010 and 2015. For this inventory report, data for 1991, 2005, and 2017 were obtained and incorporated into the inventory calculations. In addition, data for Sand Island Waste Water Treatment Plant were not previously available for the entire time series from 1990 to 2016. For this inventory report, data for 1997 and 2017 were obtained and incorporated into the inventory calculations. The resulting changes in historical emission estimates are presented in Table 6-9.

Table 6-9: Change in Emissions from Wastewater Treatment Relative to the 2015 Inventory Report

Sink Estimates	1990	2007	2010	2015
2015 Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.04	0.05
This Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.07	0.07
Percent Change	0%	0%	58.4%	54.4%

Uncertainties

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, 2015, and 2016.

Data for two NDPES wastewater treatment plants were not available for the entire time series. Data for Honouliuli Water Recycling Facility was available for 1991, 2005, 2010, 2015, and 2017. Flow data for Sand Island Waste Water Treatment Plant was only available for 1997 and 2017 and BOD_5 was only available for 1997. For instances where data for a given inventory year were not available, data from the most recent available year was used as a proxy.

To estimate uncertainty associated with emissions from wastewater treatment, uncertainties for five quantities were assessed: (1) wastewater treatment plan flow rates, (2) BOD_5 values, (3) direct N_2O emissions rate, (4) N_2O emission factor, and (5) CH_4 emission factor. Uncertainty was estimated quantitatively around each input variable based on expert judgment and IPCC (2006). The following parameters contributed the most to the quantified uncertainty estimates: (1) N_2O emission factor and (2) CH_4 emission factor.

The results of the quantitative uncertainty analysis are summarized Table 6-10. GHG emissions from wastewater treatment were estimated to be between 0.06 and 0.09 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 21 percent below and 22 percent above the emission estimate of 0.07 MMT CO_2 Eq.

Table 6-10: Quantitative Uncertainty Estimates for Emissions from Wastewater Treatment

2016 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.07	0.06	0.09	-21%	+22%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

Areas for Improvement

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 K.

Methodology Overview

> **DBEDT Macroeconomic Forecast**
>
> In June 2018, DBEDT released its *Population and Economic Projections for the State of Hawaii to 2045*. This report is publicly available and represents DBEDT's "best estimates of likely trends in important population and economic variables based on currently available information" (DBEDT 2018e). The projections for real gross state product (GSP) are used within this report. DBEDT estimates a 1.9 percent average annual growth rate in real GSP from 2016 to 2020, and 1.8 percent between 2020 and 2025.

Greenhouse gas emissions result from economic activities occurring within Hawaii. These emissions are impacted by 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.

For this analysis, a combination of top-down and bottom-up approaches were used to develop baseline projections of GHG emissions in the year 2020 and 2025. For some sources (residential energy use, commercial energy use, industrial energy use, domestic aviation, incineration of waste, oil and natural gas systems, IPPU, and waste treatment), DBEDT's *Population and Economic Projections for the State of Hawaii to 2045* (DBEDT 2018e) was primarily used to project GHG emissions for 2020 and 2025, using the 2016 statewide GHG inventory as a starting point. For domestic marine and military-related transportation, emissions are assumed to remain constant in the future relative to 2016 due to a lack of available data and inconsistencies in the historical emissions trend. For other smaller emission sources and sinks (AFOLU categories), emissions were projected by forecasting activity data using historical trends and published information available on future trends, and applying the same methodology used to estimate 2016 emissions.

For large GHG emitting sources for which there has been substantial federal and state policy intervention (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 to develop baseline projections. For these sources, the team additionally quantitatively assessed three major points of uncertainty within the GHG emissions forecast for 2020 and 2025:

- **Alternate Scenario 1A and 1B: World oil prices.** Shifts in fossil fuel prices will impact consumer use of different fuels and resulting GHG emissions. This scenario looks at both *high* (Alternate

Scenario 1A) and *low* (Alternate Scenario 1B) future oil price pathways based on the U.S. Energy Information Administration's Annual Energy Outlook 2019 (EIA 2019d).

- **Alternate Scenario 2: Renewable energy infrastructure.** Hawaii has adopted an aggressive Renewable Portfolio Standard (RPS) that mandates electric utilities 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 2018). In 2018, the Puna Geothermal unit on Hawaii Island was shut down due to the Kilauea eruption. Though it is expected to be back on by the end of 2019 (Associated Press 2019), which is assumed to be the case under the baseline, this scenario assumes that it does not come online until after 2020 and before 2025. In addition, this scenario assumes delays in the build-out of 260 megawatts (MW) of currently planned utility-scale solar photovoltaic as well as the continued use of coal through 2025.
- **Alternate Scenario 3A and 3B: Ground transportation technology adoption.** 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 2018a). 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. This scenario creates a *lower* (Alternate Scenario 3A) and *upper* (Alternate Scenario 3B) bound of possible ground transportation-based GHG emissions; for example, by assuming that there are varying levels of electric vehicle adoption, biofuels, vehicle miles traveled, and cars on the road (in comparison to vans, trucks and sports utility vehicles).

To understand these points of uncertainty within the GHG emissions forecast, each alternative is assessed independently and is not considered cumulatively with other alternatives. A detailed description of the methodologies used to project emissions by source and sink category under both the baseline scenario and the alternate scenarios, if applicable, are provided in Appendix K.

Limitations of the Projections Analysis

As with all projections of emissions into the future, uncertainty exists. This study quantitatively assessed additional scenarios that impact the energy industries and transportation source categories. Other areas of uncertainty exist, as discussed in the subsequent sections of this report, but were not quantitatively assessed as part of this analysis. Specifically, other key areas of uncertainty include the following:

- **Inventory Estimates:** The projections were developed using the historical inventory estimates as a starting point. Any uncertainties related to quality and availability of data used to develop the historical inventory estimates similarly apply to the emission projections.
- **Macroeconomy:** There are several highly used sources for macroeconomic forecasting within Hawaii. The DBEDT (2018d) forecast was used for this analysis because it is the most up-to-date forecast developed by a state agency that extends through the required time frame (up to 2025). The University of Hawaii Economic Research Organization (UHERO) also produces a quarterly forecast. The UHERO (2017) forecast was used to develop the projections presented in the 2015 inventory report as the DBEDT forecast was not available during the development of

that report. In the 2015 inventory report, the UHERO forecast resulted in an accumulated 14 percent growth in real GSP by 2025 relative to 2015. The DBEDT forecast results in an accumulated 18 percent growth in real GSP by 2025 relative to 2016 estimates. Differences in macroeconomic forecasts are driven by model-specific assumptions; a comprehensive comparison of models is outside the scope of this work.

- **Policy:** 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, were not directly considered in this analysis. In addition, due to recent court challenges and a lack of support by the current administration, 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 also not considered.

7.1. Projections Summary

Under the baseline scenario, total GHG emissions are projected to be 19.02 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.) in 2020 and 17.45 MMT CO_2 Eq. in 2025. Net emissions, which take into account carbon sinks, are projected to be 12.45 MMT CO_2 Eq. in 2020 and 10.81 MMT CO_2 Eq. in 2025. Net emissions excluding aviation, which is used for the statewide GHG target established under Act 234, are projected to be 8.37 MMT CO_2 Eq. in 2020 and 6.43 MMT CO_2 Eq. in 2025.

Under the alternate scenarios, total GHG emissions are projected to range from 18.24 to 19.87 MMT CO_2 Eq. in 2020 and 15.91 to 18.31 MMT CO_2 Eq. in 2025; net emissions are projected to range from 11.68 to 13.30 MMT CO_2 Eq. in 2020 and 9.27 to 11.67 MMT CO_2 Eq. in 2025; and net emissions excluding aviation are projected to range from 7.84 to 9.22 MMT CO_2 Eq. in 2020 and 5.34 to 7.19 MMT CO_2 Eq. in 2025. Table 7-1 summarizes emission projections of statewide emissions for 2020 and 2025 under the baseline and each alternate scenario.

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

Sector	Total Emissions (Excluding Sinks)[a]		Net Emissions (Including Sinks)[a]		Net Emissions (Including Sinks, Excluding Aviation)[a,b]	
	2020	2025	2020	2025	2020	2025
Baseline Scenario	**19.02**	**17.45**	**12.45**	**10.81**	**8.37**	**6.43**
Alternate Scenario 1A	18.24	15.91	11.68	9.27	7.84	5.34
Alternate Scenario 1B	19.68	18.31	13.11	11.67	8.86	7.08
Alternate Scenario 2	19.87	18.21	13.30	11.57	9.22	7.19
Alternate Scenario 3A	18.79	16.71	12.23	10.07	8.14	5.68
Alternate Scenario 3A	19.06	17.77	12.49	11.13	8.41	6.74

[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.

Relative to 2016, total emissions under the baseline scenario are projected to decrease by 3 percent by 2020 and 11 percent by 2025. Over the same period, net emissions are projected to decrease by 5 percent and 17 percent, respectively, and net emissions excluding aviation are projected to decrease by 9 percent and 30 percent, respectively. This trend is largely driven by the projected trend in emissions from energy industries (i.e., electric power plants and petroleum refineries), which are similarly expected to decrease between 2016 and 2025. Under all scenarios, net emissions excluding aviation are projected to be less than the 1990 emissions level by 2020. Figure 7-1 shows net GHG emissions for each historical and projected inventory year. A summary of the emission projections under each scenario is presented in Figure 7-2. Discussion on emission projections by sector are provided in the sections that follow.

Figure 7-1: Hawaii Net GHG Emissions by Year (Including Sinks)

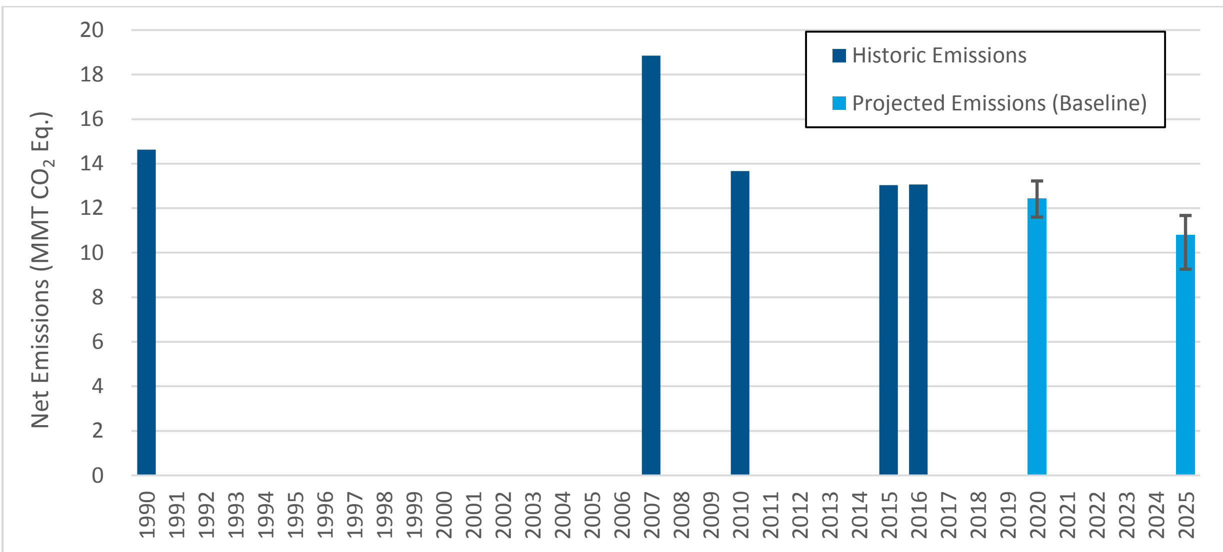
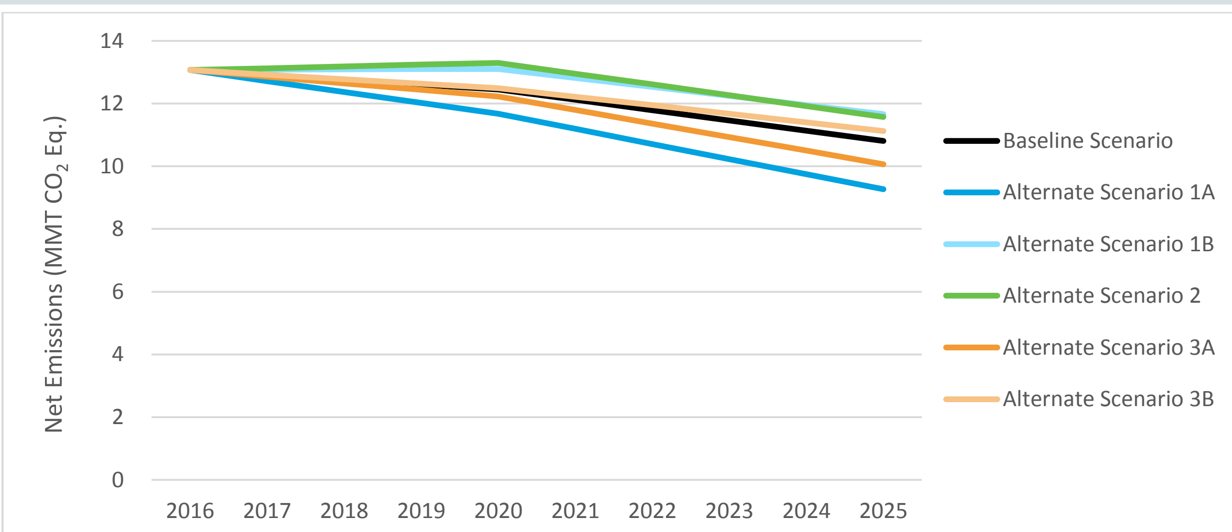


Figure 7-2: Projected Hawaii GHG Net Emissions under each Scenario (Including Sinks)



7.2. Energy

Baseline Scenario

Under the baseline scenario, emissions from the Energy sector are projected to be 16.31 MMT CO_2 Eq. in 2020 and 14.58 MMT CO_2 Eq. in 2025, accounting for 86 percent and 84 percent of total projected statewide emissions, respectively. Projected emissions under the baseline scenario by source for 2020 and 2025 are summarized in Table 7-2.

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

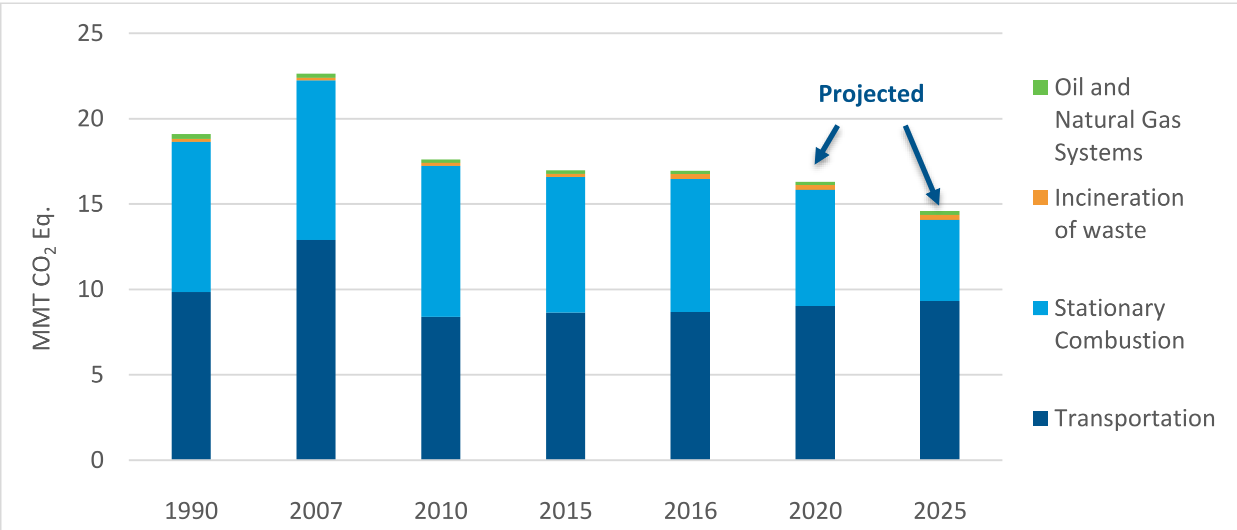
Source[a]	2020	2025
Stationary Combustion	**6.81**	**4.77**
Energy Industries[b]	*5.78*	*3.65*
Residential	*0.08*	*0.09*
Commercial	*0.49*	*0.53*
Industrial	*0.46*	*0.50*
Transportation	**9.05**	**9.33**
Ground	*4.17*	*4.15*
Domestic Marine[c]	*0.64*	*0.64*
Domestic Aviation	*3.44*	*3.75*
Military Aviation[d]	*0.64*	*0.64*
Military Non-Aviation[d]	*0.16*	*0.16*
Incineration of Waste	**0.27**	**0.29**
Oil and Natural Gas Systems[e]	**0.19**	**0.18**
Total	**16.31**	**14.58**

[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 2016 emission estimates. Further discussion of inconsistencies in historical data is included in Section 3.2 and Appendix K.
[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 2016 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 2016, emissions from the Energy sector are projected to decrease by 4 percent by 2020 and 14 percent by 2025. This trend is largely driven by the projected decrease in emissions from energy industries, which includes fuel combustion emissions from electric power plants and petroleum refineries. While emissions from the transportation sector are expected to grow between 2016 and

2025, emissions from other sources are projected to remain relatively flat. Figure 7- shows historical and projected emissions from the Energy sector by source category for each inventory year.

Figure 7-3: GHG Emissions and Projections from the Energy Sector under the Baseline Scenario



Alternate Scenarios

Under the alternate scenarios, emissions from the Energy sector are projected range from 15.54 to 17.17 MMT CO_2 Eq. in 2020 and 13.04 to 15.44 MMT CO_2 Eq. in 2025. Projected emissions under each scenario by source for 2020 and 2025 are summarized in Table 7-3 and graphically shown in Figure 7-4.

Figure 7-4: GHG Projections from the Energy Sector under each Scenario

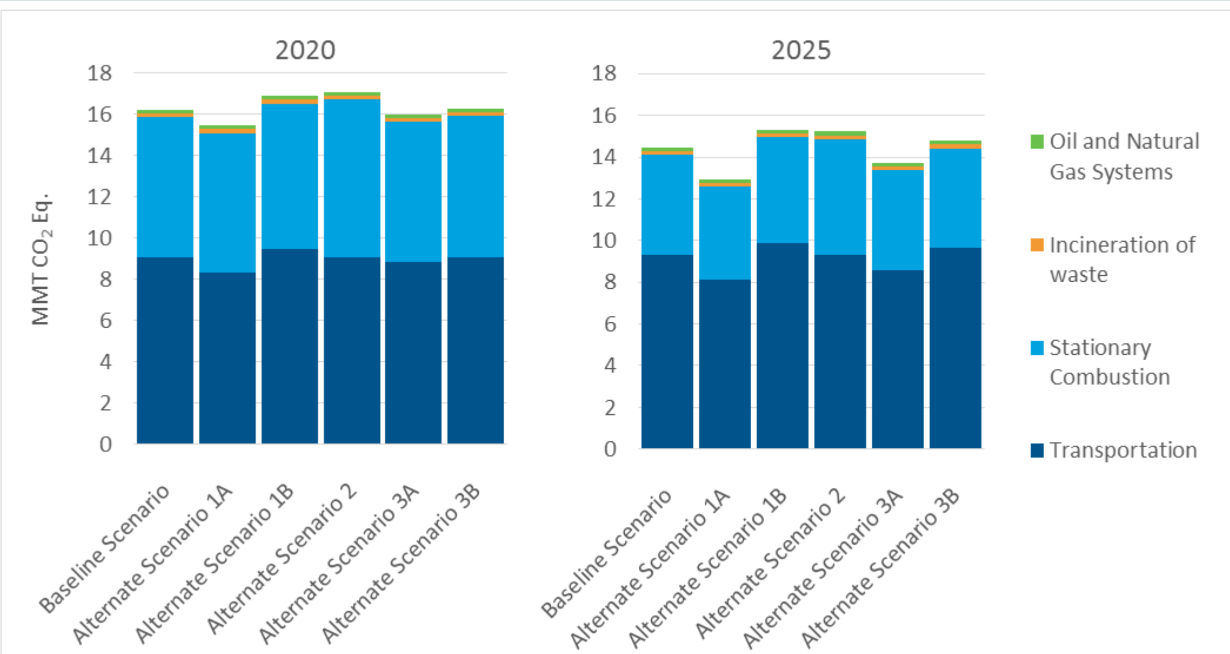


Table 7-3: Emission Projections from the Energy Sector under the Alternate Scenarios by Source (MMT CO_2 Eq.)

Source[a]	Alternate Scenario 1A		Alternate Scenario 1B		Alternate Scenario 2		Alternate Scenario 3A		Alternate Scenario 3B	
	2020	2025	2020	2025	2020	2025	2020	2025	2020	2025
Stationary Combustion	**6.76**	**4.43**	**7.04**	**5.11**	**7.66**	**5.54**	**6.81**	**4.77**	**6.81**	**4.77**
Energy Industries[b]	*5.73*	*3.31*	*6.01*	*3.99*	*6.64*	*4.41*	*5.78*	*3.65*	*5.78*	*3.65*
Residential	*0.08*	*0.09*	*0.08*	*0.09*	*0.08*	*0.09*	*0.08*	*0.09*	*0.08*	*0.09*
Commercial	*0.49*	*0.53*	*0.49*	*0.53*	*0.49*	*0.53*	*0.49*	*0.53*	*0.49*	*0.53*
Industrial	*0.46*	*0.50*	*0.46*	*0.50*	*0.46*	*0.50*	*0.46*	*0.50*	*0.46*	*0.50*
Transportation	**8.33**	**8.13**	**9.48**	**9.85**	**9.05**	**9.33**	**8.83**	**8.59**	**9.09**	**9.65**
Ground	*3.69*	*3.40*	*4.43*	*4.47*	*4.17*	*4.15*	*3.95*	*3.41*	*4.21*	*4.47*
Domestic Marine[c]	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*
Domestic Aviation	*3.20*	*3.29*	*3.61*	*3.95*	*3.44*	*3.75*	*3.44*	*3.75*	*3.44*	*3.75*
Military Aviation[d]	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*	*0.64*
Military Non-Aviation[d]	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*	*0.16*
Incineration of Waste	**0.27**	**0.29**	**0.27**	**0.29**	**0.27**	**0.29**	**0.27**	**0.29**	**0.27**	**0.29**
Oil and Natural Gas Systems[e]	**0.19**	**0.18**	**0.19**	**0.18**	**0.19**	**0.18**	**0.19**	**0.18**	**0.19**	**0.18**
Total	**15.54**	**13.04**	**16.98**	**15.44**	**17.17**	**15.34**	**16.09**	**13.84**	**16.36**	**14.90**

[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 2016 emission estimates.

Further discussion of inconsistencies in historical data is included in Section 3.2 and Appendix K.

[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 2016 emission estimates.

[e] Includes fugitive emissions and emissions from venting and flaring at refineries.

Notes: Totals may not sum due to independent rounding.

7.3. IPPU

Emissions from the IPPU sector are projected to be 0.85 MMT CO_2 Eq. in 2020 and 0.99 MMT CO_2 Eq. in 2025, accounting for 4 percent and 6 percent of total projected statewide emissions under the baseline scenario, respectively. Projected emissions by source for 2020 and 2025 are summarized in Table 7-

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

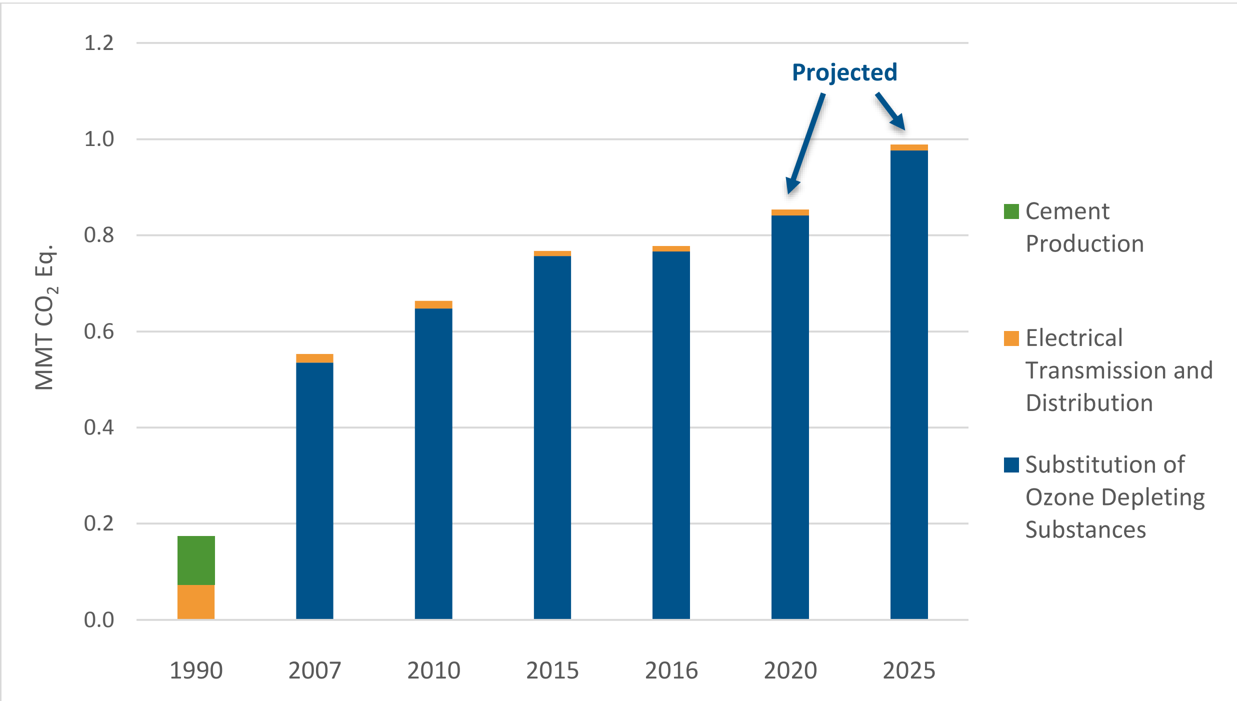
Source	2020	2025
Cement Production	NO	NO
Electrical Transmission and Distribution	0.01	0.01
Substitution of Ozone Depleting Substances	0.84	0.98
Total	**0.85**	**0.99**

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 2016, electrical transmission and distribution emissions by 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 2016, are projected to remain at zero in 2020 and 2025. Figure 7-5 shows historical and projected emissions from the IPPU sector by source category for select years.

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



7.4. AFOLU

Total emissions (excluding sinks) from the AFOLU sector are projected to be 1.01 MMT CO_2 Eq. in 2020 and 0.96 MMT CO_2 Eq. in 2025, accounting for 5 percent of total Hawaii emissions in 2020 and 6 percent in 2025 under the baseline scenario. Carbon sinks are projected to be 6.57 MMT CO_2 Eq. in 2020 and 6.64 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 5.56 MMT CO_2 Eq. in 2020 and 5.68 MMT CO_2 Eq. in 2025. Projected emissions by source and sink category for 2020 and 2025 are summarized in Table 7-.

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

Category	2020	2025
Agriculture	**0.45**	**0.45**
Enteric Fermentation	0.25	0.24
Manure Management	0.03	0.03
Agricultural Soil Management	0.17	0.18
Field Burning of Agricultural Residues	NO	NO
Urea Application	+	+
Land Use, Land-Use Change, and Forestry	**(6.02)**	**(6.13)**
Agricultural Soil Carbon	0.51	0.47
Forest Fires	0.04	0.04
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.04)
Urban Trees	(0.35)	(0.38)
Forest Carbon	(6.17)	(6.22)
Total (Sources)	**1.01**	**0.96**
Total (Sinks)	**(6.57)**	**(6.64)**
Net Emissions	**(5.56)**	**(5.68)**

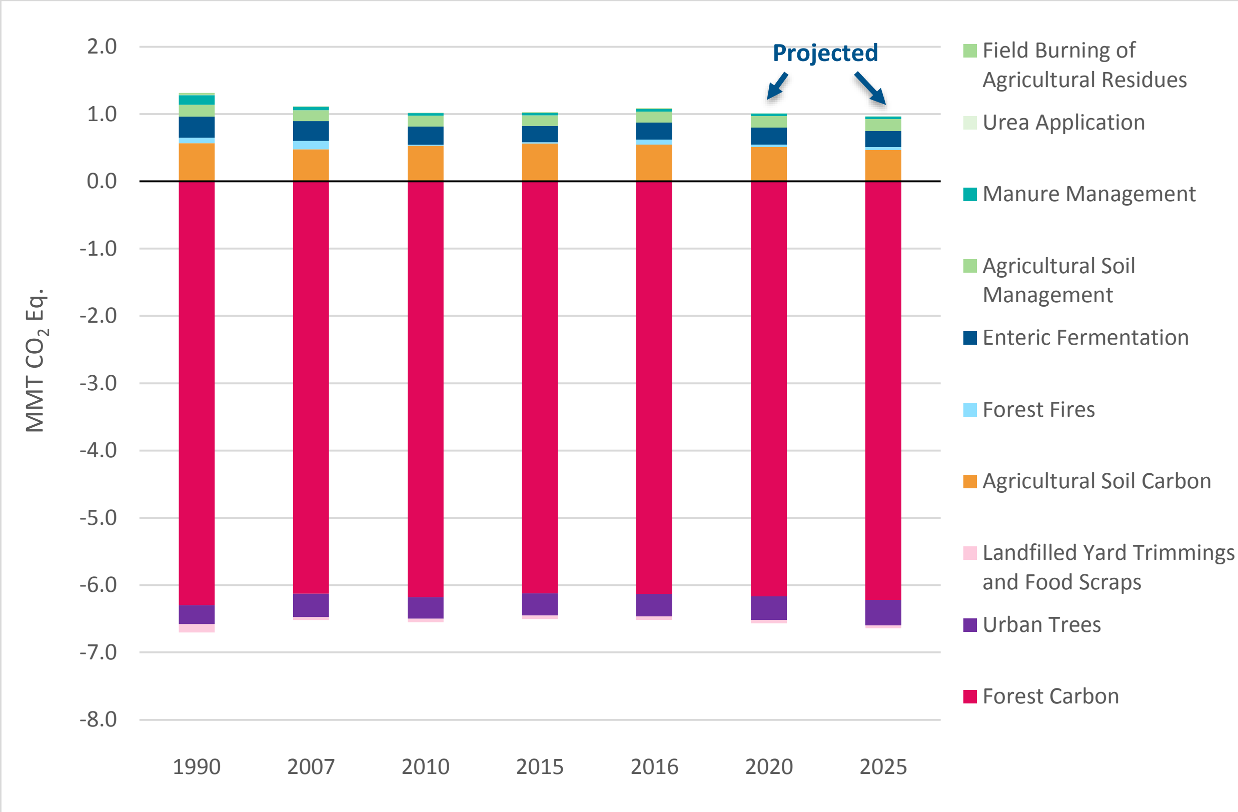
+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).

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

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. Figure 7-6 shows historical and projected emissions from the AFOLU sector by source and sink category for select years.

Figure 7-6: 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 0.92 MMT CO_2 Eq. in 2025, accounting for 4 percent and 5 percent of total projected statewide emissions under the baseline scenario, respectively. Projected emissions by source for 2020 and 2025 are summarized in Table 7-6.

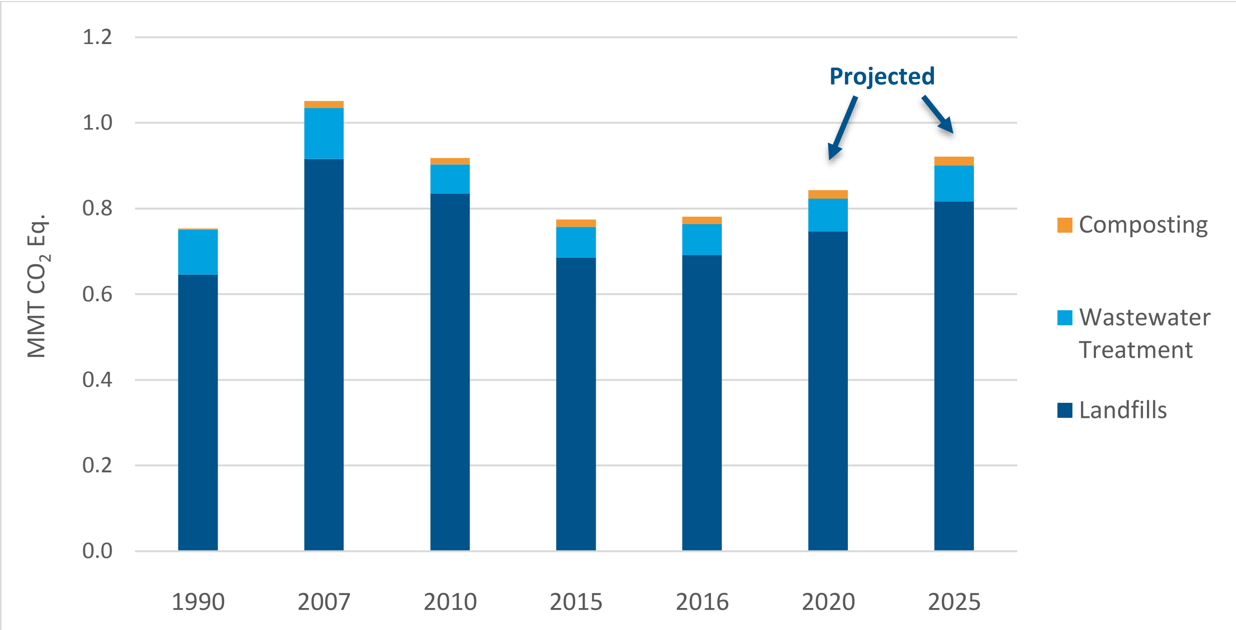
Table 7-6: GHG Emission Projections from the Waste Sector by Source (MMT CO_2 Eq.)

Source	2020	2025
Landfills	0.75	0.82
Composting	0.02	0.02
Wastewater Treatment	0.08	0.08
Total	**0.84**	**0.92**

Note: Totals may not sum due to independent rounding.

Relative to 2016, emissions from landfills, composting, and wastewater treatment are projected to remain constant or increase in 2020 and 2025. Figure 7-7 shows historical and projected emissions from the waste sector by source category for select years.

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



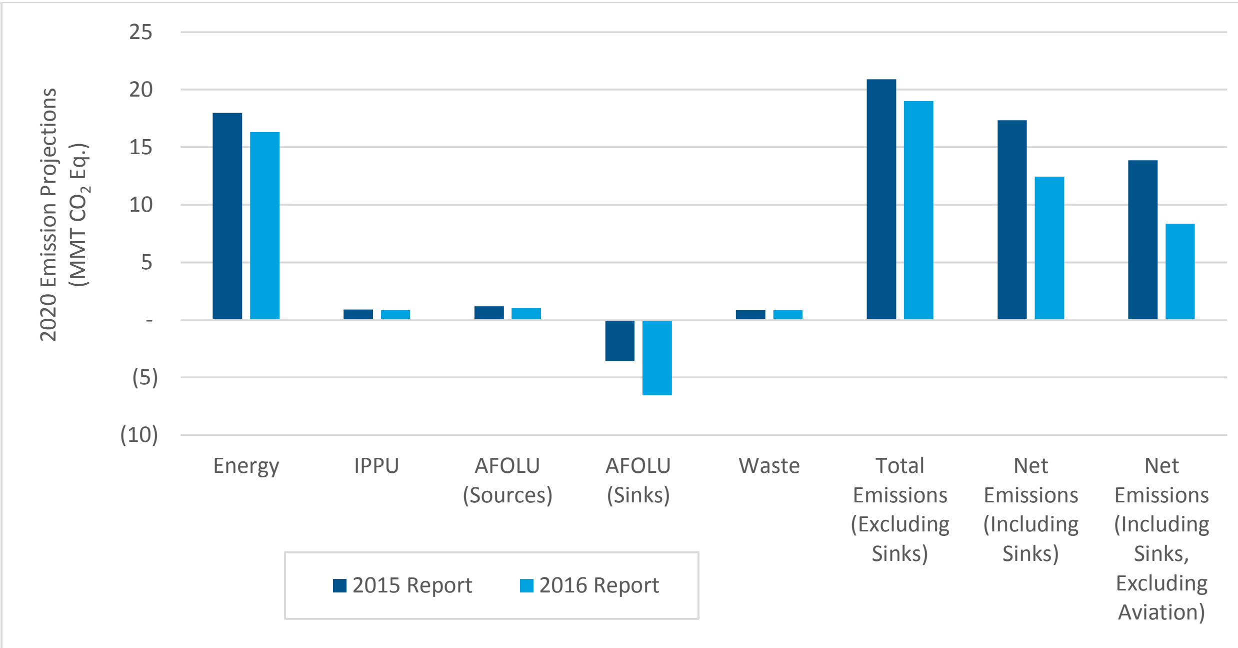
7.6. Changes in Estimates since the Previous Inventory Report

The emission projections presented in this report reflect the best available information on historical emission estimates, projections of economic activities, and the status of policies and programs that impact the intensity of GHG emissions. Key changes that impacted the emission projections for 2020 and 2025 that are presented in this report relative to the 2015 inventory report include the following:

- For the 2015 inventory report, the 2015 statewide GHG inventory was used as a starting point for emission projections. For this inventory report, the 2016 statewide GHG inventory, which reflects updates made to the historical emission estimates, was instead used as a starting point. For example, a key change that impacted historical emissions is the use of Hawaii-specific net carbon sequestration rates obtained from the USGS instead of using default values from IPCC to calculate sinks from forest carbon. See Appendix B for further discussion on the impact of updates made to the historical emission estimates.
- DBEDT's (2018e) projections for real GSP are used within this report while the UHERO (2017) forecast was used to develop the projections presented in the 2015 inventory report.
- For the service area under the Hawaiian Electric Industries (HEI), the utility generation scenario used to project emissions in this report was adjusted to account for current renewable energy capacity on the grid (DBEDT 2019a) and updated estimates of additional renewable energy capacity that will be added to the grid by 2020 and 2025 (HECO 2019b). For the 2015 inventory report, emissions projections for 2020 and 2025 were developed based only on the utility's original Power Supply Improvement Plan (PSIP) (PUC 2016; DCCA 2017).

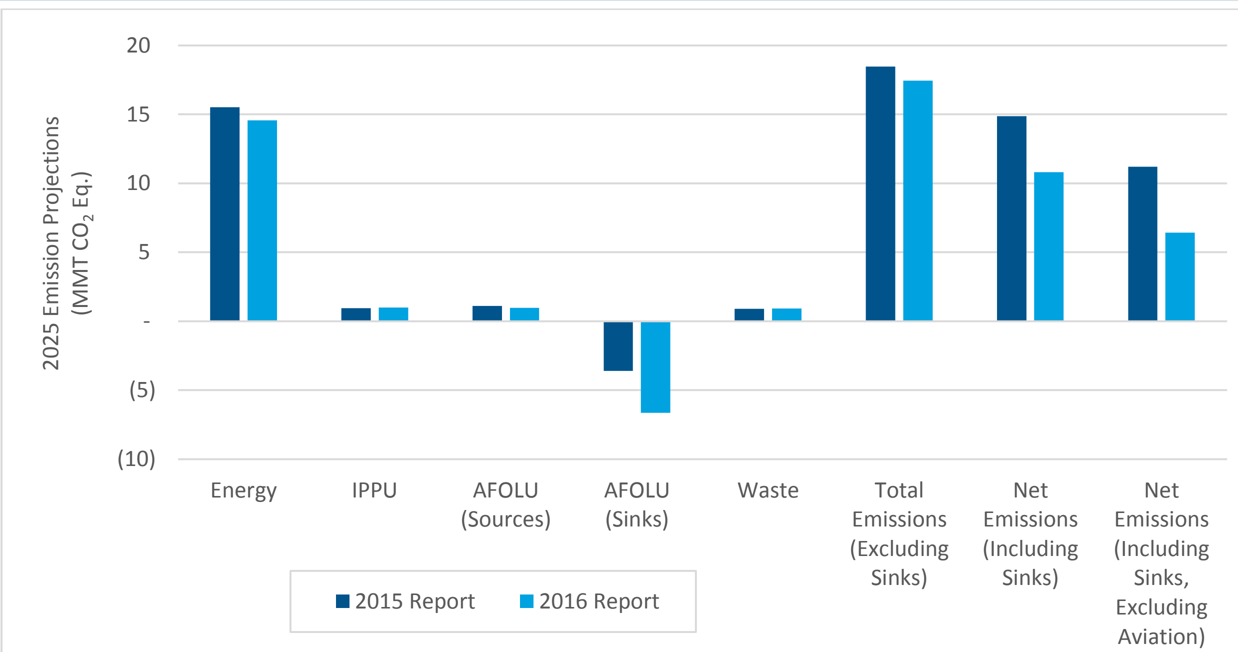
A comparison of emission projections in 2020 and 2025 as presented in this report relative to the 2015 inventory report is summarized in Figure 7-3 and Figure 7-4, respectively.

Figure 7-3: Comparison of 2020 Emission Projections in this Report Relative to the 2015 Inventory Report



Note: Domestic aviation and military emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emission reduction goal established in Act 234.

Figure 7-4: Comparison of 2025 Emission Projections in this Report Relative to the 2015 Inventory Report



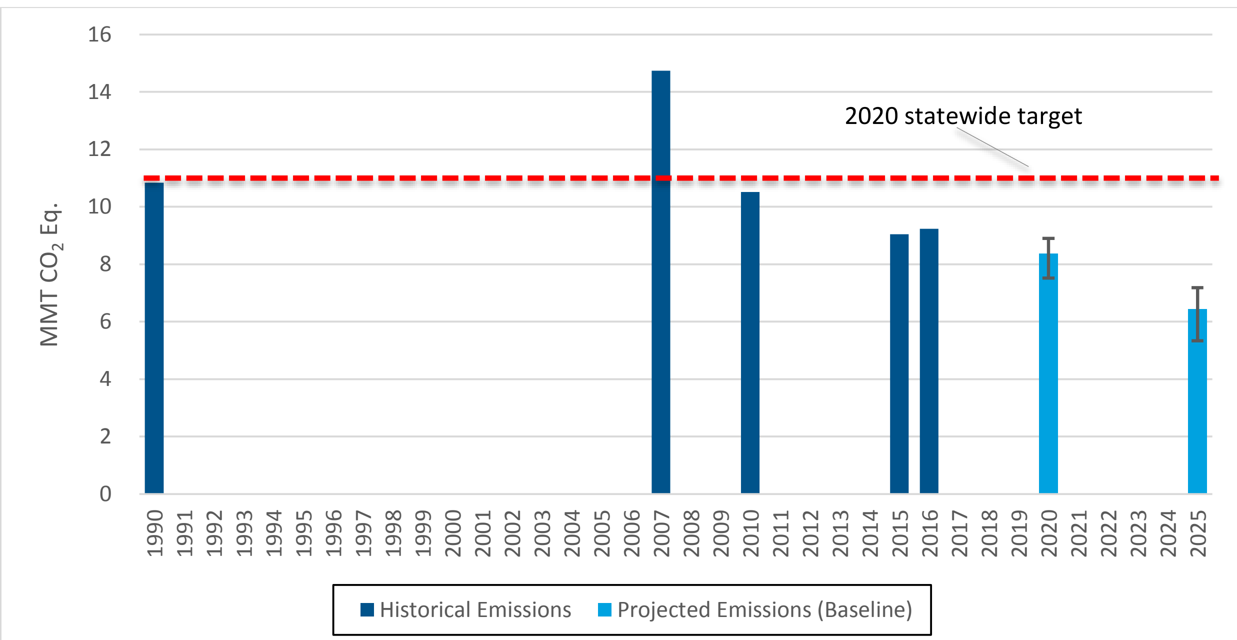
Note: Domestic aviation and military emissions, which are reported under the Energy sector, are excluded from Hawaii's GHG emission reduction goal established in Act 234.

8. GHG Reduction Goal Progress

Act 234, Session Laws of Hawaii 2007, establishes as state policy statewide GHG emissions limit 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 and military aviation) shall not be included in Hawaii's GHG target.**[57]

Excluding aviation, 1990 statewide emissions were estimated to be 10.84 MMT CO_2 Eq., which represents the level at which 2020 emissions must be at or below. This target could change with future updates to the 1990 emission estimates, but it is not likely to change significantly.[58] 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 and the 2020 statewide target, which is equal to 1990 emission levels. As net emissions excluding aviation are projected to range from 7.84 to 9.22 MMT CO_2 Eq. in 2020, this report finds that Hawaii is on track to meet its 2020 statewide emissions target.

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



[57] 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.
[58] 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.

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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. Updates to the Historical Emission Estimates Presented in the 2015 Inventory Report

When preparing emission inventories, it is best practice to review estimates for prior years and revise those 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. As such, this inventory report includes revised estimates for 1990, 2007, 2010, and 2015 relative to the estimates presented in the 2015 inventory report. Figure B-1 graphically compares the results for total emissions, net emissions, and net emission excluding aviation as presented in each inventory report. A summary of the change in emission estimates relative to the 2015 inventory report by sector is presented in Table B-1. A summary of the change in emission estimates by source and sink category is presented in Table B-2.

Figure B-1: Comparison of Emissions in this Report Relative to the 2015 Inventory Report

Table B-1: Change in Emissions Relative to the 2015 Inventory Report by Sector (MMT CO_2 Eq.)

Sector	Energy	Energy (Excluding Aviation	Energy (Aviation)	IPPU	AFOLU (Sources)	AFOLU (Sinks) [a]	Waste	Total Emissions (Excluding Sinks)	Net Emissions (Including Sinks)	Net Emissions (Including Sinks, Excluding Aviation)
1990										
2015 Report	19.61	14.95	4.66	0.17	1.61	(3.06)	0.75	22.15	19.08	14.43
2016 Report	19.09	15.30	3.79	0.17	1.31	(6.70)	0.75	21.33	14.63	10.84
Difference	(0.51)	0.35	(0.87)	+	(0.30)	(3.64)	+	(0.81)	(4.45)	(3.58)
Percent Change	-2.6%	2.3%	-18.6%	+	-18.4%	118.7%	+	-3.7%	-23.3%	-24.8%
2007										
2015 Report	21.84	17.42	4.42	0.54	1.56	(3.28)	1.05	25.00	21.71	17.29
2016 Report	22.65	18.53	4.11	0.55	1.12	(6.52)	1.05	25.37	18.85	14.73
Difference	0.81	1.11	(0.31)	0.01	(0.45)	(3.24)	+	0.37	(2.87)	(2.56)
Percent Change	3.7%	6.4%	-6.9%	1.7%	-28.6%	98.6%	+	1.5%	-13.2%	-14.8%
2010										
2015 Report	20.46	17.59	2.87	0.67	1.18	(3.44)	0.89	23.21	19.77	16.90
2016 Report	17.62	14.46	3.16	0.66	1.02	(6.55)	0.92	20.22	13.67	10.51
Difference	(2.83)	(3.13)	0.29	(0.01)	(0.17)	(3.11)	0.03	(2.98)	(6.09)	(6.39)
Percent Change	-13.9%	-17.8%	10.2%	-1.2%	-14.0%	90.5%	2.8%	-12.9%	-30.8%	-37.8%
2015										
2015 Report	18.57	15.34	3.23	0.83	1.10	(3.54)	0.78	21.28	17.75	14.52
2016 Report	16.97	12.98	3.99	0.77	1.03	(6.50)	0.77	19.54	13.04	9.04
Difference	(1.60)	(2.36)	0.77	(0.06)	(0.07)	(2.97)	(0.01)	(1.74)	(4.71)	(5.47)
Percent Change	-8.6%	-15.4%	23.8%	-7.8%	-6.5%	83.9%	-1.2%	-8.2%	-26.5%	-37.7%

+ Does not exceed 0.005 MMT CO_2 Eq. or 0.05%

[a] positive percent change indicates an increase in carbon sinks.

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

Table B-2: Change in Emissions Relative to the 2015 Inventory Report by Source/Sink Category (MMT CO_2 Eq.)

Source/Sink Category	1990			2007			2010			2015		
	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change
Energy												
Stationary Combustion	7.91	8.81	11.4%	9.26	9.35	1.0%	9.91	8.82	-11.0%	8.38	7.94	-5.4%
Energy Industries	*6.80*	*6.66*	*-2.0%*	*8.78*	*8.29*	*-5.7%*	*8.48*	*7.79*	*-8.1%*	*7.06*	*6.88*	*-2.6%*
Residential	*0.03*	*0.05*	*48.2%*	*0.04*	*0.06*	*38.5%*	*0.08*	*0.09*	*7.1%*	*0.08*	*0.06*	*-16.4%*
Commercial	*0.38*	*0.78*	*103.8%*	*0.24*	*0.30*	*24.9%*	*0.51*	*0.37*	*-27.6%*	*0.84*	*0.47*	*-43.6%*
Industrial	*0.70*	*1.32*	*90.3%*	*0.19*	*0.70*	*272.7%*	*0.84*	*0.57*	*-31.8%*	*0.40*	*0.52*	*27.6%*
Transportation	11.26	9.84	-12.6%	12.19	12.91	5.9%	10.16	8.41	-17.2%	9.79	8.64	-11.7%
Ground	*3.40*	*3.72*	*9.4%*	*4.97*	*5.12*	*3.2%*	*5.28*	*4.15*	*-21.4%*	*5.64*	*4.04*	*-28.5%*
Domestic Marine	*1.82*	*1.58*	*-13.6%*	*1.79*	*2.90*	*62.3%*	*0.91*	*0.60*	*-33.9%*	*0.39*	*0.56*	*42.6%*
Domestic Aviation	*4.66*	*2.41*	*-48.2%*	*4.42*	*3.48*	*-21.2%*	*2.87*	*2.67*	*-6.7%*	*3.23*	*3.33*	*3.2%*
Military Aviation [a]	*1.38*	*1.38*	*55.2%*	*1.02*	*0.63*	*37.2%*	*1.10*	*0.49*	*-10.7%*	*0.53*	*0.66*	*35.7%*
Military Non-Aviation [a]		0.76			0.77			0.50			0.05	
Incineration of Waste	0.18	0.18	0%	0.15	0.15	0%	0.19	0.19	0%	0.20	0.20	0%
Oil and Natural Gas Systems	0.27	0.27	0%	0.24	0.24	0%	0.20	0.20	0%	0.19	0.19	0%
International Bunker Fuels	2.95	1.53	-48.1%	1.54	1.22	-20.7%	1.38	1.31	-4.8%	1.61	1.65	2.9%
CO_2 from Wood Biomass and Biofuels Consumption	NE	2.43	NA	0.16	0.87	450.2%	1.22	1.27	4.1%	1.45	1.47	1.3%
IPPU												
Cement Production	0.10	0.10	0%	NO	NO	0%	NO	NO	0%	NO	NO	0%
Electrical Transmission and Distribution	0.07	0.07	+	0.02	0.02	-0.4%	0.02	0.02	0.3%	0.01	0.01	3.6%
Substitution of Ozone Depleting Substances	+	+	4.8%	0.53	0.54	1.7%	0.66	0.65	-1.2%	0.82	0.76	-7.9%
AFOLU												
Enteric Fermentation	0.32	0.32	0%	0.29	0.29	0%	0.27	0.27	0%	0.24	0.24	0%
Manure Management	0.15	0.15	-0.5%	0.05	0.05	-3.9%	0.04	0.04	-6.4%	0.04	0.04	-6.0%
Agricultural Soil Management	0.17	0.17	4.6%	0.16	0.16	3.7%	0.15	0.16	6.6%	0.14	0.16	12.8%

Source/Sink Category	1990			2007			2010			2015		
	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change	2015 Report	2016 Report	Percent Change
Field Burning of Agricultural Residues	0.03	0.03	0%	0.01	0.01	0%	0.01	0.01	0%	0.01	0.01	0%
Urea Application	+	+	0%	+	+	0%	+	+	0%	+	+	-6.3%
Agricultural Soil Carbon	0.57	0.57	0%	0.48	0.48	0%	0.53	0.53	0%	0.56	0.56	0%
Forest Fires	0.38	0.08	-79.0%	0.57	0.12	-78.4%	0.19	0.01	-92.8%	0.11	0.02	-79.6%
Landfilled Yard Trimmings & Food Scraps	(0.12)	(0.12)	0%	(0.05)	(0.05)	+	(0.05)	(0.05)	0.6%	(0.05)	(0.05)	2.1%
Urban Trees	(0.28)	(0.28)	0.0%	(0.37)	(0.35)	-5.3%	(0.38)	(0.32)	-15.4%	(0.40)	(0.33)	-19.4%
Forest Carbon	(2.66)	(6.30)	136.8%	(2.87)	(6.13)	113.4%	(3.01)	(6.18)	105.3%	(3.08)	(6.12)	98.8%
Waste												
Landfills	0.65	0.65	+	0.92	0.92	+	0.84	0.84	+	0.72	0.69	-4.8%
Composting	+	+	0%	0.02	0.02	0%	0.01	0.01	+	0.02	0.02	-0.3%
Wastewater Treatment	0.10	0.10	0%	0.12	0.12	0%	0.04	0.07	58.4%	0.05	0.07	54.4%

+ Does not exceed 0.005 MMT CO_2 Eq. or 0.05%; NE (emissions are Not Estimated); NA (estimates is Not Applicable); NO (emissions are Not Occurring).

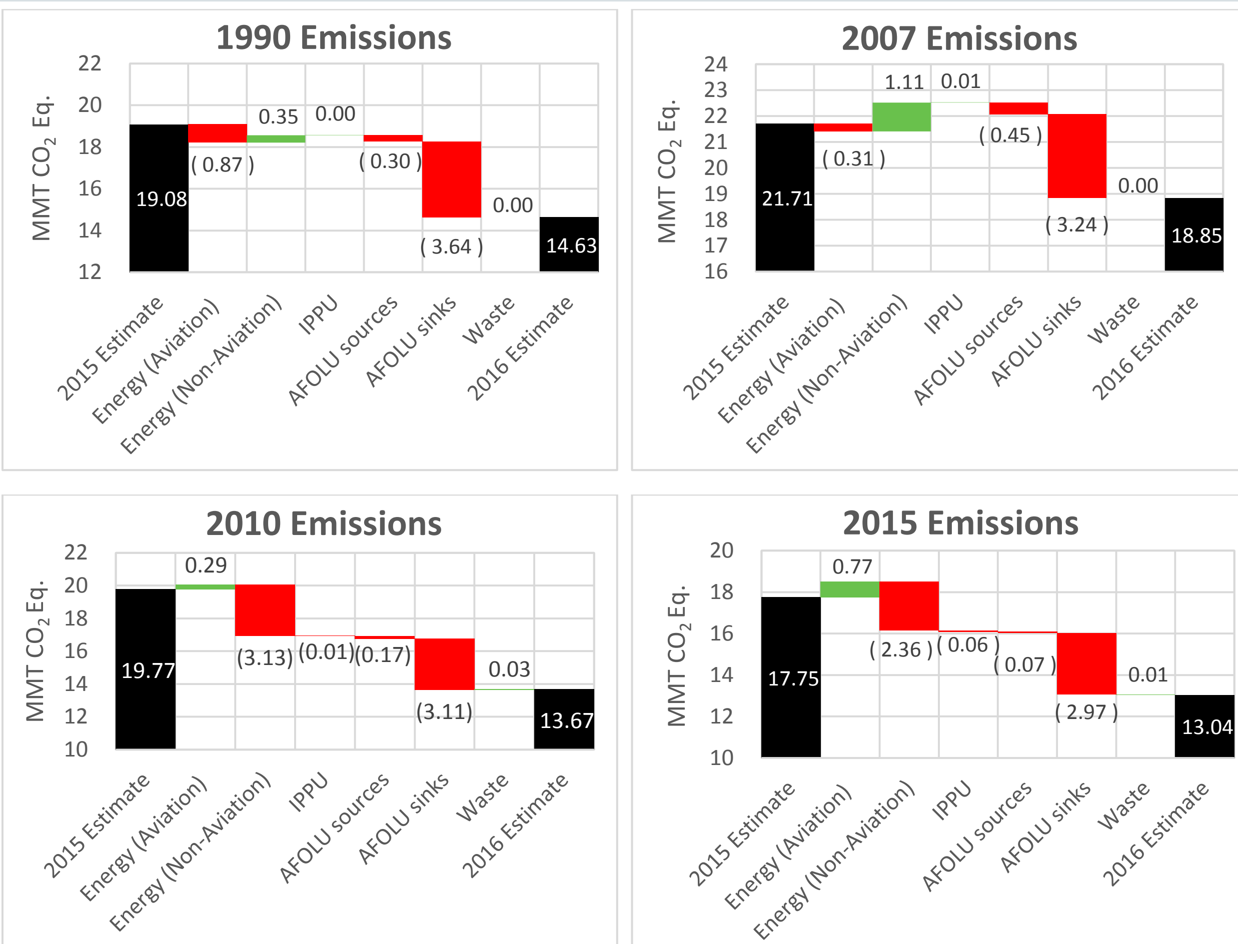
[a] In the 2015 inventory report, military emissions were presented as a single end-use sector. Therefore, military aviation and military non-aviation emissions were combined for the purposes of comparison.

The key drivers of change in the estimates between this report and the 2015 inventory report are:

1) The use of Hawaii-specific net carbon sequestration rates obtained from the USGS instead of using default values from IPCC to calculate sinks from forest carbon,
2) The use of SEDS data instead of data collected by DBEDT as the primary source of fuel consumption data to calculate emissions from the Energy sector,
3) The use of Hawaii-specific forest fire emission factors from the USGS instead of default values from IPCC to calculate emissions from forest fires,
4) The use of Hawaii's annual percent of acres burned by forest type obtained from the USGS instead of the annual share of land are by forest type to calculate emissions from forest fires; and
5) The use of annual percent urban tree cover in Honolulu and statewide instead of a static percent urban tree cover for the state to calculate sinks from urban trees.

The change in net carbon sequestration rates had the largest impact on the overall magnitude of emissions; however, the impact is relatively consistent across the inventory years. The use of SEDS energy data instead of DBEDT had a varying impact on energy sector emissions across the inventory years. Figure B-2 shows the change in net emissions for each inventory year, broken down by sector.

Figure B-2: Change in Net Emissions for 1990, 2010, 2007, and 2015, as Compared to the 2015 Report



As the changes to energy sector estimates were also significant, additional details are provided below. Figure B-3 further highlights the impact of using SEDS as the primary source of energy consumption data instead of data collected by DBEDT. For 1990, emissions from energy presented in this report have decreased by 2.6 percent relative to the 2015 report (but increased by 2.3 percent when emissions from aviation are excluded). For 2015, emissions from energy presented in this report have decreased by 8.6 percent relative to the 2015 report (and have decreased by 15.4 percent when emissions from aviation are excluded).

Figure B-3: Comparison of Energy Sector Emissions in this Report Relative to the 2015 Inventory Report

Appendix C. Energy Data Comparative Analysis

As part of the effort to inform which data set (or combination of datasets) to use as the source of fuel consumption data to estimate emissions from the Energy sector, ICF conducted a comparative analysis of available consumption data, including data obtained from EIA SEDS[59] and data collected by DBEDT.[60] This appendix presents the results of this comparison by fuel type.[61]

Comparative Analysis of 1990 and 2007 Datasets

As documented in the *Hawaii Greenhouse Gas Inventory: 1990 and 2007* (ICF 2008), a comparative analysis was previously conducted between available datasets, including the data collected by DBEDT and EIA SEDS data, in the preparation of the historical inventories for the 2008 inventory report. At the time, the data collected by DBEDT for 1990 and 2007 was determined to be the best available estimate of fuel consumption for Hawaii. However, the report also states that "while this dataset was judged as the best available dataset, further research could more thoroughly verify and improve the fuel consumption estimates."

While the information presented in this appendix does not definitively conclude that the EIA SEDS data is a more accurate dataset then the data collected by DBEDT for 1990 and 2007, SEDS was determined, at this point in time, to be the best dataset available across all inventory years. SEDS was therefore used as the primary source of fuel consumption across all inventory years in part because use of one consistent data source across all years (if available) is typically considered inventory best practice to minimize changes in data due to differences in collection methods between data providers. As discussed throughout this report, further review and validation of the data could lead to future revisions to these estimates.

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[59] Data presented in this appendix was taken directly from the sector-specific consumption tables for Hawaii, available online at https://www.eia.gov/state/seds/seds-data-complete.php?sid=HI#Consumption. For 1990, an adjustment was made to remove residual fuel and diesel fuel consumption from the Kalaeloa Facility based on the facility's 1990 Annual Emissions Report and communication with the plant manager (HECO 1991; McFall 2019).

[60] For 1990 and 2007, the data collected by DBEDT are based on a number of data sources and reports of fuel consumption submitted to DBEDT. It includes data from AES; Chevron; Hawaii Department of Taxation; EIA; Gay & Robinson; Hawaiian Commercial & Sugar Company; the Petroleum Industry Monitoring, Analysis, and Reporting Program (PIMAR), Hawaiian Electric Company (HECO), Hawaii Electric Light Company (HELCO), Maui Electric Company (MECO), and Kauai Island Utility Cooperative (KIUC). For 2010, 2015, and 2016, the data collected by DBEDT are based only on data reported under the Energy Industry Information Reporting Program (EIIRP).

[61] Diesel fuel, residual fuel, motor gasoline, and jet fuel represent roughly 90% of fossil-fuel consumption in Hawaii. Other fuels are not included in this comparative analysis due to a lack of data or their small contribution to total emissions.

Diesel Fuel

Data on diesel fuel consumption in billion British Thermal Units (Bbtu) for all inventory years were available from SEDS and collected by DBEDT. A summary of the consumption totals by end-use sector are presented in Table C-1. Consumption totals by year are graphically shown in Figure C-1.

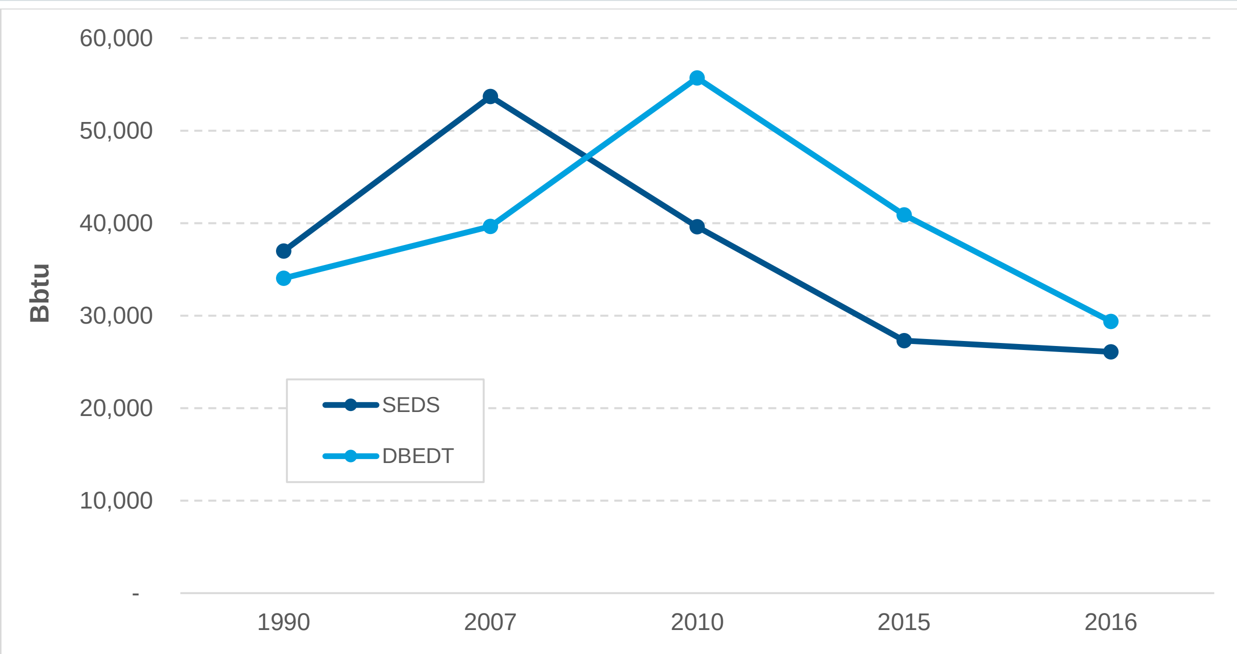
Table C-1: Diesel Fuel Consumption by Source and End-Use Sector for 1990, 2007, 2010, 2015 and 2016 (Bbtu)

End-Use Sector [a]	1990	2007	2010	2015	2016
SEDS					
Commercial	2,600	1,600	1,500	1,300	900
Industrial	4,200	2,600	1,900	1,900	900
Transportation	20,400	36,100	23,200	11,800	12,600
Energy Industries	9,785	13,400	13,000	12,300	11,700
Total	**36,985**	**53,700**	**39,600**	**27,300**	**26,100**
DBEDT					
Commercial	274	60	53[b]	4,840	4,265
Industrial	3,759	106	6,031	1,787	1,663
Transportation	20,309	23,792	35,838	26,733	7,622
Energy Industries	9,712	15,682	13,773[b]	7,544	15,812
Total	**34,054**	**39,641**	**55,695**	**40,903**	**29,362**

[a] Neither source reported consumption by the residential sector.

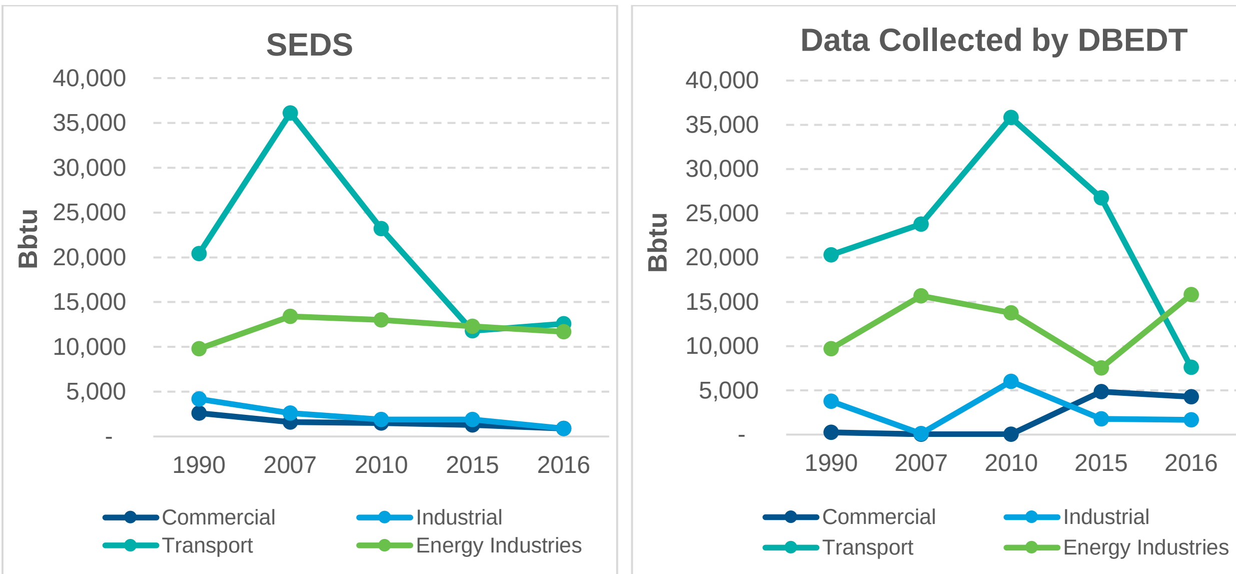
[b] The aggregate data collected by DBEDT did not include diesel consumption by energy industries. ICF apportioned commercial consumption to the commercial and energy industries sectors based on the sector breakout of the 2007 data collected by DBEDT.

Figure C-1: Diesel Fuel Consumption by Source for 1990, 2007, 2010, 2015 and 2016



As shown above, the diesel consumption totals identified by SEDS and the data collected by DBEDT are similar for 1990 and 2016, but differ considerably for the interim years, with the SEDS data peaking in 2007 and the data collected by DBEDT peaking in 2010. When analyzed by end-use sector, the SEDS data shows relatively flat consumption amounts across the inventory years for all end-uses, with the exception of the transportation sector, which drives the peak in consumption in 2007. In contrast, the data collected by DBEDT shows higher variation in the amounts by end-use across the inventory years. Figure C-2 shows diesel consumption by end-use sector and year for each data set.

Figure C-2: Diesel Fuel Consumption by Sector for 1990, 2007, 2010, 2015 and 2016



Energy Industries

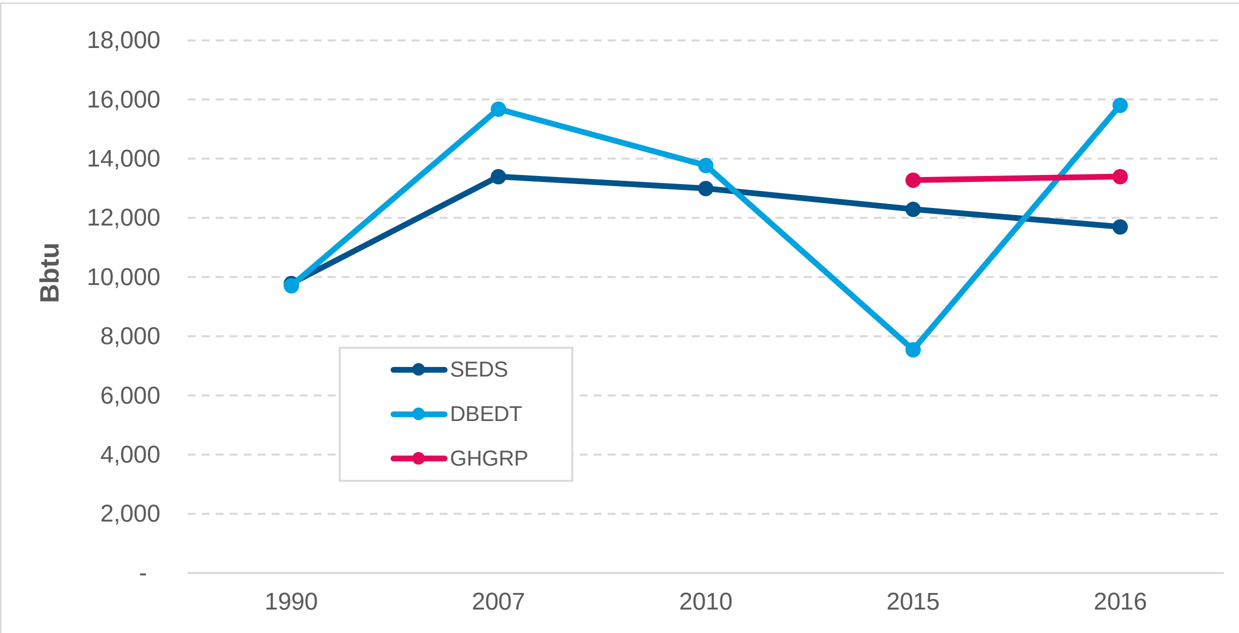
To further assess the sector-specific trends, the diesel consumption data for the energy industries end-use were compared to data reported under EPA's Greenhouse Gas Reporting Program (GHGRP). Specifically, facility-level stationary combustion data by fuel type for 2015 and 2016 were compared to consumption totals obtained from SEDS and data collected by DBEDT.[62] Since data are only available from GHGRP in metric tons carbon dioxide equivalent, these emissions were back-calculated to Bbtu for the purposes of comparison. Table C-2 shows diesel fuel consumption for energy industries by source for 2015 and 2016. Energy industry consumption totals by source and year are graphically shown in Figure C-3. While the GHGRP data does not match either the SEDS data or the data collected by DBEDT exactly, the totals and relatively flat trend align more closely with the SEDS data.

[62] GHGRP data were available for 2010 but are not included in this comparison because the data are not representative of all facilities. This is because 2010 was the first year that data were collected under GHGRP and not all facilities reported during that year.

Table C-2: Energy Industries Diesel Fuel Consumption by Source for 2015 and 2016 (Bbtu)

Source	SEDS	DBEDT	GHGRP
2015	12,300	7,544	13,277
2016	11,700	15,812	13,403

Figure C-3: Energy Industries Diesel Fuel Consumption for 1990, 2007, 2010, 2015 and 2016



Transportation

Diesel fuel consumption for the transportation end-use was also compared against trends in vehicle miles traveled (VMT) in Hawaii, as obtained from the Federal Highway Administration (FHWA) Highway Statistics. Table C-3 shows VMT for diesel-consuming vehicles and diesel fuel consumption for transportation by source for all inventory years.

Figure C-4 shows the trend in VMT for diesel-consuming vehicles and diesel fuel consumption for transportation relative to 1990. As shown, VMT increased between 1990 and 2007, decreased between 2007 and 2010, and then gradually increased between 2010 and 2016. The SEDS data shows an increase in consumption between 1990 and 2007, followed by a significant decrease in consumption between 2007 and 2015, and a slight increase in consumption between 2015 and 2016. The data collected by DBEDT also shows an increase in consumption between 1990 and 2007, with consumption continuing to increase between 2007 and 2010, and then decreasing between 2010 and 2016, with consumption decreasing by 70 percent between 2015 and 2016.

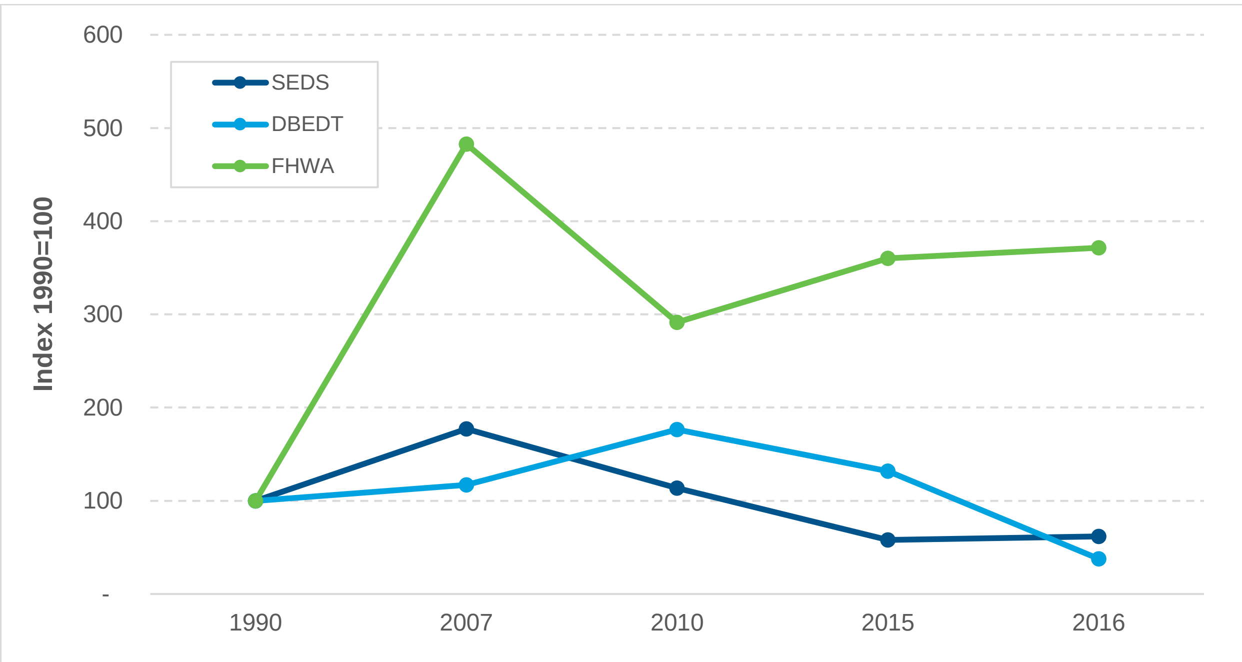
Table C-3: Miles Traveled and Transportation Diesel Fuel Consumption by Source

Source	Unit	1990	2007	2010	2015	2016
SEDS	Bbtu	20,400	36,100	23,200	11,800	12,600
DBEDT[a]	Bbtu	20,309	23,792	35,838	26,733	7,622
FHWA[b]	Million Miles	147	711	429	531	547

[a] Data collected by DBEDT.

[b] The miles shown represent miles traveled by diesel-consuming vehicles in Hawaii, which are calculated by applying estimates of fuel use by vehicle type, obtained from the U.S. Inventory (EPA 2018a), to estimates of total VMT by vehicle type from FHWA. Diesel-consuming vehicles primarily include heavy-duty buses and freight trucks.

Figure C-4: Trend in VMT (FHWA) and Transportation Diesel Fuel Consumption (SEDS and DBEDT) Relative to 1990 (Index 1990=100)



Note: Fuel consumption trends also depend on changes in the average fuel economy of diesel-consuming vehicles over time.

Residual Fuel

Data on residual fuel consumption in Bbtu for all inventory years were available from SEDS and collected by DBEDT. A summary of the consumption totals by end-use sector are presented in Table C-4. Consumption totals by year are graphically shown in Figure C-5. As shown, SEDS data and data collected by DBEDT follow a similar trend, with the data collected by DBEDT lower in all years except 2010.

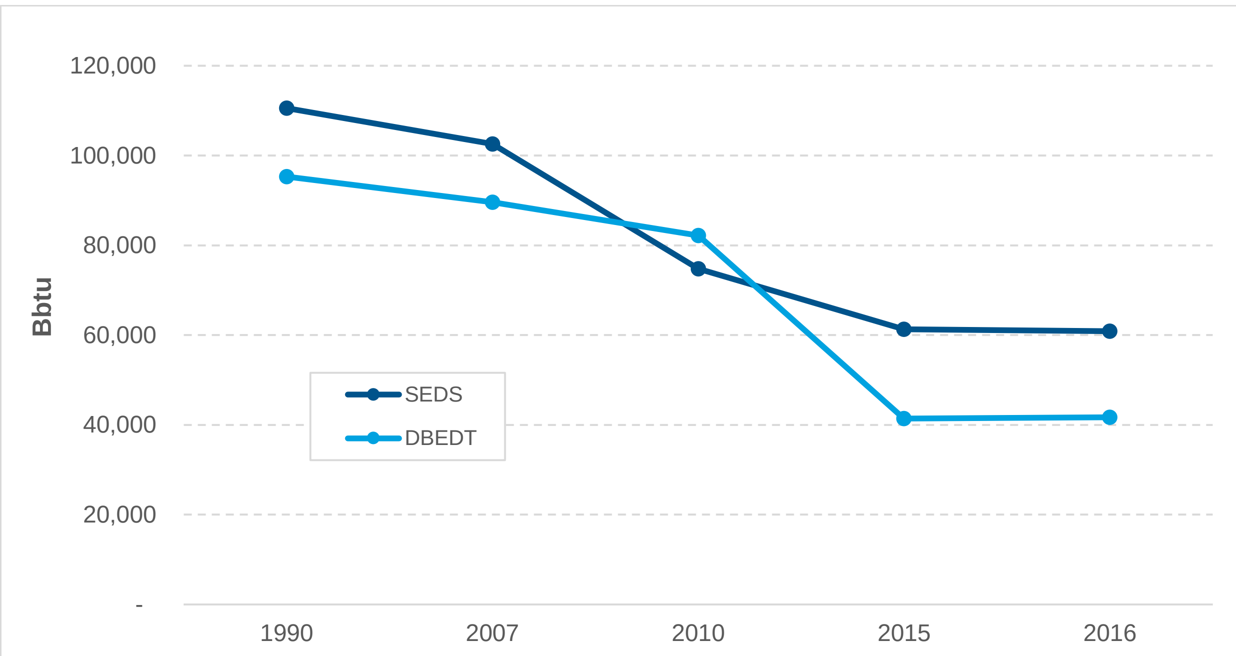
Table C-4: Residual Fuel Consumption by Source and End-Use Sector for 1990, 2007, 2010, 2015 and 2016 (Bbtu)

End-Use Sector [a]	1990	2007	2010	2015	2016
SEDS					
Commercial	5,200	0	0	0	0
Industrial	10,900	2,700	2,800	1,900	2,600
Transportation	16,700	28,100	6,800	4,400	5,100
Energy Industries	77,742	71,800	65,200	55,000	53,200
Total	**110,542**	**102,600**	**74,800**	**61,300**	**60,900**
DBEDT					
Commercial	73	0	0	0	0
Industrial	4,130	0	3,076[b]	1,282[b]	1,778[b]
Transportation	14,101	16,715	7,471[b]	2,970[b]	3,488[b]
Energy Industries	77,019	72,860	71,632[b]	37,121[b]	36,385[b]
Total	**95,322**	**89,575**	**82,179**	**41,373**	**41,652**

[a] Neither source reported consumption by the residential sector.

[b] The data collected by DBEDT were provided in aggregate. To estimate consumption by each end-use sector, ICF apportioned the raw aggregate consumption data based on the SEDS data sector breakout for that year.

Figure C-5: Residual Fuel Consumption by Source for 1990, 2007, 2010, 2015 and 2016



Energy Industries

To further assess the sector-specific trends, the residual consumption data for the energy industries end-use were compared to data reported under EPA's GHGRP. Specifically, facility-level stationary combustion data by fuel type for 2015 and 2016 were compared to consumption totals obtained from

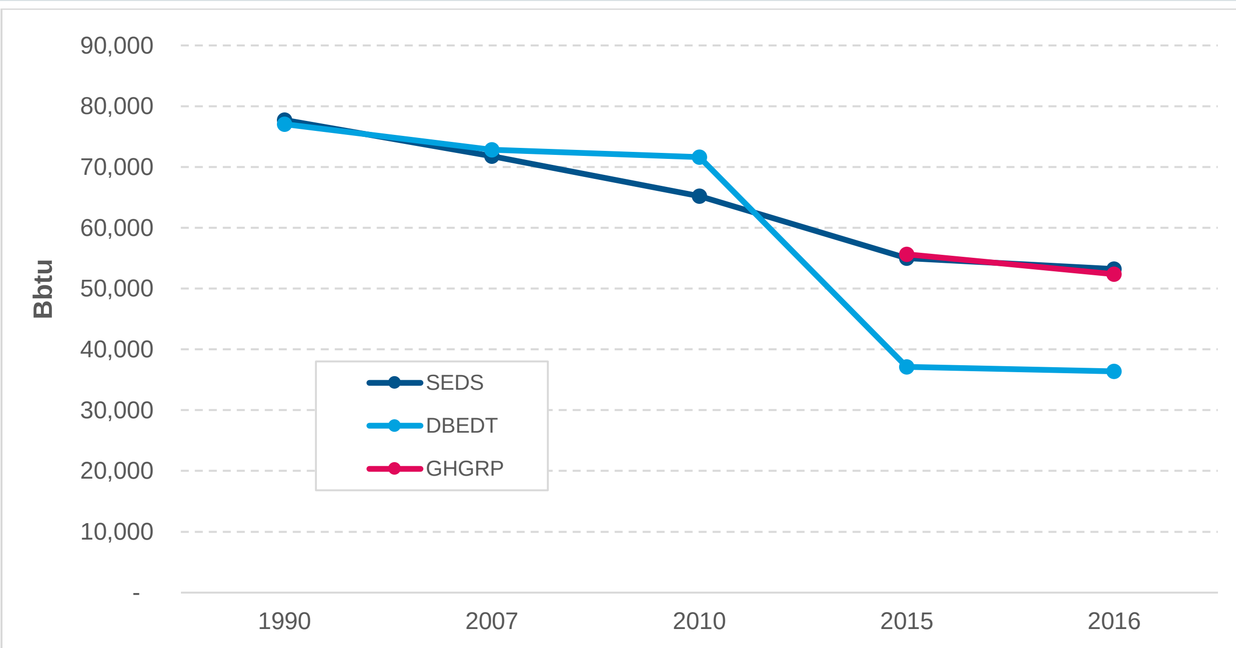
SEDS and collected by DBEDT.[63] Since data are only available from GHGRP in metric tons carbon dioxide equivalent, these emissions were back-calculated to Bbtu for the purposes of comparison. Table C-5 shows diesel fuel consumption for energy industries by source for 2015 and 2016. Energy industry consumption totals by source and year are graphically shown in Figure C-6. As shown, the SEDS data matches almost exactly with the GHGRP data while the data collected by DBEDT appears to significantly underestimate consumption by energy industries. It is important to note that the data collected by DBEDT were provided in aggregate and assumptions were applied by ICF to disaggregate the data by end-use sector; however, even if all residual consumption data collected by DBEDT were apportioned to the energy industries end-use, the totals would still be less than those identified by SEDS and GHGRP by roughly 20 percent.

Table C-5: Energy Industries Diesel Fuel Consumption by Source for 2015 and 2016 (Bbtu)

Source	SEDS	DBEDT [a]	GHGRP
2015	55,000	37,121	55,619
2016	53,200	36,385	52,390

[a] The data collected by DBEDT were provided in aggregate; therefore, consumption by energy industries was not directly provided by DBEDT. To estimate consumption by energy industries, ICF apportioned the raw aggregate consumption data to each sector based on the SEDS data sector breakout for that year.

Figure C-6: Energy Industries Diesel Fuel Consumption for 1990, 2007, 2010, 2015 and 2016



[63] GHGRP data were available for 2010 but are not included in this comparison because the data are not representative of all facilities. This is because 2010 was the first year that data were collected under GHGRP and not all facilities reported during that year.

Motor Gasoline

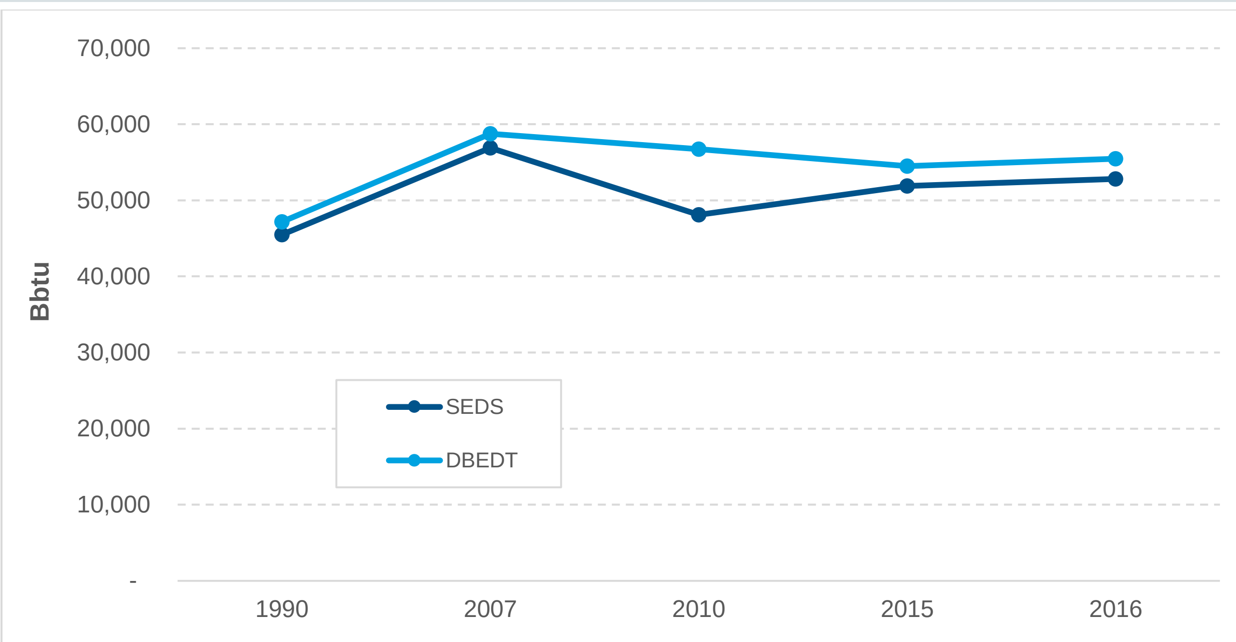
Data on motor gasoline consumption in Bbtu for all inventory years were available from SEDS and collected by DBEDT. A summary of the consumption totals by end-use sector are presented in Table C-6. Consumption totals by year are graphically shown in Figure C-7. As shown, the data collected by DBEDT and the SEDS data match up fairly closely and follow a similar trend across all years, with some deviation in 2010.

Table C-6: Motor Gasoline Consumption by Source and End-Use Sector for 1990, 2007, 2010, 2015 and 2016 (Bbtu)

End-Use Sector [a]	1990	2007	2010	2015	2016
SEDS					
Commercial	300	100	100	1,600	1,600
Industrial	700	1,300	700	1,400	1,400
Transportation	44,500	55,500	47,300	48,900	49,800
Total	**45,500**	**56,900**	**48,100**	**51,900**	**52,800**
DBEDT					
Commercial	412	0	881	1,021	1,185
Industrial	404	111	223	162	321
Transportation	46,353	58,649	55,646	53,329	53,970
Total	**47,169**	**58,759**	**56,750**	**54,512**	**55,476**

[a] Neither source reported consumption by the residential or energy industries sectors.

Figure C-7: Motor Gasoline Consumption by Source for 1990, 2007, 2010, 2015 and 2016



Transportation

To further assess the sector-specific trends, motor gasoline consumption for the transportation end-use was also compared against trends in vehicle miles traveled (VMT) in Hawaii, as obtained from the FHWA

Highway Statistics. Table C-7 shows VMT and motor gasoline consumption for transportation by source for all inventory years. Figure C-8 shows the trend in VMT and motor gasoline consumption for transportation relative to 1990. As shown, the SEDS and VMT data show a consistent trend while the data collected by DBEDT deviates from the trend, specifically from 2010 to 2015.

Table C-7: Miles Traveled and Transportation Motor Gasoline Consumption by Source

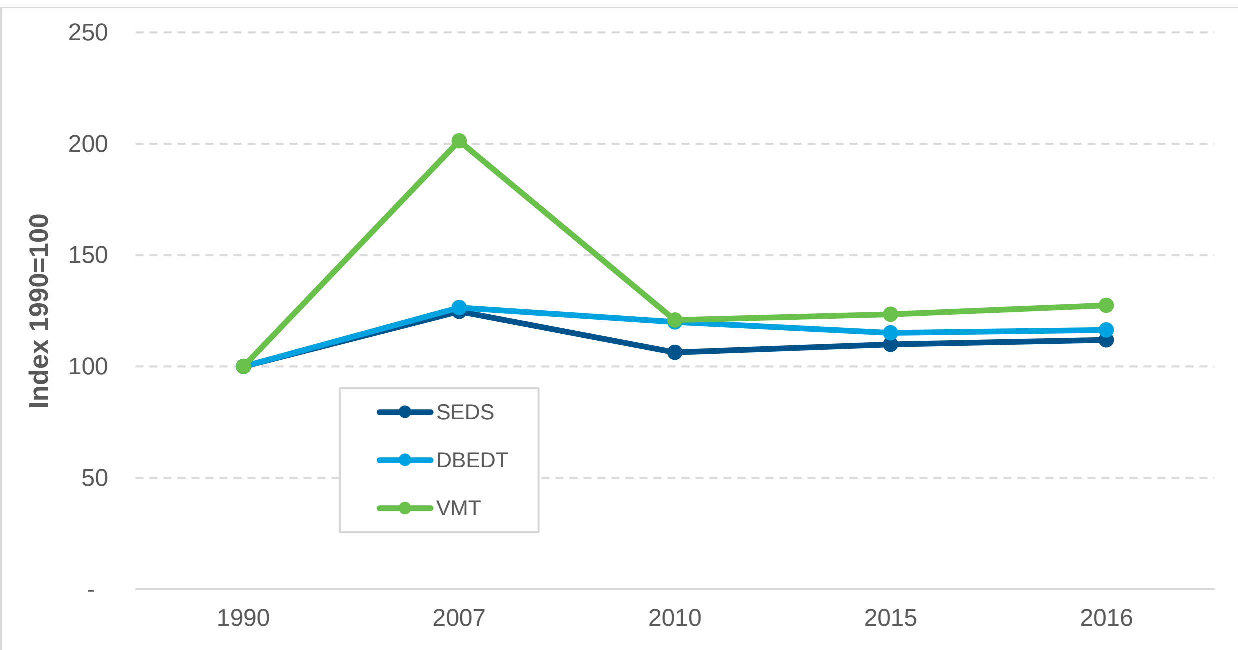
Source	Unit	1990	2007	2010	2015	2016
SEDS	Bbtu	44,500	55,500	47,300	48,900	49,800
DBEDT[a]	Bbtu	46,353	58,649	55,646	53,329	53,970
FHWA[b]	Million Miles	7,918	15,938	9,565	9,770	10,088

[a] Data collected by DBEDT.

[b] The miles shown represent miles traveled by gasoline-consuming vehicles, which are calculated by applying estimates of fuel use by vehicle type, obtained from the U.S. Inventory (EPA 2018a), to estimates of total VMT by vehicle type from FHWA. Gasoline-consuming vehicles primarily include passenger cars and light-duty trucks.

Note: Consumption values represent pure motor gasoline (excluding ethanol).

Figure C-8: Trend in VMT and Transportation Motor Gasoline Consumption Relative to 1990 (Index 1990=100)



Fuel consumption trends also depend on changes in the average fuel economy of gasoline-consuming vehicles over time. From 1990 to 2007 the sales-weighted fuel economy of new passenger cars and light-duty trucks varied marginally, ranging between roughly 19 to 21 miles per gallon (EPA 2019). However, from 2007 to 2016, the fuel economy of these vehicles increased from around 21 miles per gallon to around 25 miles per gallon as U.S. fuel economy standards were tightened (EPA 2019). In addition, ethanol mandates contribute to an increasing share of ethanol within motor gasoline from 2007 onwards, which also contributes to a decoupling between VMT and pure motor gasoline consumption.

Jet Fuel

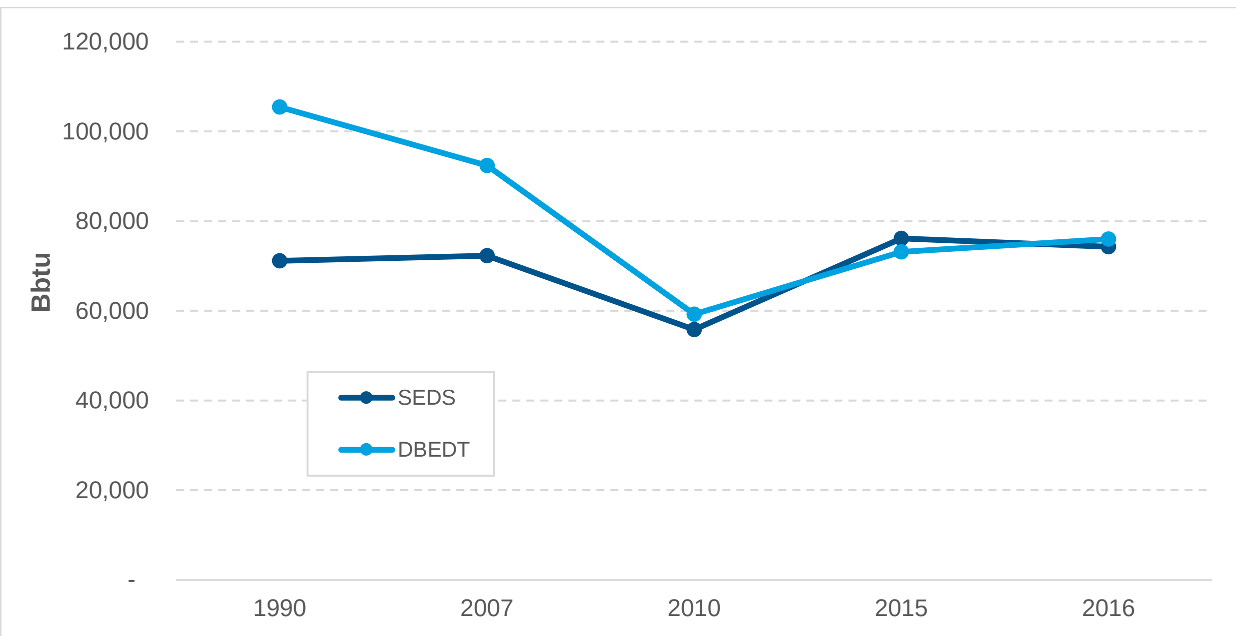
Data on jet fuel consumption in Bbtu for all inventory years were available from SEDS and collected by DBEDT. A summary of the consumption totals by end-use sector are presented in Table C-8. Consumption totals by year are graphically shown in Figure C-9. As shown, the DBEDT-collected and SEDS data show a similar trend and consumption levels for 2010, 2015, and 2016. For 1990 and 2007, the data collected by DBEDT shows much higher values.

Table C-8: Jet Fuel Consumption by Source and End-Use Sector for 1990, 2007, 2010, 2015 and 2016 (Bbtu)

End-Use Sector [a]	1990	2007	2010	2015	2016
SEDS					
Transportation	71,100	72,300	55,800	76,100	74,300
Energy Industries	0	0	0	0	0
Total	**71,100**	**72,300**	**55,800**	**76,100**	**74,300**
DBEDT					
Transportation	105,419	91,177	59,239	73,129	75,964
Energy Industries	0	1,224	0	0	0
Total	**105,419**	**92,401**	**59,239**	**73,129**	**75,964**

[a] Neither source reported consumption by the residential or energy industries sectors.

Figure C-9: Jet Fuel Consumption by Source for 1990, 2007, 2010, 2015 and 2016



Transportation

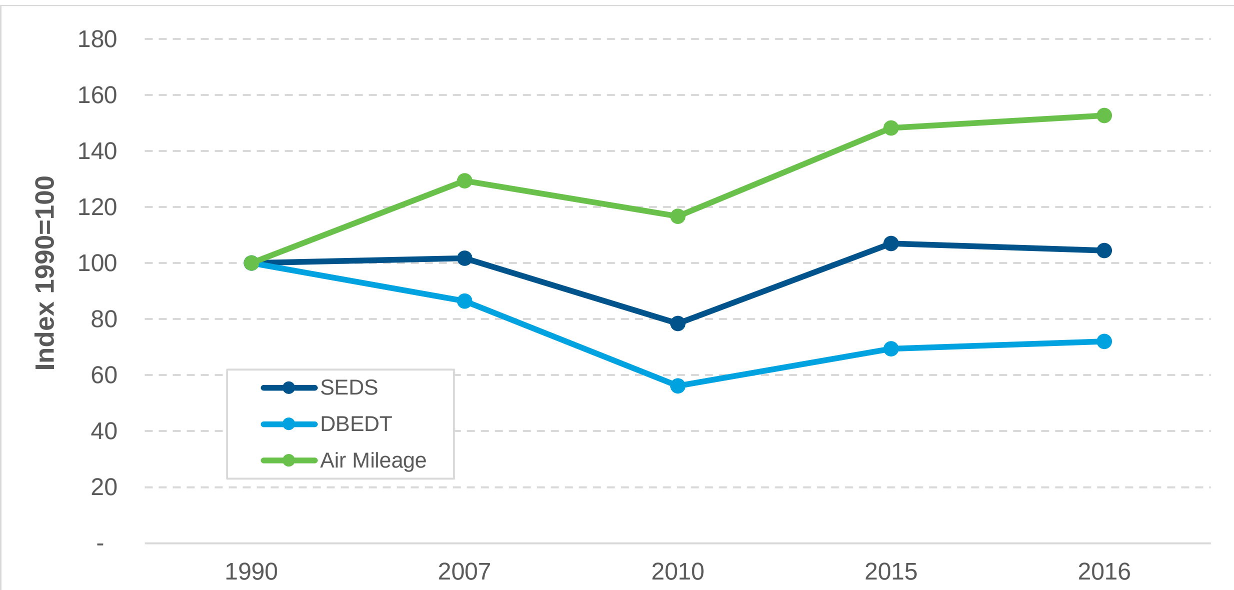
To further assess the sector-specific trends, jet fuel consumption for the transportation end-use was compared against trends in air mileage in Hawaii, as obtained from the U.S. DOT Bureau of Transportation Statistics (BTS) Transtats Database (DOT 2018). Table C-9 shows air mileage and jet fuel consumption for transportation by source for all inventory years. Figure C-10 shows the trend in air mileage and jet fuel consumption for transportation relative to 1990. As shown, from 1990 to 2007, air mileage increased, while SEDS data remained relatively flat and the data collected by DBEDT decreased. From 2007 through 2016, all three sources of data follow a similar trend.

Table C-9: Air Mileage and Transportation Jet Fuel Consumption by Source

Source	Unit	1990	2007	2010	2015	2016
SEDS	Bbtu	71,100	72,300	55,800	76,100	74,300
DBEDT[a]	Bbtu	105,419	91,177	59,239	73,129	75,964
BTS (Total)	**Miles**	**124,711,256**	**161,320,165**	**145,603,140**	**184,930,307**	**190,359,775**
Domestic	*Miles*	*77,518,903*	*120,578,107*	*108,287,767*	*126,046,426*	*130,151,515*
International	*Miles*	*47,192,353*	*40,742,058*	*37,315,373*	*58,883,881*	*60,208,260*

[a] Data collected by DBEDT.

Figure C-10: Trend in Air Mileage and Transportation Jet Fuel Consumption Relative to 1990 (Index 1990=100)



According to the International Council on Clean Transportation (ICCT), between 1968 and 2014, the average fuel consumption per passenger-km (or fuel burn) of new commercial aircraft decreased by 45 percent, or an annual reduction of about 1.3 percent. From 1980 to 1990, the average fuel burn of new aircrafts decreased by 2.6 percent, helping to explain the decoupling of air mileage and fuel consumption after 1990 as older aircrafts were retired and replaced with new aircrafts. More recently, new aircraft fuel efficiency gains have slowed to around 1 percent or less per year (ICCT 2014). Table C-10 presents the average annual fuel consumption gains of commercial aircrafts by decade.

Table C-10: Aircraft Fuel Consumption Annual Gains by Decade (fuel consumption per passenger-km)

Decade	1970-1980	1980-1990	1990-2000	2000-2010	2010-2014
Fuel Efficiency Gains	0.4%	-2.6%	-0.8%	-0.5%	-1.1%

Source: ICCT (2014).

Appendix D. Uncertainty

This section provides a summary of the methodology used to develop the quantitative uncertainty results as well as a discussion on limitations of the analysis. Consistent with the U.S. Inventory, and following the IPCC Chapter 3 Uncertainties guidelines (IPCC 2006), this inventory quantifies uncertainty for the current inventory year (i.e., 2016).

Methodology

Uncertainty analyses are conducted to qualitatively evaluate and quantify the uncertainty associated with GHG emission and sink estimates. Quantitative uncertainty analyses capture random errors based on the inherent variability of a system and finite sample sizes of available data, measurement error, and/or uncertainty from expert judgement (IPCC 2006). Systematic errors from models, measurement techniques, and data recording and interpretation are difficult to quantify and are therefore more commonly evaluated qualitatively (IPCC 2006). The results of an uncertainty analysis serve as guidance for identifying ways to improve the accuracy of future inventories, including changes to activity data sources, data collection methods, assumptions, and estimation methodologies.

The IPCC provides good practice guidance on two methods for estimating uncertainty for individual source categories (i.e., Approach 1 and Approach 2). Approach 1 is appropriate where emissions or sinks are estimated by applying an emission factor to activity data or by summing individual sub-source or sink category values to calculate an overall emissions estimation. Approach 2 is appropriate for more complex calculations and employs the Monte Carlo Stochastic Simulation technique and is more reliable than Approach 1. It is useful for input variables that are particularly large, have non-normal distributions, and are correlated with other input variables. Approach 2 is also appropriate if a sophisticated methodology or multiple input variables are used for the emissions estimation, as was the case for the sources estimated in this inventory.

For this inventory report, Approach 2 was applied to quantify uncertainty for all source categories in accordance with the *2006 IPCC Guidelines* (IPCC 2006). Under this method, GHG emissions (or sinks) for each source category are estimated by generating randomly-selected values according to the specified probability density function (PDF)[64] for each of the constituent input variables (e.g., activity data, emission factor) 10,000 times using @RISK, a commercially-available simulation software. The results of this methodology are presented as an overall emission (or sinks) PDF for each source category. The quantified uncertainties for each source category were then combined using Approach 2 to provide uncertainty estimates at the sector level as well as for the overall net and total emissions for the current inventory year.

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[64] The PDF, which is dependent upon the quality and quantity of applicable data, describes the range and likelihood of possible values for constants and estimates that are not exactly known (IPCC 2006).

Consistent with the U.S. Inventory, this inventory quantifies uncertainty for the current inventory year (i.e., 2016). Although uncertainty was not quantified for other inventory years, the uncertainty range relative to emission estimates across all inventory years are expected to be similar to those quantified for 2016. Similarities in quantitative uncertainties are expected because, in most cases, particularly for those that contribute the most to overall emissions, the same methodologies and data sources were used for all years. As a result of time series consistency, any future changes in the estimates will likely affect results similarly across all years.

Limitations of the Analysis

The uncertainty analysis results presented in this report reflect an IPCC Approach 2 Monte Carlo Uncertainty analysis that was completed for the first time for the Hawaii inventory. The IPCC publishes uncertainty information for most emission factors and some activity data (e.g., level of uncertainty associated with stationary combustion activity data), but most activity data uncertainty must be provided by the original data source.

Developing this analysis required a review of original data sources as well as outreach and collaboration with all data providers to establish uncertainty bounds for each of the input parameters. In cases where uncertainties have already been assessed for certain activity data, PDFs for these input parameters are derived using this information. If this information was not published, data providers were contacted. If data providers were unable to provide a quantitative measure of uncertainty for their data, PDFs were built around the input parameters using qualitative responses from data providers, default values provided by IPCC, and/or expert judgement based on ICF's experience in developing uncertainty bounds for the U.S. inventory of GHG emissions and sinks in accordance with the *2006 IPCC Guidelines* (IPCC 2006).

While this uncertainty analysis quantified parameter uncertainty, which arises due to a lack of precision and/or accuracy in input data such as emission factors and activity data, it did not quantify model-based uncertainty, which arises when emission/sink estimation models do not fully or accurately characterize the emission/sink process due to a lack of technical details or other resources. Model based uncertainty is extremely difficult to quantify given, in most cases, only a single model has been developed to estimate emissions from any one source. Nonetheless, these uncertainties are discussed qualitatively, where appropriate, for each emission source and sink category in the subsequent sections of this report. Confidence in the uncertainty analysis results will improve over time as gaps in understanding and quantifying the uncertainty for additional data sources are addressed.

This uncertainty analysis is specific to the methods and data used for this report and is independent from those used in previous reports. These estimates consider the inherent uncertainty associated with these methodologies and data and their ability to accurately and precisely describe the activities within the scope of the inventory. While the uncertainty analysis is a useful tool for identifying areas for improvement in an inventory, the uncertainty analysis should not be used to quantitatively compare changes observed between inventory reports where data sources and methods may have been revised.

Appendix E. County Emissions Methodology

This section summarizes the methodology used to quantify Hawaii's GHG emissions by county. The methodology used varies by emissions source, depending on data availability. For some sources, county-level activity data were available to build bottom-up county level emissions estimates. For other sources, only state-level activity data were available, requiring emissions to be allocated to each county using proxy information such as population and VMT data.

County emissions estimates were developed using the best data available at the time of this report. GHG emissions estimates from inventories prepared at the county level by other organizations may differ from those in this report due to differences in data sources, boundaries, or other assumptions. Should additional data become available, the methodology described here will be revised for future inventories.

Energy

Stationary Combustion

County-level stationary combustion emissions estimates were calculated for each economic sector using a combination of disaggregated state-level emission estimates and/or county-level activity data, based on the availability and reliability of data for each source category and inventory year. Results for each economic sector were then summed to calculate total county-level stationary combustion emissions.

Emissions for the energy industries and industrial sectors for 2010, 2015, and 2016 were calculated using the methodology described in Section 3.1 and allocated to each county based on county-level emission breakdowns calculated from GHGRP data (EPA 2018b). The county breakdowns from GHGRP were revised to allocate naphtha emissions to the industrial sector rather than the energy industries sector in alignment with EIA SEDS methodology. The emission breakdowns also include revised emissions from the AES facility, using SEDS energy consumption by state data.

Emissions for the energy industries sector for 1990 and 2007 were calculated using the methodology described in Section 3.1 and allocated to each county by county population data from DBEBT (2018a). Emissions for the industrial sector for 1990 and 2007 were calculated using the methodology described in Section 3.1. GHGRP facility level emissions data were unavailable for the years 1990 and 2007. Therefore, total sector emissions were allocated to each county for 1990 and 2007 by applying the 2010 county allocations derived from GHGRP facility level emissions data (EPA 2018b).

Residential and commercial sector emissions for all inventory years were calculated using the methodology described in Section 3.1 and allocated to each county by population data from DBEDT (2018a).

Transportation

Ground transportation emissions for 2007, 2010, 2015, and 2016 were calculated using the methodology described in section 3.2 and allocated to each county based on motor vehicle registration data from DBEDT data book (DBEDT 2018d). For 1990 ground transportation emissions, 1990 motor vehicle registration data were unavailable. Therefore, 2007 motor vehicle registration data were used to allocate 1990 ground transportation emission to each county.

Emissions from domestic marine, military aviation, and military non-aviation transportation were allocated solely to Honolulu based on available DBEDT data (DBEDT 1990, DBEDT 2007) which indicate that over 99% of fuel consumption in the military and water transportation sectors occur in Honolulu. Emissions from domestic aviation transportation were calculated using the methodology described in Section 3.2 and allocated to each county based on domestic BTS flight data (DOT 2018).

Incineration of Waste

Hawaii's two waste incineration facilities, Waipahu and HPOWER, are both in Honolulu County; therefore, total emissions from the incineration of waste were allocated to Honolulu County, calculated using the methodology described in Section 3.3.

Oil and Natural Gas Systems

Hawaii's two oil and natural gas facilities, Island Energy Services and Par Hawaii, are both in Honolulu County; therefore, total emissions from oil and natural gas systems were allocated to Honolulu County, calculated using the methodology described in Section 3.4.

IPPU

Cement Production

All process emissions from cement production in 1990 occurred within Honolulu County.

Electrical Transmission and Distribution

Emissions were calculated by apportioning U.S. emissions from this source to each island based on the ratio of the island's electricity sales to U.S. electricity sales. Estimates of national SF_6 emissions data were taken from the U.S. Inventory (EPA 2018a). National electricity sales data come from the EIA (2018c). Hawaii electricity sales data by island come from the State of Hawaii Data Book (DBEDT 2018d). Island-level data was aggregated by county to estimate county-level emissions.

Substitution of Ozone Depleting Substances

Emissions from mobile air-conditioning systems were estimated by apportioning national emissions from the U.S. Inventory (EPA 2018a) to each county based on the ratio of the county's vehicle registrations from the State of Hawaii Data Book (DBEDT 2018d) to U.S. vehicle registrations from the

U.S. Department of Transportation, Federal Highway Administration (FHWA 2017). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2018a) were apportioned to each county based on the ratio of the county's population from DBEDT (2018c) to U.S. population from the U.S. Census Bureau (2018).

AFOLU

Enteric Fermentation

County-level population data for total cattle, beef cattle and swine were obtained from USDA NASS. The years with county-level data available for these animal types varied based on the animal type and county, with 2010 being the most recent year that county-level data were available. Population estimates for years and animal types with no data were estimated based on state-level data. Emissions were calculated based on population data using the methodology described in Section 5.1.

County-level population data for sheep, goats and horses were obtained from the USDA Census of Agriculture, which is compiled every five years. For years without population data, population data were extrapolated or interpolated based on available data. Emissions were calculated based on population data using the methodology described in Section 5.1.

Manure Management

County-level population data for total cattle, beef cattle and swine were obtained from USDA NASS. The years with county-level data available for these animal types varied widely based on the animal type and county, with 2010 being the most recent year that county-level data were available. Population estimates for years and animal types with no data were estimated based on state-level data. Emissions were calculated based on population data using the methodology described in Section 5.2.

County-level population data for sheep, goats and horses were obtained from the USDA Census of Agriculture, which is compiled every five years. For years without population data, population data extrapolated or interpolated based on available data. Emissions were calculated based on population data using the methodology described in Section 5.2.

Agricultural Soil Management

County-level annual sugarcane area and production estimates for years 1990 to 2007 and 2017 were obtained directly from USDA NASS. Between 2007 and 2017, county-level data were estimated based on the average proportion of county-level area (or production) to state-level area (or production) for sugarcane over the full time series. For other crops (i.e., pineapples, sweet potatoes, ginger root, taro and corn for grain), county-level data were obtained from the USDA Census of Agriculture, which is compiled every five years. For crops for which an average proportion was not available due to limited years of data, the ratio of county-level data to state-level data in 2017 (or the most recent year available) was used. Emissions from country-level crop data were estimated using the methodology described in Section 5.3.

State-level synthetic and organic fertilizer N application data were allocated to each county based on percent cropland by county by year. Agricultural land use by county was obtained from ALUM (2015) for year 1992 and the University of Hawaii (2016) for year 2015. Agricultural land use by county for years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and year 2016 was proxied to 2015. Emissions were then estimated using the methodology described in Section 5.3.

Animal population data were used to calculate the N inputs to agricultural soils from pasture, range, and paddock manure from all animals. County-level population data for total cattle, beef cattle and swine were obtained from USDA NASS. The years with county-level data available varied widely based on the animal type and county, with 2010 being the most recent year that county-level data were available. County-level population estimates for years and animal types with no data were estimated based on state-level data. County-level population data for sheep, goats and horses were obtained from the USDA Census of Agriculture, which is compiled every five years. For years without population data, population data were extrapolated or interpolated based on available data. Emissions were calculated based on population data using the methodology described in Section 5.3.

Field Burning of Agricultural Residues

County-level annual sugarcane area and production estimates for years 1990 to 2007 were obtained directly from USDA NASS. After 2007, county-level data were estimated based on the relative proportion of available county-level to state data. Emissions were then estimated using the methodology described in Section 5.4.

Urea Application

State-level urea fertilizer application data were allocated to each county based on the percent of cropland area by county by year. Agricultural land use by county was obtained from ALUM (2015) for year 1992 and the University of Hawaii (2015) for year 2015. Agricultural land use by county for years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and year 2016 was proxied to 2015. Emissions were then estimated using the methodology described in Section 5.5.

Agricultural Soil Carbon

Emissions from agricultural soil carbon were estimated using the methodology described in Section 5.6 and allocated to each county based on the percent area of cropland and percent area of grassland by county by year. Agricultural land use by county was obtained from ALUM (2015) for year 1992 and the University of Hawaii (2015) for year 2015. Agricultural land use by county for years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and year 2016 was proxied to 2015.

Forest Fires

Emissions from forest fires were estimated using the methodology described in Section 5.7 and allocated to each county based on the share of forest and shrubland area in each county relative to total forest and shrubland area in the state (DBEDT 2018c, NOAA-CCAP 2000, Selmants et al. 2017).

Landfilled Yard Trimmings and Food Scraps

Carbon sequestration in landfilled yard trimmings and food scraps were estimated using the methodology described in Section 5.8 and allocated to each county based on the ratio of county population to state population (DBEDT 2018c).

Urban Trees

Urban tree cover by county was estimated based on urbanized area and cluster data in 1990, 2000, and 2010 from the U.S. Census and percent tree cover in Honolulu and throughout the state. Census-defined urbanized areas and clusters were mapped to their respective county to establish county-level urban area estimates. Then, county-level urban area estimates were interpolated and extrapolated throughout the time series based on available data, as described in Section 5.9. The time series of Honolulu-specific percent tree cover in urban areas (MacFaden et al. 2016; Nowak et al. 2012), described in Section 5.9, was applied to urban area in Honolulu to obtain urban tree cover, while the time series of state-level percent tree cover in urban areas (Nowak et al. 2012, 2018a, 2018b) was applied to urban areas for all counties except Honolulu. CO_2 sinks were calculated based on urban tree cover and Hawaii-specific sequestration rates, as described in Section 5.9.

Forest Carbon

Carbon sequestration in forests and shrubland were estimated using the methodology described in Section 5.10 and allocated to each county based on forest and shrubland area data by island from DBEDT (2018c). County-level emissions estimates were then calculated as the sum of each island in the county. CO_2 sinks were calculated using Hawaii-specific forest and shrubland sequestration rates (Selmants et al. 2017), as described in Section 5.10.

Waste

Landfills

Landfill emissions were calculated for each island using the methodology described in Section 6.1; county-level emissions estimates were calculated as the sum of each island in the county.

Composting

Composting emissions were calculated based on the U.S. national average per capita composting rate for each inventory year in the U.S. Inventory (EPA 2018a) and MSW composting volumes for each county were calculated using population data from the State of Hawaii Data Book (DBEDT 2018d).

Wastewater Treatment

Wastewater treatment emissions were calculated for each island using the methodology described in Section 6.3; county-level emissions estimates were calculated as the sum of each island in the county.

Appendix F. 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.[65] 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 2018b), Table F-1 summarizes annual GHG emissions from HAR affected facilities for 2010 to 2016. Table F-2 summarizes projected GHG emissions for the HAR affected facilities for 2020 and 2025. These tables include 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.

HAR Facility Projections

Methodology: For the HEI electric power plants, data were taken directly from the PSIP E3 with Grid Modernization Plan (PUC 2016; DCCA 2017).[66] Emissions for KIUC's affected facilities reflect the total GHG emissions estimates for KIUC (2019) distributed among Port Allen and Kapaia Generating Stations based on the average ratio of emissions from 2016-2020 as presented in KIUC's 2016 GHG Emissions Reduction Plan (KIUC 2016). Emissions for the two petroleum refineries were projected forward using the same methodology described in Appendix K. These emissions were distributed to each of the refineries using the 2016 breakout of emissions.

Uncertainties: HECO and Independent Power Producers have elected to meet the 2020 emissions cap on their affected facilities by a partnership wide emissions cap. By doing so they are proposing a total partnership emissions cap of 6.23 MMT CO_2 Eq. This combined emissions cap would allow each HAR facility to exceed the individual cap of 16 percent below 2010 emissions as long as the company or partnership wide emissions cap is not exceeded. It is thus likely that the distributions of emissions presented for HAR facilities in Table F-2 could change.

Due to this uncertainty, the facility-specific emission projections were not adjusted to account for revisions to future renewable energy capacity, as described in Section 3.1, which are estimated to lead to additional emissions of 0.77 MMT CO_2 Eq. in 2020 and 1.22 MMT CO_2 Eq. in 2025. As shown in Table F-2, current projections indicate that emissions from the affected facilities will be lower than the aggregated emissions cap. Therefore, it is anticipated that the affected facilities will be able to absorb the 0.77 MMT CO_2 Eq. while still meeting the requirements of the rule. How these emissions will be absorbed remains unknown.

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[65] Hawaii Administrative Rules, Chapter 11-60.1, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.
[66] Though the Palaau unit is not reported in the PSIP (2016), the plan states that this unit will be converted to biofuels prior to 2020.

Table F-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	2016
AES Hawaii, Inc.[a]	Energy Industries (1A1ai)	1.50	1.41	1.48	1.33	1.52	1.39	1.55
Hamakua Energy Partners	Energy Industries (1A1ai)	0.17	0.13	0.14	0.10	0.11	0.13	0.09
Hawaiian Commercial & Sugar Company[b]	Industrial (1A2)	0.14	0.13	0.12	0.15	0.14	0.12	0.04
HELCO Kanoelehua Hill Generating Station	Energy Industries (1A1ai)	0.20	0.19	0.17	0.17	0.17	0.18	0.23
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.17	0.18	0.15	0.19	0.21	0.21	0.21
HELCO Shipman Generating Station[c]	Energy Industries (1A1ai)	NE	NE	NE	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
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.97	0.88	0.86	0.86	0.88	1.01	0.80
HECO Kahe Generating Station	Energy Industries (1A1ai)	2.52	2.63	2.41	2.22	2.13	2.02	2.03
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	NO	+	+	+	+	+	+
HECO Honolulu Generating Station[d]	Energy Industries (1A1ai)	0.12	0.10	0.05	0.06	+	NO	NO
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[e]	Energy Industries (1A1ai)	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	0.85
Kauai Island Utility Co. Kapaia Power Station	Energy Industries (1A1ai)	0.13	0.12	0.13	0.12	0.13	0.12	0.11
Kauai Island Utility Co. Port Allen Generating Station	Energy Industries (1A1ai)	0.15	0.15	0.14	0.14	0.13	0.12	0.08
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.21	0.19	0.18	0.13	0.14	0.11	0.14
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.56	0.55	0.52	0.49	0.46	0.49	0.48
MECO Palaau Generating Station	Energy Industries (1A1ai)	0.03	0.03	0.02	0.02	0.02	0.02	0.02
Island Energy Services Refinery[f]	Energy Industries (1A1b)	0.34	0.35	0.34	0.30	0.32	0.33	0.31
	Oil and Natural Gas (1B2)	0.19	0.21	0.23	0.16	0.21	0.18	0.19
Par Hawaii Refinery[f]	Energy Industries (1A1b)	0.44	0.45	0.41	0.26	0.43	0.44	0.43
	Oil and Natural Gas (1B2)	0.12	0.13	0.12	0.07	0.13	0.11	0.01
Energy Industries Subtotal[g]		**8.55**	**8.45**	**8.00**	**7.46**	**7.62**	**7.56**	**7.35**
Industrial Subtotal[g]		**0.14**	**0.13**	**0.12**	**0.15**	**0.14**	**0.12**	**0.04**
Oil and Natural Gas Subtotal		**0.20**	**0.21**	**0.23**	**0.16**	**0.21**	**0.19**	**0.19**
Total		**8.90**	**8.79**	**8.35**	**7.77**	**7.98**	**7.87**	**7.59**

[a] Due to calibration issues on emissions monitoring equipment at the facility that were reported to GHGRP, AES Hawaii emissions were recalculated based on SEDS energy industries coal consumption data and a site-specific emission factor provided by DOH.
[b] The Hawaiian Commercial & Sugar Company plant closed in December 2016.
[c] The HELCO Shipman Generating Station was deactivated in 2012 and closed in 2014. Emissions data for 2010-2012 was not available from GHGRP.
[c] The HECO Honolulu Generating Station closed in January 2014.
[e] The Hu Honua Bioenergy, LLC Pepeekeo Power Plant is currently under development.
[f] 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.
[g] Sector subtotals presented in this table, which are based on GHGRP facility-level data, differ from the estimates by end-use sector presented in this inventory report, which are based largely on SEDS sector-specific fuel consumption data. The differences are a result of differences in how SEDS allocates its data by end-use sector. In addition, the data in this table only represent emissions from HAR facilities and may not represent total statewide emissions.
+ 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.

Table F-2: Projected HAR Affected Facility Emissions (excluding biogenic CO_2 emissions) (MMT CO_2 Eq.)

HAR Affected Facility	Inventory Sector (IPCC Source Category)	2020	2025	2020 Cap	Difference
AES Hawaii, Inc.	Energy Industries (1A1ai)	1.51	NO	1.53	0.02
Hamakua Energy Partners	Energy Industries (1A1ai)	0.16	0.11	0.14	(0.02)
Hawaiian Commercial & Sugar Co.	Industrial (1A2)	NO	NO	NA	NA
HELCO Kanoelehua Hill Generating Station	Energy Industries (1A1ai)	+	+	0.16	0.16
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.13	0.07	0.22	0.09
HELCO Shipman Generating Station	Energy Industries (1A1ai)	NO	NO	NA	NA
HELCO Puna Generating Station	Energy Industries (1A1ai)	0.02	0.02	0.03	0.01
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.67	0.21	0.73	0.07
HECO Kahe Generating Station	Energy Industries (1A1ai)	1.16	0.31	1.94	0.77
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	0.01	0.01	0.05	0.04
HECO Honolulu Generating Station	Energy Industries (1A1ai)	NO	NO	NA	NA
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[a]	Energy Industries (1A1ai)	NO	NO	NA	NA
Kalaeloa Cogeneration Plant	Energy Industries (1A1ai)	0.95	1.06	0.99	0.05
KIUC Kapaia Power Station	Energy Industries (1A1ai)	0.08	0.07	0.14	0.05
KIUC Port Allen Generating Station	Energy Industries (1A1ai)	0.04	0.03	0.09	0.05
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.10	+	0.14	0.04
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.40	0.24	0.42	0.02
MECO Palaau Generating Station[b]	Energy Industries (1A1ai)	NO	NO	0.02	0.02
Island Energy Services Refinery[c]	Energy Industries (1A1b)	0.32	0.29	NA	NA
	Oil and Natural Gas (1B2)	0.19	0.17	NA	NA
Par Hawaii Refinery[c]	Energy Industries (1A1b)	0.44	0.40	NA	NA
	Oil and Natural Gas (1B2)	0.01	0.01	NA	NA
TBD[d]	*Energy Industries (1A1b)*	*0.77*	*1.22*	*NA*	*NA*
Energy Industries Subtotal[e]		**5.95**	**2.82**	**6.60**	**1.37**
Industrial Subtotal[e]		**NO**	**NO**	**NA**	**NA**
Oil and Natural Gas Subtotal		**0.19**	**0.18**	**NA**	**NA**
Total		**6.96**	**4.24**	**6.60**	**1.37**

[a] Once Hu Honua Bioenergy, LLC Pepeekeo Power Plant becomes operational, emissions are expected to not occur because the plant will use biomass as its fuel source.

[b] Emissions for the MECO Palaau Generating Station are not estimated in the PSIP but an assumption of no emissions was made based on the PSIP long term plan for Molokai, which assumes that all facilities that burn fossil fuel will convert to biodiesel in the year 2020. This may, however, be a blend.

[c] 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.

[d] Represents additional emissions that are estimated to result from revisions to the PSIP. These emissions have not been distributed among the HAR facilities due to uncertainty in how these emissions will be absorbed.

[e] Subtotals shown above, which are based on facility-level data, differ from the projections by end-use sector presented in this report, which were adjusted to ensure consistency with how SEDS allocates its data by end-use sector. In addition, the data only represent emissions from HAR facilities and may not represent total statewide emissions.

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

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

Appendix G. Activity Data

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

Energy

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

Sector/Fuel Type	1990	2007	2010	2015	2016
Residential					
Diesel Fuel	2	19	1	2	0
Propane	217	479	918	504	690
Natural Gas	605	528	529	562	560
Wood and Waste	0	172	298	295	237
Commercial					
Diesel Fuel	2,636	1,629	1,528	1,299	905
Motor Gasoline[a]	310	60	58	1,453	1,474
Propane	358	856	2,038	2,316	2,324
Residual Fuel	5,189	3	0	0	0
Natural Gas	2,378	1,904	1,848	1,874	1,889
Ethanol	0	2	3	111	112
Wood and Waste	0	2,350	2,945	3,234	3,786
Other Fuels[b]	1	0	0	0	0
Industrial[c]					
Coal	692	1,776	1,400	1,119	267
Diesel Fuel	4,195	2,568	1,873	1,843	935
Motor Gasoline[a]	701	1,219	686	1,336	1,321
Propane	16	43	25	4	6
Residual Fuel	10,942	2,690	2,834	1,876	2,565
Natural Gas	0	521	353	434	532
Ethanol	0	37	40	102	100
Wood and Waste	18,159	5,447	4,392	3,169	3,360
Other Fuels[b]	1	0	0	0	0
Energy Industries					
Coal	26	15,313	15,702	14,495	16,160
Diesel Fuel[e]	9,747	13,377	12,976	12,310	11,746
Residual Fuel[e]	77,780	71,832	65,157	54,987	53,197
Natural Gas[e]	2	0	0	0	0
Fuel Gas[d]	0	1,763	2,601	3,943	3,285
Biodiesel[f]	0	0	0	1,223	954
Wood and Waste	7,765	0	40	853	1,076

Sector/Fuel Type	1990	2007	2010	2015	2016
Other Fuels[b, e]	(2,905)	573	241	(148)	67

[a] The motor gasoline consumption totals by end-use sector, as provided by SEDS, include ethanol blended into motor gasoline. Ethanol was subtracted from the motor gasoline totals and is presented separately in the table.
[b] Other fuels include asphalt and road oil, butane, kerosene, lubricants, waxes, aviation gasoline blending components, aviation gasoline blending components and unfinished oils.
[c] Non-energy use consumption is excluded from the totals based on the assumptions presented in Table G-3.
[d] Fuel Gas data were obtained from EPA's GHGRP (EPA 2018b) for 2010, 2015, and 2016 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 2018a).
[e] The 1990 data was adjusted to account for the inaccurate inclusion of diesel and residual fuel consumption at the Kalaeloa facility in the SEDS data as well as consumption of butane and syngas at the facility (HECO 1991).
[f] Biodiesel data were obtained from EPA's GHGRP (EPA 2018b) for 2015 and 2016 and were only available in MMT CO_2 Eq. Fuel consumption in Bbtu was estimated by back-calculating emissions using the corresponding biodiesel emissions factor from the U.S. Inventory (EPA 2018a).
Note: Totals may not sum due to independent rounding.
Sources: EIA (2018a); EPA (2018a); EPA (2018b); HECO (1991).

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

Mode/Fuel Type	1990	2007	2010	2015	2016
Aviation[a]					
Aviation Gasoline	1,375	206	188	45	31
Jet Fuel Kerosene[b]	32,208	47,590	36,515	45,657	44,719
Ground[a]					
Diesel Fuel[c]	9,674	16,096	9,617	6,604	6,037
Motor Gasoline[d]	39,916	55,445	47,180	49,126	49,935
Propane	49	48	25	16	14
Natural Gas	0	3	2	2	2
Ethanol	0	1,699	2,745	3,769	3,788
Biodiesel[e]	0	0	707	381	454
Marine[a]					
Diesel Fuel[c]	4,624	9,350	3,760	3,083	3,430
Motor Gasoline[d]	18	35	31	32	33
Residual Fuel[f]	15,422	27,644	3,987	4,147	4,787
Military Aviation					
Aviation Gasoline	0	0	+	+	+
Jet Fuel Kerosene[b]	1,449	8,659	6,677	9,109	8,895
Naphtha[g]	17,786	0	0	0	0
Military Non-Aviation					
Diesel Fuel[c]	4,929	10,428	6,738	669	2,202
Motor Gasoline	4,597	0	0	0	0
Residual Fuel[f]	806	0	0	0	0

+ Does not exceed 0.5 Bbtu

[a] International bunker fuels and non-energy use consumption are excluded from the totals based on the assumptions and data presented in Table G-3, Table G-5, and Table G-6.
[b] SEDS jet fuel consumption was apportioned between aviation and military aviation based on the breakout of the data collected by DBEDT (2008a) into military aviation and non-military aviation. For 1990, a portion of jet fuel consumption was allocated to military aviation naphtha consumption based on communication with EIA (2019c).
[c] SEDS diesel consumption was apportioned between ground, marine, and military non-aviation based on the breakout of the data collected by DBEDT (2008a) by end-use sector. Biodiesel consumption data collected by DBEDT (2018a and 2018b) was subtracted from the SEDS diesel total as the SEDS data includes biodiesel.
[d] The motor gasoline consumption totals by end-use sector, as provided by SEDS, include ethanol blended into motor gasoline. Ethanol was subtracted from the motor gasoline totals and is presented separately in the table.
[e] Biodiesel data was collected by DBEDT (2018a and 2018b).
[f] 1990 residual fuel data from SEDS were apportioned between marine and military non-aviation based on military residual fuel data obtained from EIA Fuel Oil and Kerosene Sales (EIA 2019e).
[g] Military aviation naphtha consumption was obtained from direct communication with EIA (2019a).
Note: Totals may not sum due to independent rounding.
Sources: EIA (2018a); EIA (2019c); EIA (2019e); DBEDT (2018a and 2018b).

Table G-3: Share of Consumption Used for Non-Energy Uses

Fuel Type	1990	2007	2010	2015	2016
Industrial					
Coal	0%	1%	1%	1%	2%
Asphalt and Road Oil	100%	100%	100%	100%	100%
Propane	71%	79%	86%	84%	82%
Lubricants	100%	100%	100%	100%	100%
Diesel Fuel	1%	1%	1%	1%	1%
Transportation					
Lubricants	100%	100%	100%	100%	100%

Source: EPA (2018h).

Table G-4: Non-Energy Use Consumption (Bbtu)

Fuel Type	1990	2007	2010	2015	2016
Industrial					
Coal	3	19	15	17	4
Diesel Fuel	27	38	10	10	6
Propane	39	162	161	24	30
Other Fuels[a]	2,652	169	5,323	4,405	2,903
Aviation					
Other Fuels[a]	214	185	214	210	194
Ground Transportation					
Other Fuels[a]	187	162	188	184	170
Marine Transportation					
Other Fuels[a]	61	53	61	60	56

[a] Other fuels include asphalt and road oil, lubricants, and waxes.
Sources: EIA (2018a), EPA (2018h).

Table G-5: Mileage Data Used to Apportion Jet Fuel Data to International Bunker Fuels

Aviation Miles	1990	2007	2010	2015	2016
International Miles	47,192,353	40,742,058	37,315,373	58,883,881	60,208,260
Domestic Miles	77,518,903	120,578,107	108,287,767	126,046,426	130,151,515
International Miles Share	38%	25%	26%	32%	32%
Domestic Miles Share	62%	75%	74%	68%	68%

Note: Mileage data are from flights originating in Hawaii. Flights with a destination within Hawaii or to the mainland U.S. are considered domestic while flights with an international destination are considered international.
Source: DOT (2018).

Table G-6: International Bunker Fuel Consumption by Fuel Type, Mode, and Year (Bbtu)

Mode/Fuel Type	1990	2007	2010	2015	2016
Aviation[a]					
Jet Fuel Kerosene	19,608	16,080	12,583	21,329	20,687
Marine[b]					
Diesel Fuel	1,146	251	2,398	1,084	442
Residual Fuel	475	425	2,769	247	304

[a] Calculated based on domestic and international flight mileage data from DOT (2018).
[b] Obtained directly from the Census Bureau (DOC 2008 and 2018). Data are provided in barrels, then converted to gallons using a conversion factor of 42 gallons per barrel before being converted to Bbtu using a conversion factor of 0.000139 Bbtu per gallon. For 1990, marine bunker fuel consumption was estimated based on the ratio Hawaii consumption to total U.S. consumption in 2006 (the earliest year data is available for Hawaii marine bunker fuel). National marine bunker fuel consumption was obtained from the U.S. Inventory (EPA 2018a).
Note: Totals may not sum due to independent rounding.
Source: EIA (2018a), DOT (2018), DOC (2008), DOC (2018), EPA (2018a).

IPPU

Table G-7: Clinker production by Year (MT)

	1990	2007	2010	2015	2016
Clinker Production	195,044	0	0	0	0

Source: Wurlitzer (2008).

Table G-8: Electricity Sales by Year (MWh)

	1990	2007	2010	2015	2016
Hawaii	8,310,537	10,585,037	10,013,104	9,388,577	9,284,424
U.S.	2,712,554,665	3,764,560,712	3,754,841,368	3,758,992,390	3,762,461,630

Sources: EIA (2018) (U.S.); DBEDT (2018c) (Hawaii).

Table G-9: Registered Vehicles by Year

	1990	2007	2010	2015	2016
Hawaii	870,657	1,103,782	1,086,185	1,193,863	1,194,727
U.S.	188,170,927	246,430,169	241,214,494	254,120,376	259,143,542

Sources: FHWA (2017) (U.S.); DBEDT (2018c) (Hawaii).

Table G-10: U.S. GHG Emissions by Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016
Cars and Trucks A/C ODS Substitutes	0	71.5	68.7	47.7	44.8
Other ODS Substitutes	0.3	45.2	71.3	108.4	114.4
Electrical Transmission and Distribution	23.1	6.2	5.9	4.3	4.3

Source: EPA (2018a).

AFOLU

Table G-11: Animal Population by Animal Type, Year (Head)

Animal Type	1990	2007	2010	2015	2016
Cattle	**205,000**	**158,000**	**151,000**	**133,000**	**140,000**
Dairy Cattle	**19,174**	**5,013**	**2,930**	**3,355**	**3,347**
Dairy Cows	11,000	3,800	1,800	2,200	2,200
Dairy Replacement Heifers	6,000	1,000	1,000	1,000	1,000
Other Dairy Heifers	2,174	213	130	155	147
Beef Cattle	**185,826**	**152,987**	**148,070**	**129,645**	**136,653**
Beef Cows	75,000	85,200	81,200	68,800	72,800
Beef Replacement Heifers	16,000	15,000	12,000	11,000	11,500
Other Beef Heifers	14,826	4,787	5,870	4,845	4,853
Steers	26,000	8,000	8,000	9,000	9,500
Calves	49,000	35,000	36,000	32,000	34,000
Bulls	5,000	5,000	5,000	4,000	4,000
Sheep and Lambs	**22,526**	**22,376**	**22,103**	**22,923**	**23,080**
Goats	**192**	**863**	**1,000**	**1,301**	**1,361**
Swine	**36,000**	**15,000**	**12,500**	**9,000**	**10,000**
Horses and ponies	**3,770**	**6,547**	**5,687**	**5,737**	**5,739**
Chickens	**1,183,000**	**398,000**	**366,000**	**272,964**	**257,413**

Sources: USDA (2018a, 2018b, 2018c) (cattle, swine, and chicken); USDA (1989, 1994, 2009, and 2014) (sheep, goats, and horses).

Table G-12: Crop Area by Crop Type, Year (Acres)

Crop Type	1990	2007	2010	2015	2016
Sugarcane for sugar	72,000	20,400	15,500	12,900	15,500
Pineapples	18,205	7,875	6,738	5,196	4,933
Sweet potatoes	193	297	648	979	1,047
Ginger root	300	80	64	36	32
Taro	462	535	503	458	449
Corn for grain	0	3,115	4,365	4,986	5,118

Sources: USDA (2018d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain).

Table G-13: Crop Production by Crop Type, Year (Tons)

Crop Type	1990	2007	2010	2015	2016
Sugarcane for sugar	6,538,000	1,493,000	1,195,000	1,139,000	1,336,000
Pineapples	607,322	242,967	208,065	160,676	152,582
Sweet potatoes	1,024	1,430	3,120	4,975	5,351
Ginger root	4,503	1,266	908	443	385
Taro	3,511	2,554	2,060	1,728	1,659
Corn for grain	0	3,497	7,567	10,431	11,025

Sources: USDA (2018d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain).

Table G-14: Fertilizer Consumption by Fertilizer Type, Fertilizer Years

Fertilizer Type	1990	2007	2010	2015	2016
Urea Fertilizer Consumption (short tons)	2,638	2,038	2,002	2,262	2,305
Synthetic Fertilizer Consumption (kg N)	16,218,014	12,550,066	12,324,312	13,953,712	14,227,325

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

Table G-15: Wildfire Area Burned by Year (Hectares)

Area Burned	1990	2007	2010	2015	2016
Area Burned (Hectares)	8,172	11,975	3,856	2,264	7,335

Source: DLNR (1994 through 2008, 2011, 2016, 2017).

Table G-16: Area Burned by Forest Type (Hectares)

Forest Type	1990	2007	2010	2015	2016
Forest	946	1,480	220	261	847
Shrubland	2,043	2,801	1,173	564	1,829

Source: DLNR (1994 through 2008, 2011, 2016, 2017) and Selmants et al. (2017).

Table G-17: Percent of Total Area Burned by Forest Type (Percent)

Forest Type	1990	2007	2010	2015	2016
Forest	13.2%	12.1%	6.7%	13.2%	13.2%
Shrubland	28.5%	22.9%	35.8%	28.5%	28.5%

Source: Selmants et al. (2017).

Table G-18: Forest and Shrubland Area (Hectares)

Forest and Shrubland Area	1990	2007	2010	2015	2016
Forest and Shrubland Area (Hectares)	497,430	486,100	491,039	487,449	488,159

Source: DBEDT (2018c).

Table G-19: Forest and Shrubland Area (Percent)

Forest and Shrubland Area	1990	2007	2010	2015	2016
Forest	52.0%	60.9%	64.5%	68.4%	68.4%
Shrubland	48.0%	39.1%	35.5%	31.6%	31.6%

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

Table G-20: Hawaii Landfilled Yard Trimmings and Food Scraps (thousand short tons, wet weight)

Yard Trimming and Food Scraps	1990	2007	2010	2015	2016
Landfilled Yard Trimmings	**126**	**45**	**56**	**53**	**51**
Grass	38	14	17	16	16
Leaves	51	18	22	21	21
Branches	37	13	16	16	15
Food Scraps	**85**	**119**	**136**	**149**	**147**

Source: EPA (2018f).

Table G-21: Hawaii Urban Area (km^2)

Hawaii Urban Area	1990	2007	2010	2015	2016
Urban Area (km^2)	757.0	988.9	1,018.2	1,089.4	1,105.3

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

Table G-22: Hawaii Percent Urban Tree Cover (Percent)

Area	1990	2007	2010	2015	2016
Honolulu	39.9%	35.2%	27.8%	23.0%	23.0%
Hawaii (state)	39.9%	40.5%	41.2%	41.7%	41.7%

Sources: MacFaden et al. (2016) and Nowak et al. (2005, 2012, 2018a, 2018b)

Waste

Table G-23: 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
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); Otsu (2008); EPA (2018c).

Table G-24: Volume of Composted MSW (MT)

MSW Composted	1990	2007	2010	2015	2016
Hawaii	18,934	92,564	85,861	102,549	102,206
U.S.	3,810,000	19,695,000	18,298,000	21,052,000	21,163,000

Sources: DBEDT (2018c); EPA (2018a).

Table G-25: Per Capita Biological Oxygen Demand for Wastewater treatment (kg/person/day)

Island	1990	2007	2010	2015	2016
Hawaii	0.0615	0.0615	0.0004	0.0002	0.0002
Kauai	0.0615	0.0615	0.0001	0.0002	0.0002
Lanai/Molokai/Niihau	0.0615	0.0615	0.0615	0.0615	0.0615
Maui	0.0615	0.0615	0.0003	0.0003	0.0006
Oahu	0.0615	0.0615	0.0001	0.0001	0.0009

Source: Pruder (2008) and Hawaii DOH (2017b and 2018).

Table G-26: Fraction of Population not on Septic (Percent)

Island	1990	2007	2010	2015	2016
Hawaii	99.976%	87.885%	87.885%	87.885%	87.885%
Kauai	99.773%	84.753%	84.753%	84.753%	84.753%
Lanai/Maui/Molokai	99.973%	93.745%	93.745%	93.745%	93.745%
Niihau	99.999%	99.967%	99.967%	99.967%	99.967%
Oahu	99.960%	99.353%	99.353%	99.353%	99.353%

Source: U.S. Census Bureau (1990b, 2012).

Appendix H. Emission Factors

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

Energy

Table H-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	2016
Residential					
Diesel Fuel	43.98	43.98	43.98	43.98	43.98
Propane	37.17	37.93	37.93	37.93	37.93
Natural Gas	31.86	31.87	31.87	31.87	31.90
Commercial					
Diesel Fuel	43.98	43.98	43.98	43.98	43.98
Motor Gasoline	42.82	43.12	42.89	42.89	42.85
Propane	37.17	37.93	37.93	37.93	37.93
Residual Fuel	47.38	47.38	47.38	47.38	47.38
Natural Gas	31.86	31.86	31.86	31.86	31.90
Other Fuels					
Kerosene	43.48	43.48	43.48	43.48	43.48
Industrial					
Coal	57.22	57.41	57.41	57.41	56.78
Diesel Fuel	43.98	43.98	43.98	43.98	43.98
Motor Gasoline	42.82	42.89	42.89	42.89	42.89
Propane	37.17	37.93	37.93	37.93	37.93
Residual Fuel	47.38	47.38	47.38	47.38	47.38
Natural Gas	31.86	31.86	31.86	31.86	31.90
Other Fuels					
Asphalt and Road Oil	45.46	45.46	45.46	45.46	45.46
Kerosene	43.48	43.48	43.48	43.48	43.48
Lubricants	44.62	44.62	44.62	44.62	44.62
Waxes	43.64	43.64	43.64	43.64	43.64
Energy Industries					
Coal	57.22	57.42	57.25	57.25	57.25
Diesel Fuel	43.98	43.98	43.98	43.98	43.98
Residual Fuel	47.38	47.38	47.38	47.38	47.38
Fuel Gas[a]	38.60	38.60	38.60	38.60	38.60

Sector/Fuel Type	1990	2007	2010	2015	2016
Other Fuels					
Aviation Gasoline Blending Components	41.60	41.60	41.60	41.60	41.60
Motor Gasoline Blending Components	42.82	43.12	42.89	42.89	42.89
Unfinished Oils	44.41	44.71	44.77	44.77	44.77

Source: EPA (2018a).

Table H-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	10	1.5
Energy Industries	1	1.5
Petroleum		
Residential	10	0.6
Commercial	10	0.6
Industrial	3	0.6
Energy Industries	3	0.6
Natural Gas		
Residential	5	0.1
Commercial	5	0.1
Industrial	1	0.1
Wood		
Residential	300	4
Commercial	300	4
Industrial	30	4
Energy Industries	30	4

Source: IPCC (2006).

Table H-3: CO_2, CH_4, and N_2O Emission Factors Used to Estimate Emissions from Biofuel Use by Fuel Type

Fuel Type	CO_2 (lb/MMBtu)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Ethanol	41	18	NA
Biodiesel	33	147	4
Wood[a]	94	NA	NA

[a] Methane and N_2O emission factors for Wood are reported in Table F-2.

NA (emissions are Not Applicable).

Source: EPA (2018a).

Table H-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	2016
Aviation Gasoline	41.60	41.60	41.60	41.60	41.60
Diesel Fuel	43.98	43.98	43.98	43.98	43.98
Jet Fuel Kerosene	42.77	42.62	42.62	42.62	42.62
Motor Gasoline	42.82	42.89	42.89	42.89	42.89
Propane	37.65	37.93	37.93	37.93	37.93
Residual Fuel	47.38	47.38	47.38	47.38	47.38
Natural Gas	31.90	31.90	31.90	31.90	31.90
Ethanol	41.16	41.16	41.16	41.16	41.16
Biodiesel	33.49	33.49	33.49	33.49	33.49
Lubricants	44.62	44.62	44.62	44.62	44.62

Source: EPA (2018a).

Table H-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

Vehicle Type/Control Technology	CH_4	N_2O
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 (2018a).

Table H-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 H-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 H-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	NA
Diesel Fuel	0.08	0.315
Residual Fuel	0.08	0.315

NA (emissions are Not Applicable).

Source: IPCC (1996).

IPPU

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

	1990	2007	2010	2015	2016
Clinker Production Emission Factor	0.51	0.51	0.51	0.51	0.51
Cement kiln dust (CKD) correction factor	1.02	1.02	1.02	1.02	1.02

Source: IPCC (2006).

AFOLU

Table H-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	2016
Dairy Cows	117.93	107.74	110.59	120.12	120.12
Dairy Replacement Heifers	60.24	58.01	57.62	57.27	57.27
Other Dairy Heifers	60.24	58.01	57.62	57.27	57.27
Beef Cows	94.40	100.47	100.47	100.47	100.47
Beef Replacement Heifers	62.67	69.39	69.41	69.33	69.33
Other Beef Heifers	36.36	36.63	31.20	36.45	36.45
Steers	34.10	35.81	30.85	36.05	36.05
Calves	11.57	11.29	11.27	11.31	11.31
Bulls	103.89	103.89	103.89	103.89	103.89

Source: EPA (2018a).

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

Cattle Type	1990	2007	2010	2015	2016
Dairy Cows	679.77	679.77	679.77	679.77	679.77
Dairy Replacement Heifers	407.72	406.35	406.87	406.32	406.32
Other Dairy Heifers	407.72	406.35	406.87	406.32	406.32
Beef Cows	553.34	610.89	610.89	610.89	610.89
Beef Replacement Heifers	371.54	405.73	406.33	403.98	403.98
Other Beef Heifers	383.38	420.76	424.92	445.25	445.25
Steers	418.46	449.66	451.89	470.36	470.36
Calves	122.10	122.54	122.48	122.54	122.54
Bulls	830.00	916.34	916.34	916.34	916.34

Source: EPA (2018a).

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

Cattle Type	1990	2007	2010	2015	2016
Dairy Cows	7.99	8.21	8.44	9.22	9.22
Dairy Replacement Heifers	7.86	8.48	8.44	8.44	8.44
Other Dairy Heifers	7.86	8.48	8.44	8.44	8.44
Beef Cows	8.80	8.48	8.48	8.48	8.48
Beef Replacement Heifers	7.96	8.52	8.44	8.50	8.50
Other Beef Heifers	5.72	4.37	4.36	4.25	4.25
Steers	5.18	3.99	4.00	3.89	3.89
Calves	6.41	7.59	7.70	7.70	7.70
Bulls	5.99	5.85	5.85	5.85	5.85

Source: EPA (2018a).

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

Cattle Type	1990	2007	2010	2015	2016
Dairy Cows	146.32	127.82	126.51	134.83	134.83
Dairy Replacement Heifers	79.10	71.27	68.93	68.84	68.84
Other Dairy Heifers	79.10	71.27	68.93	68.84	68.84
Beef Cows	52.71	59.14	59.14	59.14	59.14
Beef Replacement Heifers	33.60	41.18	40.75	40.80	40.80
Other Beef Heifers	57.36	53.07	54.64	55.80	55.80
Steers	59.86	54.57	56.13	56.82	56.82
Calves	13.37	19.57	20.12	20.13	20.13
Bulls	61.14	68.53	68.53	68.53	68.53

Source: EPA (2018a).

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

Animal Type	1990	2007	2010	2015	2016
Dairy Cows	62%	58%	62%	65%	65%
Dairy Replacement Heifers	2%	2%	2%	2%	2%
Other Dairy Heifers	2%	2%	2%	2%	2%
Beef Cows	2%	2%	2%	2%	2%
Beef Replacement Heifers	2%	2%	2%	2%	2%
Other Beef Heifers	2%	2%	2%	2%	2%
Steers	2%	2%	2%	2%	2%
Calves	2%	2%	2%	2%	2%
Bulls	2%	2%	2%	2%	2%
Sheep	2%	2%	2%	2%	2%
Goats	2%	2%	2%	2%	2%
Swine	35%	47%	47%	47%	47%
Horses	2%	2%	2%	2%	2%
Chickens	60%	20%	20%	20%	20%

Sources: EPA (2018a) (all animal types except chicken and swine); EPA (2018e) (chicken and swine).

Table H-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 (2018a); EPA (2018e) (VS for horses and Nitrogen Excretion rates).
NA (Not Applicable).

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

Animal Type	Maximum Potential Emissions (B_0)
Dairy Cows	0.24
Dairy Replacement Heifers	0.17
Other Dairy Heifers	0.17
Beef Cows	0.17
Beef Replacement Heifers	0.17

Animal Type	Maximum Potential Emissions (B_0)
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 (2018a)

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

Animal Type	WMS	1990	2007	2010	2015	2016
Dairy Cows	Pasture	0%	10%	5%	0.69%	0.69%
Dairy Cows	Anaerobic Lagoon	68%	57%	63%	67%	67%
Dairy Cows	Liquid/Slurry	21%	23%	22%	21%	21%
Dairy Cows	Solid Storage	11%	9%	10%	11%	11%
Dairy Cows	Deep Pit	0%	0%	0%	0%	0%
Dairy Replacement Heifers	Liquid/Slurry	1%	1%	1%	1%	1%
Dairy Replacement Heifers	Dry Lot	100%	100%	100%	100%	100%
Dairy Replacement Heifers	Pasture	0%	0%	0%	0%	0%
Other Dairy Heifers	Liquid/Slurry	1%	1%	1%	1%	1%
Other Dairy Heifers	Dry Lot	100%	100%	100%	100%	100%
Other Dairy Heifers	Pasture	0%	0%	0%	0%	0%
Beef Cows	Pasture	100%	100%	100%	100%	100%
Beef Cows	Other WMS	0%	0%	0%	0%	0%
Beef Replacement Heifers	Pasture	100%	100%	100%	100%	100%
Beef Replacement Heifers	Other WMS	0%	0%	0%	0%	0%
Other Beef Heifers	Liquid/Slurry	1%	1%	1%	1%	1%
Other Beef Heifers	Dry Lot	100%	100%	100%	100%	100%
Other Beef Heifers	Pasture	0%	0%	0%	0%	0%
Steers	Liquid/Slurry	1%	1%	1%	1%	1%
Steers	Dry Lot	100%	100%	100%	100%	100%
Steers	Pasture	0%	0%	0%	0%	0%
Calves	Pasture	100%	100%	100%	100%	100%
Calves	Other WMS	0%	0%	0%	0%	0%
Bull	Pasture	100%	100%	100%	100%	100%
Bull	Other WMS	0%	0%	0%	0%	0%

Animal Type	WMS	1990	2007	2010	2015	2016
Sheep	Pasture	55%	69%	69%	69%	69%
Sheep	Dry Lot	45%	31%	31%	31%	31%
Goats	Pasture	92%	92%	92%	92%	92%
Goats	Dry Lot	8%	8%	8%	8%	8%
Swine	Pasture	36%	31%	41%	47%	47%
Swine	Anaerobic Lagoon	13%	14%	13%	11%	11%
Swine	Liquid/Slurry	18%	19%	16%	15%	15%
Swine	Deep Pit	30%	32%	28%	25%	25%
Swine	Solid Storage	3%	3%	3%	2%	2%
Horses	Pasture	92%	92%	92%	92%	92%
Horses	Dry Lot	8%	8%	8%	8%	8%
Chickens	Pasture	0%	0%	0%	0%	0%
Chickens	Anaerobic Lagoon	80%	25%	25%	25%	25%
Chickens	Poultry without bedding	10%	75%	75%	75%	75%
Chickens	Solid Storage	10%	0%	0%	0%	0%

Source: EPA (2018a).

Table H-18: Urea Emission Factor

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

Source: IPCC (2006).

Table H-19: N_2O Emission Factors by Waste Management System Type (kg N_2O-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 H-20: Crop Residue Factors by Crop for Estimating Emissions from Agricultural Soil Management

Crop	IPCC Crop Proxy	Dry matter fraction of harvested product (DRY)	Aboveground 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 H-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 H-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 H-23: Emission Factors to Estimate Direct N_2O Emissions from Agricultural Soil Management (kg N_2O-N/kg N)

Emission Factor	Value
Emission factor for N additions from mineral fertilizers, organic amendments and crop residues	0.01
Emission factor for cattle, poultry and pigs	0.02
Emission factor for sheep and other animals	0.01

Source: IPCC (2006).

Table H-24: Forest Fire Carbon Emission Factor (MT Carbon/ha)

Emission Factor	Value
Forest	
Dry forest	1.44
Mesic forest	34.97
Wet forest	15.05
Alien tree plantations	22.76
Shrubland	
Dry shrubland	2.12
Mesic shrubland	10.29

Source: Selmants et al. (2017).

Table H-25: Ratio of Hawaii Forest Land to Wildland (Dimensionless)

Factor	1990	2007	2010	2015	2016
Ratio of Hawaii forestland to wildland	0.37	0.36	0.36	0.36	0.36

Source: National Association of State Foresters (1998, 2002); DLNR (2011, 2016, 2017).

Table H-26: Forest Fire Emission Factor (g/kg dry matter burnt)

Emission Factor	Value
CH_4	4.70
N_2O	0.26

Source: IPCC (2006).

Table H-27: 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

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
Food Scraps	NA	70.0	15.7	50.8	0.156

Source: EPA (2018f).

NA (Not Applicable).

Table H-28: 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 H-29: Forest Carbon Net Sequestration Factors

Type of Forest	Annual Net C Sequestration Rate (MT C/ha/year)
Forest	3.38
Shrubland	3.53

Source: Selmants et al. (2017).

Waste

Table H-30: Landfilling CH_4 Emission Factors for Estimating Emissions from Waste Sector

Emission 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 (2018a).

Table H-31: Composting CH_4 and N_2O Emission Factors for Estimating Emissions from Waste Sector

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

Source: IPCC (2006).

Table H-32: Wastewater CH_4 and N_2O Emission Factors for Estimating Emissions from Waste Sector

Emission 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

Emission Factor	Value
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 I. Areas for Improvement

This section summarizes potential areas for improvement by sector and category, ranked by priority (H = high priority improvement; M = medium priority improvement; L = low priority improvement). The priority levels presented in Table I-1 were developed based on the following criteria:

1. Expected impact on statewide emissions results,
2. Expected availability of data, and
3. Expected level of effort needed to implement the improvement.

Additional details on the rationale for the priority level for each potential area for improvement are provided in Table I-1.

Table I-1: Summary of Potential Areas for Improvement by Sector/Category

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
Energy				
1	Stationary Combustion + Transportation + International Bunker Fuels	Further review and verification of the SEDS fuel consumption data should be explored, depending in part on the availability of additional data. For example, Hawaii Senate Bill SB1241, which will allows DBEDT to share the EIIRP data with DOH for the purposes of regulating GHG emissions, was signed into law on June 7, 2019. Therefore, additional year by year trend analyses from 2010 onwards could be performed for fuel types and sectors to compare the EIIRP data against SEDS and other sources such as GHGRP. In addition, to further assess fuel consumption estimates for 1990 and 2007, a closer review of year-over-year trends in the SEDS data by fuel type and end-use sector could be explored to identify possible anomalies in the data.	H	Potentially higher impact on emissions[67]; SEDS data currently available while DBEDT data are not yet available; potentially high level of effort for implementation, depending on availability of DBEDT data
2	Transportation	For the purposes of verifying current estimates, transportation fuel consumption could alternatively be estimated based on mileage data and	H	Potentially higher impact on emissions; data are

[67] Impact on emissions is relative to other measures; it does not necessarily mean that the improvement is likely to have a high impact on emission estimates for Hawaii as a whole.

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
		registered vehicles in Hawaii. Building on the work that has already been done to calculate CH_4 and N_2O emissions, an annual estimate of transportation fuel consumption could be made using compiled data on VMT by vehicle type, shares of gasoline and diesel vehicles by vehicle type, and vehicle age distribution data for each year. Data on fuel economy characteristics by vehicle type could then be added to estimate fuel consumption volumes and trends, which could then be compared to SEDS and the data collected by DBEDT.		currently available; potentially high level of effort for implementation
3	International Bunker Fuels	Additional analysis could be done on the existing domestic and international flight mileage data to better allocate fuel consumption estimates. Specifically, data on the distance and aircraft type by journey obtained from the DOT (2018) could be used to improve estimates by differentiating the fuel efficiency of each aircraft type, accounting for the fact that long haul flights tend to be more fuel efficient on a per mile basis.	H	Potentially higher impact on emissions; data are currently available; potentially high level of effort for implementation
4	Oil and Natural Gas Systems	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 2016 (EPA 2018b), are not currently captured in this inventory. These emissions should be incorporated into future inventory analyses.	H	Moderate impact on emissions; data are currently available
5	Stationary Combustion	Emissions from NEU of fuels are assumed to be captured within the Industrial Processes sector calculations. Future analyses could confirm this assumption, estimate emissions from the consumption of fossil fuel feedstocks for NEU, and include these emissions under the Energy sector.	M	Moderate impact on emissions; data are not currently available
6	Transportation	The U.S. Inventory uses non-road emission factors for CH_4 and N_2O emissions developed based on the 2006 IPCC Guidelines Tier 3 guidance and EPA's MOVES2014 model. The use of these updated emission factors for off-road vehicles should be considered for future analyses.	M	Moderate impact on emissions; data are currently available
7	Oil and Natural Gas Systems	Improvements to 1990 and 2007 emissions calculations should be made if additional data becomes available.	M	Moderate potential impact on emissions; high

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
				uncertainty in availability of data
8	Stationary Combustion	If data becomes available, the following emissions could be calculated and incorporated into the totals for this source category: CO_2 emissions from biodiesel consumption for 1990 and 2007; and CO_2 emissions from biodiesel consumption at energy industries facilities that fall below the reporting threshold for EPA's GHGRP for 2010, 2015, and 2016.	L	Low impact on emissions; data are not currently available
9	Transportation	Methane and N_2O emissions from biodiesel consumption for 1990 and 2007 should be incorporated into the totals for this source category if data becomes available.	L	Low impact on emissions; high uncertainty in availability of data
10	International Bunker Fuels	If data becomes available, actual data on jet fuel consumption for international trips originating in Hawaii, as well as data by specific aircraft type, number of individual flights, and movement data could be used in emissions calculations for this source category.	L	Moderate impact on emissions; some uncertainty around data availability
11	International Bunker Fuels	If data becomes available, marine bunker fuel consumption data for 1990 should be incorporated into emissions calculations for this source category.	L	Low impact on emissions; some uncertainty in availability of data
12	CO_2 Emissions from Wood Biomass and Biofuel	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. However, in 2017 Hawaii Gas announced a project to install equipment to capture biogas at the Honouliuli Wastewater Treatment Plant and convert it to renewable natural gas (Hawaii Free Press 2018). If and when this project is completed, future inventories will account for the volume of CH_4 emissions from wastewater treatment that is captured and combusted for energy.	L	Low impact on emissions; high uncertainty in availability of data
13	CO_2 Emissions from Wood Biomass and Biofuel	If data becomes available, the following emissions could be calculated and incorporated into the totals for this source category: CO_2 emissions from biodiesel consumption for 1990 and 2007; and CO_2 emissions from biodiesel consumption at energy industries facilities that fall below the reporting threshold for EPA's GHGRP for 2010, 2015, and 2016.	L	Low impact on emissions; high uncertainty in availability of data

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
IPPU				
14	Substitutes of ODS	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.	M	Moderate impact on emissions; high uncertainty in availability of data
15	Electrical Transmission and Distribution	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.	L	Low impact on emissions; high uncertainty in availability of data
AFOLU				
16	Forest Carbon	Additional land cover data and annually variable net sequestration rates should be incorporated into future analyses if they become available. Further research into the age of Hawaii forests, improved forest management practices, and their emissions reduction potential may also be considered in future analyses.	H	Higher potential impact on emission results; relatively high level of effort for research, depending on data availability
17	Enteric Fermentation	Further research into the accuracy of interpolated and extrapolated animal population data as well as aligning animal groupings with those used in the U.S. Inventory may be considered in future analyses.	M	Moderate impact on emission results; data are available for aligning animal groupings
18	Manure Management	Further research into the accuracy of interpolated and extrapolated animal population data, the availability of animal population data that are disaggregated by weight, and aligning animal groupings with the U.S. Inventory may be considered in future analyses.	M	Moderate priority reflects alignment with animal groupings under Enteric Fermentation; low impact on emissions; data are available for aligning animal groupings
19	Agricultural Soil Carbon	EPA continues to investigate improvements in estimating changes in additional carbon pools for other land types converted to cropland or grassland. These improvements, once implemented, should be reflected in future analyses.	M	Moderate impact on emissions; availability of data depends on EPA

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
				improvements in latest U.S. Inventory
20	Agricultural Soil Carbon	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.	M	Moderate impact on emissions; moderate level of effort required for research
21	Urban Trees	Further research into urban tree sequestration rates by county or island may be considered in future analyses.	M	Moderate impact on emissions; moderate level of effort required for research
22	Urban Trees	The Hawaii Greenhouse Gas Sequestration Task Force established by Act 15 will work to identify opportunities to increase urban tree cover (Hawaii Legislature 2018). Other examples of initiatives include a 35 percent tree canopy goal by 2035, which was championed by Trees for Honolulu's Future (TFHF) and adopted by the City and County of Honolulu (City & County of Honolulu 2019). The tree canopy goal also has sub-goals of planting 100,000 new trees by 2025 in Oahu (TFHF 2018). 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.	M	Moderate impact on emissions; moderate level of effort required for research
23	Enteric Fermentation	Updated and/or Hawaii-specific enteric emission factors should be incorporated into future analyses if data becomes available.	L	Low impact on emissions; uncertainty in availability of updated emission factors
24	Manure Management	If updated data becomes available, updated and/or Hawaii-specific emission factors should be incorporated into future analyses.	L	Low impact on emissions; uncertainty in availability of updated emission factors
25	Agricultural Soil Management	Further research into the accuracy of interpolated and extrapolated animal population, crop production, and synthetic fertilizer application data may be considered in future analyses.	L	Low impact on emissions; moderate level of effort required for research

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
26	Agricultural Soil Management	Further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses.	L	Low impact on emissions; high uncertainty in availability of data
27	Agricultural Soil Management	As crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly.	L	Low impact on emissions; uncertainty in availability of updated emission factors
28	Agricultural Soil Management	Conducting further research to identify seed production activity data may be considered to estimate emissions from seed production in future analyses.	L	Low impact on emissions; moderate level of effort required for research
29	Field Burning of Agricultural Residues	If information on the field burning of crop residues from other crops, besides sugarcane, becomes available, this information should be incorporated into future inventory analyses.	L	Low impact on emissions; uncertainty in availability of updated emission factors
30	Field Burning of Agricultural Residues	As crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly.	L	Low impact on emissions; uncertainty in availability of updated emission factors
31	Urea Application	Further research into the accuracy of extrapolated data as well as calendar year fertilizer consumption patterns may be considered in future analyses.	L	Low impact on emissions; 2015 fertilizer data are available for purchase
32	Urea Application	If more recent urea fertilizer application data become available, it should be incorporated into future inventory analyses.	L	Low impact on emissions; 2015 fertilizer data are available for purchase
33	Forest Fires	Further investigation into alternative sources for historical wildfire acres burned and prescribed fire acres burned may be considered in future analyses.	L	Low impact on emissions; moderate level of effort required for research
34	Forest Fires	Coordination with EPA to understand the cause for the discrepancy between emission estimates presented in this report and NEI prescribed fire emissions may be considered.	L	Low impact on emissions; data are currently available to understand discrepancies; moderate

Item Number	Category	Potential Area for Improvement	Priority Level	Prioritization Rationale
				level of effort required to coordinate with EPA
35	Forest Fires	Additional data for percent of area burned by forest type for each year in the time series should also be incorporated into future analyses if they become available.	L	Low impact on emissions; moderate level of effort required for research
36	Landfilled Yard Trimmings and Food Scraps	Further research into Hawaii trends in diverting yard trimmings and food scraps from landfills, as well as yard trimmings and food scraps sequestration rates that incorporate Hawaii's climate may be considered in future analyses.	L	Low impact on emissions; moderate level of effort required for research
37	Various	Identify data and estimate emissions for source and sink categories that are currently not estimated due to lack of data as identified in Appendix A. These sources and sinks include Land Converted to Forest Land, Wetlands, Land Converted to Settlements, Other Land, Biomass Burning in Grassland, Liming, and Harvested Wood Products.	L	Low impact on emissions; high uncertainty in availability of data
Waste				
38	Landfills	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.	M	Moderate potential impact on emissions; high uncertainty in availability of data
39	Composting	Hawaii-specific data on composting volumes, if it becomes available, should be incorporated into future inventory analyses.	L	Low impact on emissions; high uncertainty in availability of data
40	Wastewater Treatment	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.	L	Low potential impact on emissions; high uncertainty in availability of data

Appendix J. 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 J-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 2018a). National population numbers were obtained from the U.S. Census Bureau (2018) while Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2018d). Table J-2 summarizes ODS emissions in Hawaii by gas for 1990, 2007, 2010, 2015, and 2016.[68]

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

Gas	1990	2007	2010	2015	2016
CFC-11	0.15	0.05	0.11	0.12	0.12
CFC-12	0.67	0.06	0.03	0.02	0.01
CFC-113	0.30	0.06	0.03	+	+

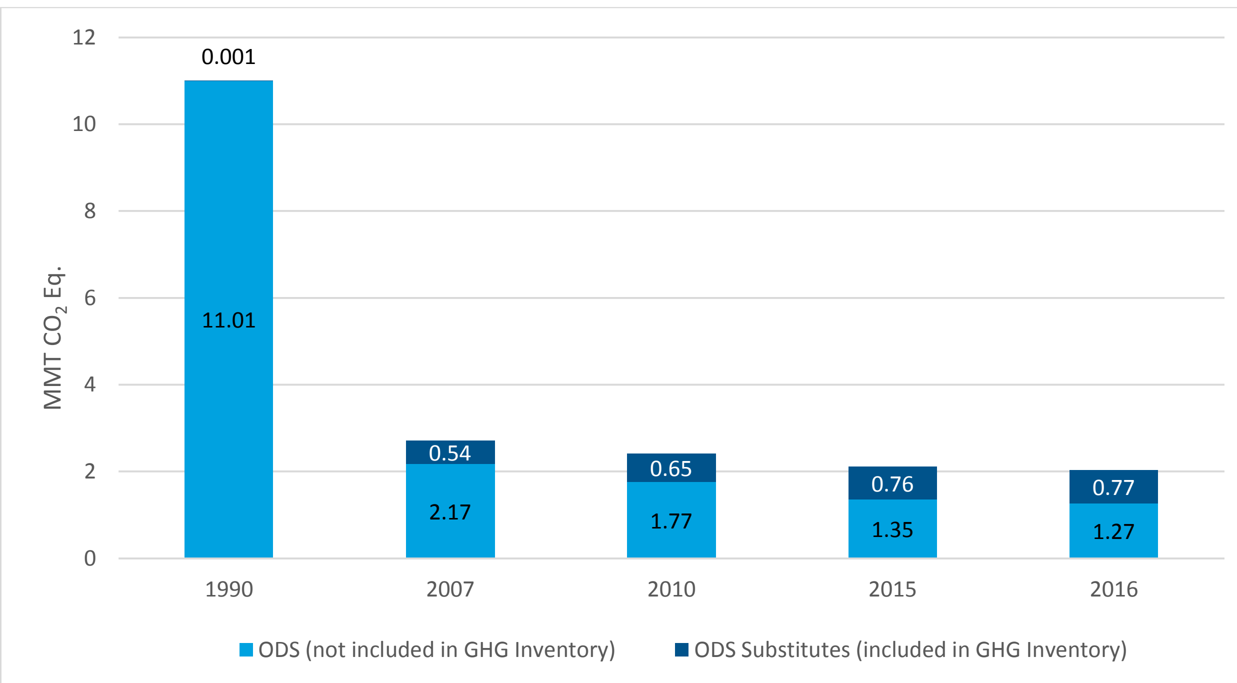
[68] The methodology and data sources used to estimate ODS emissions in Hawaii are consistent with the methodology and data sources used to estimate emissions from ODS substitutes. As such, the uncertainties and areas for improvement that are discussed in Section 4.3 are also applicable to the estimates of ODS emissions in Hawaii presented in this appendix.

Gas	1990	2007	2010	2015	2016
CFC-114	0.02	+	+	+	+
CFC-115	0.04	0.01	+	+	+
Carbon Tetrachloride	0.02	NO	NO	NO	NO
Methyl Chloroform	1.12	NO	NO	NO	NO
Halon 1211	0.01	+	+	+	+
Halon 1301	0.01	+	+	+	+
HCFC-22	0.25	0.39	0.36	0.29	0.26
HCFC-123	NO	+	+	+	+
HCFC-124	NO	0.01	+	+	+
HCFC-141b	0.01	0.03	0.04	0.05	0.04
HCFC-142b	0.01	0.02	0.01	0.01	0.01
HCFC-225ca/cb	+	+	+	+	+
Total	**2.59**	**0.64**	**0.60**	**0.49**	**0.46**

+ Does not exceed 0.005 kt; NO (emissions are Not Occurring).
Source: EPA (2018a).

Emissions from ODS in Hawaii have decreased significantly since 1990, following the implementation of the *Montreal Protocol*. Figure J-1 below presents combined emissions from ODS and ODS substitutes in Hawaii. Combined emissions have similarly decreased between 1990 and 2016, even though emissions from ODS substitutes increased during the same period.

Figure J-1: Emissions from ODS and ODS Substitutes



Appendix K. Emission Projections Methodology

This section summarizes the methodology used to project emissions for 2020 and 2025 by source and sink category under both the baseline and alternate scenarios, as applicable. A discussion of key uncertainties and areas for improvement is also provided.

Energy

Stationary Combustion

Baseline Scenario Methodology

Emissions from stationary combustion were projected based on the DBEDT forecast as well as utility-specific emission projections. For the residential, commercial, and industrial sectors, emissions were assumed to grow at the rate of GSP. For the energy industries sector, emissions were projected for the two petroleum refineries (Island Energy Services and Par Hawaii)[69] 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. An adjustment factor was then applied to the energy industries total to account for differences in how EIA SEDS, which was used as the primary source of fuel consumption data to prepare the 2016 statewide inventory, allocates its data by end-use sector relative to the facility-specific data to avoid double-counting with commercial and industrial sector emissions.

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 KIUC, emissions projections for 2020 and 2025 were developed based on the utility's 2019 generation and GHG estimates (KIUC 2019). 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), which provides utility generation scenarios out to 2045. For the purposes of this analysis, projections were based on the preferred plan to achieve the RPS (i.e., the E3 Plan with Grid Modernization). The estimates in the original plan were then adjusted to account for current renewable energy capacity on the grid (DBEDT 2019a) and updated estimates of additional renewable energy capacity that will be added to the grid by 2020 and 2025 (HECO 2019b). Table K-1 summarizes the difference in projected renewable energy capacity by 2020 and 2025 under the original PSIP and the updated plan.

[69] 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.

Table K-1: HEI Projected Renewable Energy Capacity (MW)

Source	Original PSIP		Updated Plan & Current Installations		Difference	
	2020	2025	2020	2025	2020	2025
Solar						
Oahu County	1,012	1,512	714	1,141	(298)	(371)
Maui County	146	192	114	229	(32)	37
Hawaii County	125	184	107	200	(18)	16
Solar Total	**1,283**	**1,888**	**935**	**1,570**	**(348)**	**(318)**
Wind						
Oahu County	133	333	123	170	(10)	(163)
Maui County	134	134	72	72	(62)	(62)
Hawaii County	57	107	34	34	(23)	(73)
Wind Total	**324**	**574**	**229**	**276**	**(94)**	**(297)**
Hydro						
Oahu County	-	-	-	-	-	-
Maui County	1	1	-	-	-	-
Hawaii County	18	18	16	16	(2)	(2)
Hydro Total	**19**	**19**	**16**	**16**	**(2)**	**(2)**

Sources: PUC (2016), HECO (2019b), DBEDT (2019a).

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values.

To adjust the original PSIP emission estimates, the differences in solar, wind, and hydro capacity were converted to energy generation using island-specific capacity factors for each technology, as provided by the original PSIP (PUC 2016). This output was then converted to emissions using the following equation:

$$E_t = \left(D(solar)_{t,c} \times CF(solar)_{t,c} + D(wind)_{t,c} \times CF(wind)_{t,c} + D(hydro)_{t,c} \times CF(hydro)_{t,c}\right) \times HR_t \times EF_g \times GWP_g$$

where,

E_t = Adjusted stationary energy GHG emissions for year *t* (MMT CO_2 Eq.)
$D(solar)_{t,c}$ = Difference in solar capacity for year *t* and county *c* (MW)
$CF(solar)_{t,c}$ = Capacity factor for solar for year *t* and county *c* (GWh/MW)
$D(wind)_{t,c}$ = Difference in wind capacity for year *t* and county *c* (MW)
$CF(wind)_{t,c}$ = Capacity factor for wind for year *t* and county *c* (GWh/MW)
$D(hydro)_{t,c}$ = Difference in hydro capacity for year *t* and county *c* (MW)
$CF(hydro)_{t,c}$ = Capacity factor for hydro for year *t* and county *c* (GWh/MW)
HR_t = Weighted average heat rate for oil-fired units within the PSIP for year *t* (btu/kWh)
EF_g = GHG emissions factor for gas *g* (g per btu)
GWP_g = GWP of gas *g*

Alternate Scenario 1A and 1B

Future energy prices, especially oil prices, is one of the greatest sources of uncertainty that will affect future GHG emissions. Hawaii's demand for refined petroleum products depends greatly on the price of refined petroleum products, which depends directly on world crude oil prices. Prices could fluctuate due to market forces external to Hawaii as well as state or national policy regarding GHG pricing.[70]

To understand the potential effect of oil prices on Hawaii's future emissions, the study team considered both a *high* (Alternate Scenario 1A) and *low* (Alternate Scenario 1B) future oil price pathway based on the EIA's Annual Energy Outlook (AEO) 2019 (EIA 2019d). Table K-2 below summarizes future crude oil prices under each scenario. As shown, under the *high* oil price forecast, the price of oil is expected to be roughly double the price under the reference case, while under the low oil price forecast, the price of oil is expected to be roughly half the price under the reference case.[71]

Table K-2: Crude Oil Prices (2018$/bbl)

Scenario	2020	2025
High (Alternate Scenario 1A)	$122.92	$155.56
Reference Case	$73.27	$81.73
Low (Alternate Scenario 1B)	$43.92	$43.87

Source: EIA (2019d).

To estimate the percent change in electricity rates as a result of higher or lower world oil prices, the price difference between each price pathway and the reference case was divided by the current effective electricity rate (HECO 2019a) using the following equation:

$$\%\Delta EP_{t,s} = {(AEO_{t,s} - AEO_{t,ref}) * HR_{t,}}/{0.29}$$

where,

$\%\Delta EP_{t,s}$	= The percentage change in electricity price in year *t* under scenario *s*
$AEO_{t,s}$	= The AEO oil price forecast in year *t* under scenario *s* ($/million Btu)
$AEO_{t,ref}$	= The AEO oil price forecast in year *t* under the reference case ($/million Btu)
HR_t	= The weighted average heat rate of oil-fired units within the PSIP for year t (million Btu/kWh)
0.29	= Effective electricity rate ($/kWh)

To estimate the impact of this change on the change in demand in refined oil products, the price differentials were then multiplied by the price elasticity of demand in the electric sector. Based on recent literature, electricity demand in the electric sector is found to be relatively inelastic, meaning that

[70] An economy-wide carbon pricing scheme would also affect the price of coal and natural gas, which is not accounted for as part of this analysis. Given that coal is assumed to phase out of the baseline prior to 2025 and natural gas currently represents a relatively small portion of total fuel consumption in Hawaii, the impact of a carbon-pricing scheme on future coal and natural gas emissions is expected to be small.

[71] For context, a $25/MT CO_2 Eq. tax equates to approximately an additional $10/bbl of crude oil.

a 1 percent increase in price is expected to result in much less than a 1 percent decrease in consumption (Coffman et al. 2016). For this analysis, elasticity parameters equal to -0.1 and -0.3 in 2020 and 2025, respectively, were selected based on the Electric Power Research Institute (2010). This means that a 1 percent increase in electricity price results in a 0.1 percent decrease in electricity demand in 2020 and a 0.3 percent decrease in 2025. These elasticity parameters are similar to findings published by Nakajima and Hamori (2010), Paul et al. (2009), and Metcalf (2008).[72] Using these parameters, the change in demand for electricity under each scenario was calculated based on the following equation:

$$\%\Delta ED_{t,s} = \sigma_t \times \%\Delta EP_{t,s}$$

where,

$\%\Delta EDt,s$	= The percentage change in electricity demand in year *t* under scenario *s*
σ_t	= The price elasticity of demand in year *t*
$\%\Delta EPt,s$	= The percentage change in electricity price in year *t* under scenario *s*

As a last step, the percent change in electricity demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions, accordingly.

Alternate Scenario 2

Although the baseline scenario accounts for recent updates to HEI's planned renewable energy infrastructure, there is still uncertainty associated with the energy technologies that will ultimately be used to meet future electricity demand. To quantify these uncertainties, this scenario assumes:

1. **Delay in the re-start of the Puna Geothermal power plant:** The Puna Geothermal unit on Hawaii Island was closed in 2017 due to the active lava flow from the Kilauea eruption. In March 2019 the owner of the plant announced that it plans to have the plant operational by the end of the year (Associated Press 2019). However, subsequent news articles suggest it could take longer (Perez 2019). Under this scenario, the 38 MW geothermal plant is assumed to come back into operation by 2025, instead of the baseline assumption that it will be operational by 2020.
2. **Continued delays to the buildout of renewable energy infrastructure:** As discussed earlier in this section, there have been delays in renewable energy infrastructure adoption relative to the plan outlined in the original PSIP (PUC 2016, HECO 2019b). Rather than assume that the utility-scale solar projects that comprise the "Phase 2 RFP," a total of 247 MW, come into operation in 2022 (HECO 2019c), under this scenario these projects are not completed until after 2025.

[72] For the electric sector, the value of the price elasticity of demand is adopted from literature-based estimates. This is because there is robust literature on the topic and AEO's implied elasticity of demand for electricity with respect to changes in oil prices are not applicable to Hawaii. Changes in oil prices affect national electricity rates differently than Hawaii's electricity prices since at a national level the share of oil-fired generation is below one percent while in Hawaii oil-fired generation comprises more than 70 percent of its generation. Therefore, changes in oil prices are estimated to have nearly no effect on national electricity prices while they are likely to have a greater effect on Hawaii's electricity rates.

3. **Renegotiation of the contract for AES coal unit:** The current contract for the coal-fired power plant on Oahu is scheduled to sunset in 2022. Though continued use of coal is not within the utility's plans, the State of Hawaii Legislature in 2019 considered but failed to advance a bill that would have banned coal use past the current purchase power agreement (HB 563 HD1 2019). Under this scenario it is assumed that coal continues to be consumed through 2025.

Uncertainties and Areas for Improvement

As highlighted by the alternate scenarios described above, there is uncertainty associated with future oil prices and the sensitivity of consumers in response to price changes as well as the energy technology build-outs that will be used to meet future electricity demand. In addition, the methodology used to project emissions from the residential, commercial, and industrial end-use sectors is based on the observation that emissions from these end-uses correlate with economic activity. This analysis does not account for policies or programs that could impact fuel consumption by these sectors. Future analyses should be revised to reflect new information on the impact of oil prices on demand, changes in the actual build-out of renewable energy infrastructure relative to the current plan, and additional policies and programs that could impact fuel consumption by the residential, commercial, and industrial sectors.

Transportation

Methodology

Projected emissions for ground transportation were estimated based on changes to on-road vehicle fossil fuel consumption due to vehicle miles traveled (VMT), vehicle fuel efficiency, types of vehicles on the road, and the share of travel by new and existing vehicles. For domestic marine and military-related transportation, emissions are assumed to remain constant in the future relative to 2016 due to a lack of available data and inconsistencies in the historical emissions trend. Further discussion of these assumptions is provided in the sections that follow.

Ground Transportation

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

<u>Light Duty Vehicles</u>

For LDVs, on-road gasoline consumption was estimated based on the future fleet vehicle fuel efficiency and future LDV VMT by non-electric vehicles. Fleet fuel efficiency was derived based on the estimated fuel efficiency of new vehicles, the average fuel efficiency of the existing fleet, and the share of miles traveled by new vehicles.

New LDV fuel efficiency. New LDV fuel efficiency was estimated using the U.S. Environmental Protection Agency's (EPA) corporate average fuel economy (CAFE) standards for cars and light trucks (DOT 2012). Specifically, the CAFE standards require light duty cars and trucks to have an EPA rated efficiency of 143 g CO_2e/mile and 203 g CO_2e/mile, respectively, by 2025. These standards can be met through a combination of improving vehicle efficiency and/or reducing hydrofluorocarbons (HFCs) for vehicle air conditioning. For this analysis, it was assumed based on Davis and Boundy (2019) that a portion of improvements is made through reductions in leakage of refrigerants from vehicle air conditioning systems. Specifically, this method of compliance means that fleet average fuel economy standards in 2020 decline from 41.7 mpg to 38.9 mpg and in 2025 decline from 54.5 to 49.7 mpg (Lattanzio et al. 2018; Davis and Boundy 2019). These fleet average fuel efficiency standards translate into effective tailpipe fuel efficiency standards for light duty cars and trucks, respectively, of 44.8 and 31.2 mpg in 2020 and 56.2 and 40.3 mpg in 2025 (Davis and Boundy 2019).

In addition, vehicle fuel efficiency was adjusted to account for the difference between CAFE standards and true on-road fuel efficiency as estimated by new car window labels. EPA estimates this difference to range from 20 to 25 percent (EPA 2014). For the purpose of this analysis, it was assumed that the actual fuel efficiency of new vehicles will be 22.5 percent lower than the CAFE standards.

Finally, to derive the average fuel efficiency of all new LDVs, the adjusted CAFE standards for cars and light trucks were weighted based on current sales of cars and light trucks. The share of sales for cars and light trucks (including vans and sports utility vehicles) in 2017 was obtained from Hawaii Automobile Dealers Association sales records as reported by DBEDT (2018c). In 2017 there were a total of 59,137 new car and light truck registrations in Hawaii. Of those, 21,804 or 36 percent were cars.

The average fuel efficiency of all new LDVs accounting for adjustment for true on-road efficiency (compared to CAFE) was then calculated using the following equation:

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

where,

$FE(t)_{new}$	= Fleet fuel efficiency for new LDV in year *t* (mpg)
$S(t)_{cars}$	= Share of sales for cars in year *t* (%)
$CAFE(t)_{cars}$	= CAFE standards for cars in year *t* (mpg)
$CAFE(t)_{trucks}$	= CAFE standards for light trucks in year *t* (mpg)
A	= Adjustment of CAFE for on-road fuel economy

Average fuel efficiency of the existing fleet. The average fuel efficiency for all LVDs on the road in 2016 was calculated by dividing total miles traveled as reported by DBEDT (2019b) by LDV gasoline consumption, as derived from the ground transportation gasoline consumption estimate used to prepare the 2016 statewide inventory (ICF 2016).

$$FE(2016)_{fleet} = VMT(2016) \Big/ C(2016)_{gasoline}$$

where,

$FE(2016)_{fleet}$	= Fleet fuel efficiency for all LDVs in 2016 (mpg)
$C(2016)_{gasoline}$	= E10 gasoline consumed by LDVs in 2016 (gal)
$VMT(2016)$	= LDV VMT in 2016 (miles)

Fleet fuel efficiency in future years. Each year, a certain percentage of vehicle miles is traveled by new vehicles while the rest is traveled by vehicles in the existing fleet. New vehicles tend to drive relatively further than older vehicles. For this analysis, approximately 8 percent of vehicle miles are assumed to be driven by new vehicles each year, which is derived from estimates of LDV VMT by model year as obtained from the U.S. Inventory (EPA 2018a).[73] Taking the average fuel efficiency of vehicles in 2016 and the share of miles driven by new vehicles on the road each year, fleet fuel efficiency for future years was calculated using the following equation:

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

where,

VMT_{LDVnew}	= Share of miles driven by new vehicles on the road annually (%)
$FE(t)fleet$	= Fleet fuel efficiency for all LDVs in year *t* (mpg)
$FE(t-1)_{fleet}$	= Fleet fuel efficiency for all vehicles in year *t-1* (mpg)
$FE(t)_{new}$	= Fuel efficiency for new vehicles in year *t* (mpg)

Future LDV VMT. To estimate future LDV VMT, the team estimated an Ordinary Least Squares regression between historical GSP (UHERO 2018) and LDV VMT (DBEDT 2018d) from 1984 to 2017.[74] Using the DBEDT forecast to project forward GSP, LDV VMT was then calculated using the following equation:

$$VMT(t) = 409 + 0.122 \times GSP(t)$$

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*

Future LDV Electric Vehicle (EV) VMT. Vehicles miles traveled by EVs 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 7 percent of new car sales in 2020 and 11 percent in 2025.[75]

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[73] The share of miles driven by new vehicles is estimated based on new vehicle data for 2007 because 2007 is believed to be a relatively representative year in terms of typical vehicle sales.
[74] This time frame is chosen because there is a break in the data in 1983.
[75] For comparison, EVs comprised 1.5 percent of new car sales in 2015, 1.4 percent in 2016, 2.3 percent in 2017 and 2.6 percent in 2018 (Alliance of Automobile Manufacturers 2019).

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

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*

LDV gasoline consumption. To estimate LDV gasoline consumption, VMT was divided by the fuel efficiency of the LDV fleet. The energy consumed by EVs was removed from total energy consumption by LDVs 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.

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

where,

$C(t)_{gasolineblend}$	= Total LDV gasoline (E10) 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* (mpg)
$VMT(t)_{EV}$	= EV VMT in year *t* (Billions of miles)
$FE(t)_{EV}$	= Fuel efficiency of EV in year *t* (mpg)

Emissions from LDV. It is assumed in the baseline that all gasoline consumed in Hawaii is E10—a blend of 10 percent ethanol and 90 percent pure motor gasoline by volume. To calculate the quantity of petroleum motor gasoline consumed, total LDV gasoline consumption was multiplied by 0.9. Carbon dioxide emissions from LDV were then calculated by multiplying petroleum motor gasoline consumption by emission factors obtained from the U.S. Inventory (EPA 2018a).

For CH_4 and N_2O emissions associated with combustion of petroleum gasoline, the fleet average per mile emissions factors was multiplied by annual VMT for non-EV LDVs. The fleet average per mile emissions factor was calculated using the following equation:

$$EF(g,t)_{fleet} = 1 \Big/ \left(\frac{1 - VMT_{LDVnew}}{EF(g,t-1)_{fleet}} + \frac{VMT_{LDVnew}}{EF(g,t)_{new}} \right)$$

where,

VMT_{LDVnew}	= Share of miles driven by new vehicles on the road annually (%)
$\mathrm{EF(g,t)_{fleet}}$	= Fleet average emissions factor for all LDVs in year *t* for gas *g* (g/mile)
$\mathrm{EF(g,t\text{-}1)_{fleet}}$	= Fleet average emissions factor for all LDVs in year *t-1* for gas *g* (g/mile)
$\mathrm{EF(g,t)_{new}}$	= Average emissions factor for new LDVs in year *t* for gas *g* (g/mile)

Heavy Duty Vehicles

For heavy duty trucks,[76] diesel consumption was estimated based on future VMT and fuel efficiency. Heavy duty VMT is assumed to grow at the rate of GSP, which was projected based on the DBEDT forecast. The fuel efficiency of the HDV fleet in 2016 was estimated to be 7.4 mpg, based on the average fuel consumption per vehicle of all HDVs over 10,000 pounds (DOT 2017). The fuel efficiency of new trucks is assumed to increase over time in proportion with the increase in EPA's fuel efficiency standards for HDVs (EPA 2016). Specifically, vehicle efficiency standards for new HDVs increase by about 10 percent from 2010 to 2016. Vehicle efficiency in 2010 was 7.3 mpg; therefore, the vehicle efficiency of new HDVs in 2016 is estimated to be 8.0 mpg (EPA 2016). From 2016 to 2025, efficiency of new HDVs is assumed to increase from 8.0 mpg to 8.9 mpg, consistent with the change in efficiency standards for heavy duty vehicles over this period.

For this analysis, approximately 9 percent of vehicle miles are assumed to be driven by new vehicles each year, which is derived from estimates of HDV VMT by model year as obtained from the U.S. Inventory (EPA 2018a).[77] Using this information, the fleet average fuel efficiency for HDVs was calculated using the following equation:

$$FE(t)_{HDVfleet} = 1 \Big/ \left(\frac{1 - VMT_{HDVnew}}{FE(t-1)_{HDVfleet}} + \frac{VMT_{HDVnew}}{FE(t)_{HDVnew}} \right)$$

where,

VMT_{HDVnew}	= Share of miles driven by new vehicles on the road annually (%)
$FE(t)_{HDVfleet}$	= Fleet fuel efficiency for all HDV in year *t* (mpg)
$FE(t-1)_{HDVfleet}$	= Fleet fuel efficiency for new HDV in year *t-1* (mpg)
$FE(t)_{HDVnew}$	= Fleet fuel efficiency for new HDV in year *t* (mpg)

Fuel consumption by HDVs was then calculated using the following equation:

$$C(t)_{totaldiesel} = VMT(t)_{HDV} \big/ FE(t)_{HDVfleet}$$

where,

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

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. Carbon

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[76] 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.

[77] The share of miles driven by new vehicles is estimated based on new vehicle data for 2007 because 2007 is believed to be a relatively representative year in terms of typical vehicle sales.

dioxide emissions from HDVs were then calculated by multiplying fossil fuel diesel consumption by emission factors obtained from the U.S. Inventory (EPA 2018a).

For CH_4 and N_2O emissions associated with combustion of petroleum diesel, the fleet average per mile emissions factors was multiplied by annual VMT for HDVs. The fleet average per mile emissions factor was calculated using the following equation:

$$EF(g,t)_{fleet} = 1 \Big/ \left(\frac{1 - VMT_{HDVnew}}{EF(g,t-1)_{fleet}} + \frac{VMT_{HDVnew}}{EF(g,t)_{new}} \right)$$

where,

VMT_{HDVnew}	= Share of miles driven by new vehicles on the road annually (%)
$\mathrm{EF(g,t)_{fleet}}$	= Fleet average emissions factor for all HDVs in year *t* for gas *g* (g/mile)
$\mathrm{EF(g,t\text{-}1)_{fleet}}$	= Fleet average emissions factor for all HDVs in year *t-1* for gas *g* (g/mile)
$\mathrm{EF(g,t)_{new}}$	= Average emissions factor for new HDVs in year *t* for gas *g* (g/mile)

Motorcycles

Emissions from motorcycles were calculated based on the average fuel efficiency of motorcycles and the total annual VMT for motorcycles. Data on the total VMT for motorcycles in Hawaii in 2016 were obtained from the U.S. Inventory (EPA 2018a). Total VMT for motorcycles is assumed to grow at the rate of GSP, which was projected based on the DBEDT forecast. The average fuel efficiency of motorcycles was assumed to be 44 mpg (DOT 2017). Motorcycle gasoline consumption was then calculated using the following equation:

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

where,

$C(t)_{gasoline}$	= Total motorcycle gasoline consumption in year *t* (gallons)
$FE(t)_{Motorcycles}$	= Fuel efficiency for motorcycles (mpg)
$VMT(t)_{Motorcycles}$	= Motorcycle VMT in year *t* (miles)

Carbon dioxide emissions from motorcycles were calculated by multiplying gasoline consumption by emissions factors obtained from the U.S. Inventory (EPA 2018a). Methane and N_2O emissions were calculated by multiplying motorcycle VMT by emissions factors obtained from the U.S. Inventory (EPA 2018a).

Domestic Aviation

Emissions from domestic aviation were projected based on the DBEDT forecast and assumptions regarding energy efficiency. Jet fuel consumption was assumed to grow at the rate of GSP, which was projected based on the DBEDT 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.

$$C(t)_{Jetfuel} = C(2016)_{Jetfuel} * G(t)_{GSP} * (1 - E)^\wedge(\mathrm{t} - 2016)$$

where,

$C(t)_{Jetfuel}$	= Total jet fuel consumption in year *t* (B Btu)
$C(2016)_{Jetfuel}$	= Total jet fuel consumption in 2016 (B Btu)
$G(t)_{GSP}$	= Growth in GSP in year *t* relative to 2016
E	= Annual efficiency gains (%)

Emissions from domestic aviation were calculated by multiplying jet fuel consumption by emissions factors obtained from the U.S. Inventory (EPA 2018a).

Domestic Marine, Military Aviation, and Military Non-Aviation

Emission projections were not developed for domestic marine or military. Instead, future emissions are assumed to remain constant relative to 2016. For domestic marine, emissions were not projected due to inconsistencies in the historical 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.

Alternate Scenario 1A and 1B

As described under the stationary combustion section above, future energy prices, especially oil prices, is one of the greatest sources of uncertainty that will affect future GHG emissions. Under this scenario, the potential effect of oil prices on future emissions from ground and air transportation were quantified using the future crude oil prices projected by AEO 2019 (see Table K-2).

Ground Transportation

<u>Light Duty Vehicles</u>

To estimate the impact of a price change on LDV fossil fuel demand, the percent change in gasoline price between each price pathway and the reference case was multiplied by the price elasticity of demand for gasoline. Based on recent literature, this analysis assumes that the elasticity is -0.3 for both 2020 and 2025 (Levin et al. 2016; Hossinger et al. 2017).[78] The change in demand for LDV gasoline for each scenario was then calculated based on the following equation:

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[78] To understand the sensitivity of LDV fuel demand to changing gasoline prices, studies estimating elasticities for both gasoline demand as well as changes to VMT were reviewed. There is considerable debate as to the magnitude of price elasticity within the ground transportation sector, mainly due to the complex nature of demand. However, studies concur that demand is inelastic. In a review of twenty-five studies, the short-run elasticity of fuel demand ranged from a low of -0.03 to a high of -0.51 (Hossinger et al. 2017). In the long-run, it ranged from 0.09 to -0.98. Hughes et al. (2008) note a major difference in findings between studies focusing on two periods of similarly high prices, 1975 to 1980 and 2001 to 2006. Within their review, short-run price elasticities range from -0.034 to -0.077 during 2001 to 2006 and -0.21 to -0.34 for 1975 to 1980, suggesting that markets have become less price

$$\%\Delta LDV_{t,s} = \sigma_t \times \%\Delta GP_{t,s}$$

where,

$\%\Delta LDV_{t,s}$	= The percent change in LDV gasoline demand in year *t* under scenario *s*
σ_t	= The price elasticity of LDV gasoline demand in year *t*, -0.3
$\%\Delta GP_{t,s}$	= The percent change in gasoline price in year *t* under scenario *s*

As a last step, the percent change in gasoline demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions, accordingly.

Heavy Duty Vehicles

To estimate the sensitivity of HDV fuel demand to changing diesel prices, AEO's low and high oil and gas resource and technologies cases were first used to compute the price elasticity of demand for transportation diesel. Specifically, the price elasticity of demand for transportation diesel for a given year was calculated using the following equation:

$$\sigma_t = (D_{t,high} - D_{t,low})/D_{t,low} * P_{t,low}/(P_{t,high} - P_{t,low})$$

where,

$D_{t,high}$	= The AEO demand for HDV diesel in year *t* and the *high* price scenario
$D_{t,low}$	= The AEO demand for HDV diesel in year *t* and the *low* price scenario
$P_{t,high}$	= The AEO price of HDV diesel in year *t* and the *high* price scenario
$P_{t,low}$	= The AEO price of HDV diesel in year *t* and the low price scenario
σ_t	= The estimated price elasticity of HDV diesel demand for year *t*

To improve on the robustness of the estimate for elasticity, the elasticity for each year from 2020 to 2025 was computed and the average of these six numbers was used as the elasticity estimate. Averaging these values over the six years yields an estimate for σ of -0.46. The change in demand for HDV diesel under each scenario was then calculated based on the following equation:

$$\%\Delta HDV_{t,s} = \sigma \times \%\Delta DP_{t,s}$$

where,

$\%\Delta HDV_{t,s}$	= The percent change in HDV diesel demand in year *t* under scenario *s*
σ	= The price elasticity of HDV diesel demand, -0.46
$\%\Delta DPt,s$	= The percent change in diesel price in year *t* under scenario *s*

responsive. Levin et al. (2016) critique the findings of studies that use aggregate level demand data. They use high frequency data from credit card transactions to conclude that the price elasticity of demand of this more detailed data is an order of magnitude larger than studies that use aggregated data (such as Hughes et al. 2008). For the purposes of this work, Levin et al. (2016)'s finding of a price elasticity of demand for gasoline are used for LDVs (-0.3 for both 2020 and 2025), which is also near the mid-point of estimates found by Hossinger et al. (2017).

As a last step, the percent change in diesel demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions, accordingly.

Domestic Aviation

To estimate the sensitivity of aviation fuel demand to changing fuel prices, the same methodology used to calculate the sensitivity of HDV fuel demand to changing diesel prices was applied to aviation fuel. Specifically, AEO's low and high oil and gas resource and technologies cases were first used to compute the price elasticity of demand for aviation fuel using the following equation:

$$\sigma_t = (D_{t,high} - D_{t,low})/D_{t,low} * \ P_{t,low}/(P_{t,high} - P_{t,low})$$

where,

$D_{t,high}$	= The AEO demand for aviation fuel in year *t* and the *high* price scenario
$D_{t,low}$	= The AEO demand for aviation fuel in year *t* and the *low* price scenario
$P_{t,high}$	= The AEO price of aviation fuel in year *t* and the *high* price scenario
$P_{t,low}$	= The AEO price of aviation fuel in year *t* and the low price scenario
σ_t	= The estimated price elasticity of aviation fuel demand for year *t*

Averaging the values of σ_t over the six years yields an estimate for σ of -0.14. The change in demand for aviation fuel under each scenario was then calculated based on the following equation:

$$\%\Delta A_{t,s} = \sigma \times \%\Delta AP_{t,s}$$

where,

$\%\Delta A_{t,s}$	= The percent change in aviation fuel demand in year *t* under scenario *s*
σ	= The price elasticity of aviation fuel demand, -0.46
$\%\Delta AP_{t,s}$	= The percent change in aviation fuel price in year *t* under scenario *s*

As a last step, the percent change in aviation fuel demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions, accordingly.

Alternate Scenario 3A and 3B

There are a number of notable uncertainties associated with projecting emissions from the ground transportation sector. To quantify these uncertainties, this scenario accounts for potential variations in (1) the adoption of EVs; (2) the implementation of the U.S. Renewable Fuel Standard; 3) the share of cars versus light trucks on the road; and (4) future VMT.[79] Specifically, to estimate a low GHG emissions

[79] While Alternate Scenario 3 considers changes to the deployment of ground transportation technology, fuels, and driving behaviors, it does not assess the cost of higher levels of technology deployment. This report does not advocate for the implementation of a specific type of policy to achieve higher levels of technology deployment;

(alternate scenario 3A) and a high GHG emissions (alternate scenario 3B) scenario, the following modifications to the baseline assumptions were made:

Low GHG Emissions Scenario Assumptions (Alternate Scenario 3A)

- EVs reach 10 and 19 percent of new car sales in 2020 and 2025, respectively.[80]
- Diesel contains 20 percent biodiesel (B20) by 2025.
- Gasoline contains 15 percent ethanol (E15) by 2025.
- The share of new LDVs that are cars increases to 50 percent.
- VMT remains constant relative to 2018.
- The share of VMT by new gasoline-powered LDVs is assumed to 9.5 percent by 2020.[81]

High GHG Emissions Scenario Assumptions (Alternate Scenario 3B)

- EVs reach 7 and 9 percent of new car sales in 2020 and 2025, respectively.[82]
- There are no improvements in CAFE standards after 2018.
- There are no improvements in HDV efficiency after 2016.
- The share of new car sales continues to decline linearly, reaching 25 percent by 2025.
- The share of VMT by new gasoline-powered LDVs is assumed to 6 percent by 2020.[83]

Uncertainties and Areas for Improvement

As highlighted by the alternate scenarios described above, there is uncertainty associated with future oil prices as well as future trends in VMT, electric vehicle adoption, and biofuel usage. There is also uncertainty regarding the impact of the Honolulu Rail Project on LDV VMT. The Honolulu Authority for Rapid Transportation 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.

In addition, for domestic aviation, jet fuel consumption is projected based on GSP, even though commercial jet fuel consumption from 2010 to 2016 grew by 22 percent, which is inconsistent with GSP, which grew by 10 percent over the same period. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Lastly, 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 2016. Specifically, marine-based diesel fuel consumption decreased by more than 60 percent from 2010 to 2016, which does not align with the activities of the overall economy. This incongruity may be a result of applying DBEDT (2008a) 2007 allocations to 2010, 2015, and 2016 diesel fuel consumption from EIA (2018a) in the absence of more recent disaggregated data. For the military, the data show a similarly large decrease in

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rather, the purpose of this analysis is only to provide a sense of the range of variability of future emissions from Hawaii's ground transportation sector.

[80] Based on Coffman et al. (2015)'s high EV adoption scenario.

[81] Based on the 2016 share of miles driven by new gasoline-powered LDVs.

[82] Based on Coffman et al. (2015)'s low EV adoption scenario.

[83] Based on the 2010 share of miles driven by new gasoline-powered LDVs.

non-aviation fuel consumption from 2010 to 2016. Decisions regarding future military operations in Hawaii are largely external to Hawaii's economy and are not expected to correlate with GSP. Further research into the accuracy and drivers of historical trends may 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 (40:100) from the 2016 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:

$$SG(t) = {(SE_t - SE_{2016})}/{SE_{2016}}$$

where,

$SG(t)$	= Growth in stationary combustion emissions by year t
SE_t	= Stationary combustion emissions in year t
SE_{2016}	= Stationary combustion emissions in 2016

$$TG(t) = {(TE_t - TE_{2016})}/{TE_{2016}}$$

where,

$TG(t)$	= Growth in transportation emissions by year t
TE_t	= Transportation emissions in year t
TE_{2016}	= Transportation emissions in 2016

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

$$OG(t) = \frac{SG(t) \times SE_{2016} + TG(t) \times TE_{2016}}{SE_{2016} + TE_{2016}}$$

where,

$OG(t)$	= Growth in oil emissions by year *t*
$SG(t)$	= Growth in stationary combustion emissions by year *t*
SE_{2016}	= Stationary combustion emissions in 2016
$TG(t)$	= Growth in transportation emissions by year *t*
TE_{2016}	= Transportation emissions in 2016

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

$$OE(t) = OE_{2016} \times OG(t)$$

where,

$OE(t)$	= Oil emissions by year *t*
OE_{2016}	= Oil emissions in 2016
$OG(t)$	= 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).

IPPU

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 2016-2025 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 this report 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.

Substitution of Ozone Depleting Substances

Methodology

Emissions from the substitution of ozone depleting substances (ODS) were assumed to grow at the rate of GSP, which was projected based on the DBEDT forecast. These emissions were then adjusted to account for improvements in transportation-based air conditioning (AC). This adjustment was made based on the assumption that CAFE standards will be met through a combination of improvements to vehicle fuel efficiency and AC systems (Davis and Boundy 2018).

To calculate these reductions, the VMT of new vehicles was multiplied by the difference in the fuel efficiency of new vehicles that meet the fuel efficiency standard by reductions in tailpipe emissions versus AC improvements (Davis and Boundy 2018), shown by the equation below.

$$R = VMT_{t,v} \times (FE(NoAC)_{t,v} - FE(AC)_{t,v})$$

where,

R	= Reduction in emissions
$VMT_{t,v}$	= VMT for vehicle type *t* and vintage *v* (miles)
$FE(NoAC)_{t,v}$	= Fuel efficiency of vehicle type *t* and vintage *v* with no AC improvements (g CO_2e/mile)
$FE(AC)_{t,v}$	= Fuel efficiency of vehicle type *t* and vintage *v* with AC improvements (g CO_2e/mile)

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. It also assumes that the CAFE standards will lead to reductions in HFC emissions. Due to recent court challenges and a lack of support by the current administration, other 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 in this analysis. These regulations largely target new installations; therefore, even if these other policies were implemented, the impact of these regulations on HFC emissions in the near-term are expected to be minimal. Further review of these policies and their impact on emissions may be considered in future work.

AFOLU

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 2016 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 2019b) and the USDA Census of Agriculture (USDA 2009, USDA 2014, USDA 2019a). Annually variable enteric fermentation emission factors were projected using the ten-year average by cattle type from the U.S. Inventory (EPA 2018a). 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 reported every five years in the USDA Census of Agriculture. As a result, historical estimates for these animals are interpolated between years up to 2017, the most recent year of reported data. 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 2016 emissions. Animal population data were projected based on the trend of the last ten years of data, as obtained from the USDA NASS (USDA 2019b) and the USDA Census of Agriculture (USDA 2009, USDA 2014, USDA 2019a). 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 2018a; EPA 2018e). 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 2018a). 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 2018a), 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 reported every five years in the USDA Census of Agriculture. As a result, historical estimates for these animals are interpolated between years up to 2017, the most recent year of reported data. 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 2016 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 2019b) and the USDA Census of Agriculture (USDA 2009, USDA 2014, USDA 2019a). 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 2018 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 2009, USDA 2014, USDA 2019a). For pineapple 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 2018a). 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 reported every five years in the USDA Census of Agriculture. As a result, historical estimates for these data are interpolated between years up to 2017, the latest year of reported data. Historical fertilizer consumption data are also extrapolated out to 2016 based on data available through 2014. 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 2018 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 2016 emissions. Fertilizer consumption data were projected based on the five-year historical trend (AAPFCO 2011 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 2016 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 2016 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). Total 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 2018d). Forest and shrubland area burned were projected by applying the average annual percent of area burned that is forest or shrubland from USGS (Selmants et al. 2017) to the projected estimate of wildfire acres burned in 2020 and 2025.

Emission factors for CO_2 by forest type and moisture scenario from USGS and emission factors for CH_4 and N_2O were obtained from IPCC (2006) and were assumed to remain constant.

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 the percent of area burned that is forest or shrubland will remain constant. This methodology does not consider inter-annual variability in the percent of forest and shrubland area burned. Further research into the annual changes in the percent of forest vs. shrubland burned 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 2016 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 2018f). 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 2018d) 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 2018f) 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 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 2016 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 2016 estimate of urban area to project 2020 and 2025 estimates. The estimated carbon sequestration rates for urban trees in Honolulu and the percent tree cover in urban areas in Honolulu, as well the state of Hawaii were assumed to remain constant with 2016 estimates (Vargas et al. 2007; Nowak et al. 2012, 2018a, 2018b; MacFaden et al. 2016).

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 2016 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 2018d).

Average net C sequestration rates by forest type in Hawaii from 2004 through 2013 were obtained from USGS (Selmants et al. 2017). These estimates were 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). To obtain annual net C flux, the total of net sequestration rates for native and invaded mesic-wet forest, dry forest, and alien tree plantations was applied to forest area, while the net sequestration rate for shrubland was applied to shrubland area.

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 annual changes in 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.

Waste

Landfills

Methodology

Emissions from landfills are assumed to grow at the rate of GSP, which was projected based on the DBEDT forecast (DBEDT 2018e).

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 DBEDT forecast (DBEDT 2018e).

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. This 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 DBEDT forecast (DBEDT 2018e).[84]

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.

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[84] The City and County of Honolulu in 2018 implemented a biogas project at the Honouliuli Wastewater Treatment Plant. Each year the project will capture and reuse 800,000 therms of biogas (County & City of Honolulu 2018b). While this biogas may be used to displace other fuel types used to generate energy and therefore lead to emission reductions from the energy sector, this activity is outside the scope of the Waste sector and, for accounting purposes, does not lead to a reduction in GHG emissions from wastewater treatment.

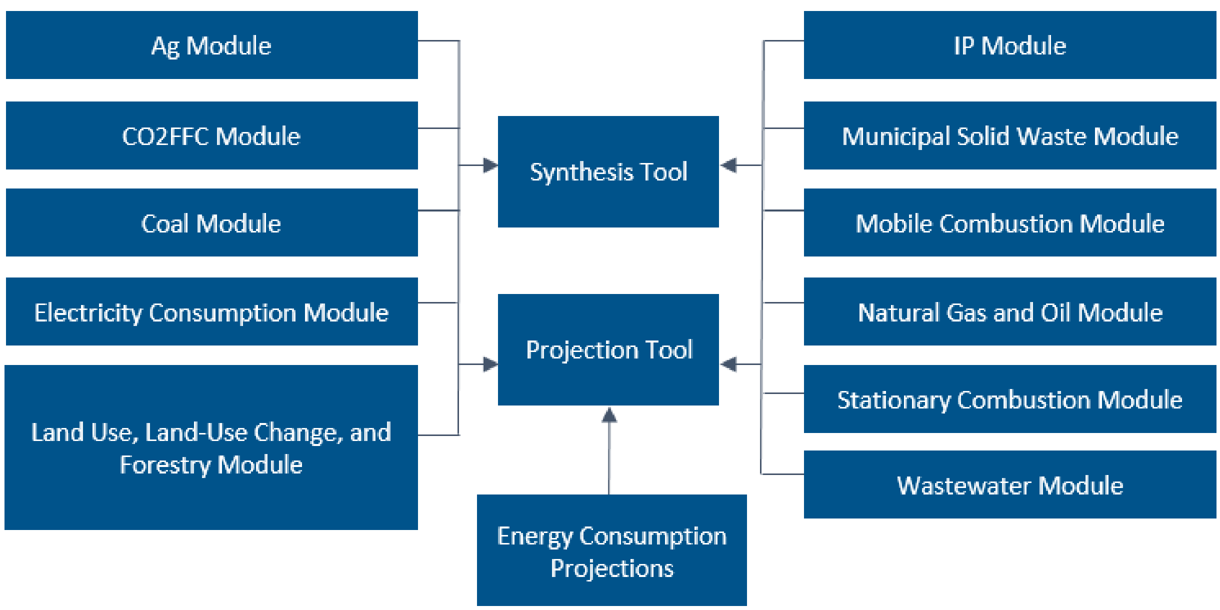
Appendix L. Comparison of Results with the State Inventory Tool and Projection Tool

EPA's State Inventory and Projection Tool is an interactive spreadsheet model designed to help states develop GHG emissions inventories. 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 L-1 below provides an overview of the files that make up the SIT and projection tool.

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

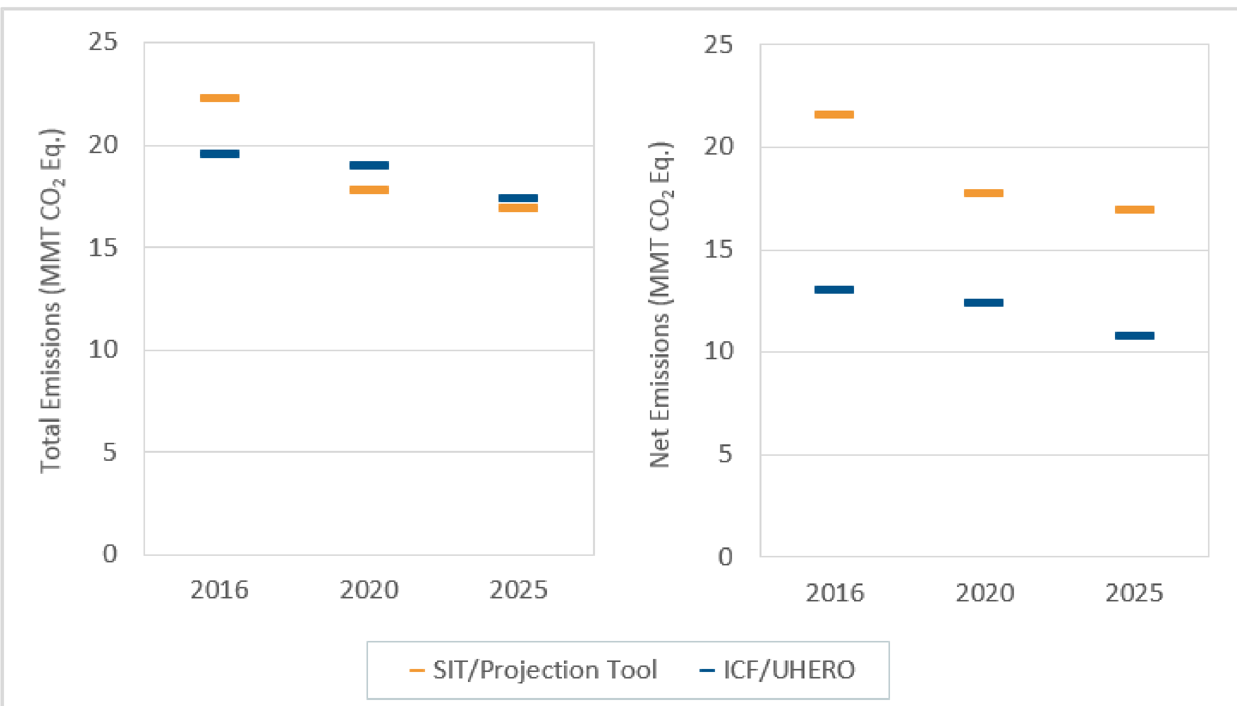


In an effort to evaluate the accuracy and usability of the SIT and Projection Tool estimates for the state of Hawaii, ICF ran the tool for Hawaii using default values and compared the output against the 2016 inventory and the inventory projections for 2020 and 2025, as developed by ICF and UHERO.[85] This appendix presents the results of this comparison.

Key Observations and Conclusions

The difference between the SIT and ICF's estimate of total GHG emissions for Hawaii in 2016 is 14 percent while the difference in net GHG emissions is 65 percent. The difference in total emissions is largely due to the inclusion of international bunker fuels in the SIT estimates (ICF's estimate excludes international bunker fuels), while the difference in net emissions is largely due to the lack of default forest carbon flux data available in the SIT as well as the inclusion of international bunker fuels. Total GHG emissions for Hawaii is 6 percent lower in 2020 using the Projection Tool compared to ICF/UHERO's analysis, and 3 percent lower in 2025. Net GHG emissions for Hawaii is 43 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, and 57 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. Total and net emissions for 2016, 2020, and 2025, as estimated by ICF/UHERO and the SIT/Projection Tool, are shown in Figure L-2.

Figure L-2: Comparison of Total and Net GHG Emission Estimates (2016, 2020, and 2025)



[85] The SIT and Projection Tool are available online at https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool. The SIT modules, Synthesis Tool, and Projection Tool used for this analysis were downloaded from EPA's website in January 2019.

Key observations from using the SIT for 2016 GHG estimates include the following:

- About 62 percent of the difference in net emissions is from Forest Carbon (see Table L-2). The SIT does not provide default data for estimating Forest Carbon sinks.
- About 54 percent of the difference in total emissions and 17 percent of the difference in net emissions is from Transportation (see Table L-2). The SIT includes emissions from international bunker fuels in its Transportation estimates.
- Estimates for six categories comprise 93 percent of the difference in net emissions between the SIT and ICF analysis. These include Forest Carbon, Transportation, Stationary Combustion, Urban Trees, Iron & Steel Production, and Incineration of Waste.
- Relative to ICF's estimates, the SIT estimated higher emissions from the Energy, IPPU, and Waste sectors, but lower emissions from AFOLU emission sources.

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.
- About 77 percent of the difference in 2020 net emission projections is from Forest Carbon, Stationary Combustion, and Transportation source and sink categories (see Table L-4).
- The estimate for Stationary Combustion is 25 percent lower in 2020 using the SIT (however, it is only 3 percent lower in 2025).
- Roughly 77 percent of the difference in 2025 net emission projections are from the Forest Carbon, Substitution of ODS, and Iron & Steel Production source and sink categories (see Table L-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 in both 2020 and 2025.
- Relative to ICF/UHERO's estimates, the Projection Tool estimates higher emissions from the Waste sector in 2020, but lower emissions in 2025.

Detailed results and observations can be found in the body of this report.

Next Steps for Future Analyses

In subsequent iterations of this analysis, ICF will continue to 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 for suggestion to EPA.

Comparison of Results

To compare the results from the SIT against the 2016 inventory developed by ICF, results from each of estimation modules were compared against the source and sink categories defined in the 2016 inventory.[86] Figure L-3 summarizes how the results from the SIT were mapped to the 2016 inventory.

Figure L-3: Mapping of SIT Modules to Hawaii's 2016 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)
	Urea Application	Ag (Urea Fertilization)
	Liming	Ag (Liming)
	Forest Carbon	LULUCF (Forest Carbon Flux)
	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	

[86] 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.

2016 Inventory Comparison

For the state of Hawaii, ICF estimates that in 2016 total GHG emissions were 19.58 MMT CO_2 Eq., while the SIT estimates 22.33 MMT CO_2 Eq., a difference of 14 percent. At the same time, ICF estimate that in 2016 net emissions were 13.07 MMT CO_2 Eq., while the SIT estimates 21.60 MMT CO_2 Eq., a difference of 65 percent. A summary of 2016 emissions and sinks by sector and category, as estimated by ICF and the SIT, are provided in Table L-1.

Table L-1: Comparison of 2016 Emission Results (MMT CO_2 Eq.)

Sector/Category	ICF	SIT	Difference	% Difference
Energy	**16.94**	**19.18**	**2.25**	**13%**
Stationary Combustion	7.79	8.26	0.48	6%
Transportation[a]	8.69	10.39	1.70	20%
Incineration of Waste	0.27	0.53	0.26	98%
Oil and Natural Gas Systems[b]	0.19	NE	(0.19)	NA
IPPU	**0.78**	**1.03**	**0.25**	**32%**
Electrical Transmission and Distribution	0.01	0.01	+	3%
Substitution of ODS	0.77	0.70	(0.06)	(8%)
Soda Ash Manufacture and Consumption[c]	NO	0.01	0.01	NA
Urea Consumption[c]	NO	+	+	NA
Iron and Steel Production[c]	NO	0.30	0.30	NA
AFOLU	**(5.43)**	**0.40**	**5.83**	**107%**
Enteric Fermentation	0.25	0.25	+	0%
Manure Management	0.04	0.04	0.01	13%
Agricultural Soil Management	0.16	0.20	0.04	22%
Field Burning of Agricultural Residues	0.01	NO	(0.01)	NA
Urea Application	+	+	+	(7%)
Agricultural Soil Carbon	0.55	0.62	0.07	13%
Forest Fires[b]	0.07	NE	(0.07)	NA
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.05)	+	(8%)
Urban Trees	(0.33)	(0.68)	(0.27)	66%
Forest Carbon[b]	(6.13)	NE	6.13	NA
Liming	NO	NO	NA	NA
N_2O from Settlement Soils[d]	NE	0.01	0.01	NA
Waste	**0.78**	**0.99**	**0.21**	**27%**
Landfills	0.69	0.83	0.14	20%
Composting[e]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.07	0.16	0.09	121%
Total Emissions (Excluding Sinks)	**19.58**	**22.33**	**2.75**	**14%**
Net Emissions (Including Sinks)	**13.07**	**21.60**	**8.53**	**65%**

+ Does not exceed 0.005 MMT CO_2 Eq.

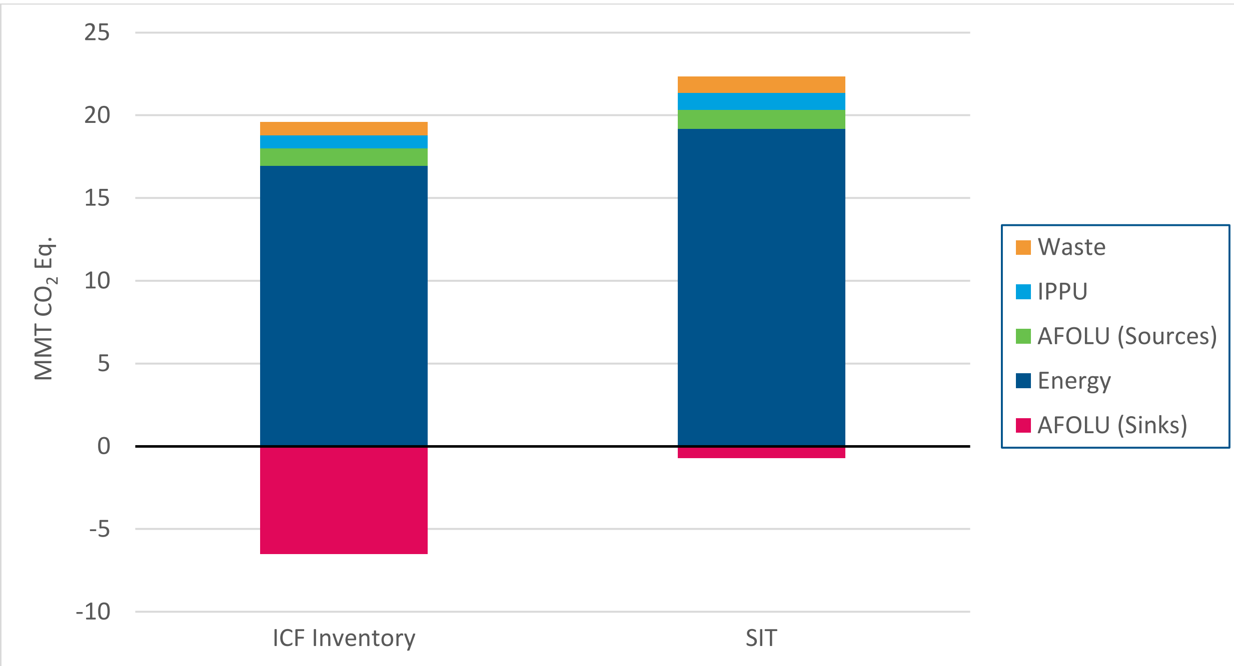
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[a] The SIT includes emissions from international bunker fuels.

[b] The SIT does not provide default data for Oil and Natural Gas Systems, Forest Fires, or Forest Carbon.
[c] ICF estimates that this activity is not applicable to Hawaii, and therefore emissions are not occurring.
[d] ICF did not estimate emissions from N_2O from Settlement Soils due to lack of available state-specific data.
[e] 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 L-4.

Figure L-4: Comparison of 2016 Emission Results (Including Sinks)



The difference in emission estimates between ICF's Inventory and the SIT are driven by differences in six source and sink categories, which account for 91 percent of the absolute difference. Table L-2 summarizes the absolute and cumulative difference in emission estimates for these seven categories.

Table L-2: Key Sources of Differences between ICF Inventory and SIT 2016 Emission Results

Category	ICF	SIT	Absolute Difference	Cumulative % of Total Difference
Forest Carbon	(6.13)	NE	6.13	62%
Transportation	8.69	10.39	1.70	79%
Stationary Combustion	7.79	8.26	0.48	84%
Urban Trees	(0.33)	(0.68)	0.35	87%
Iron & Steel Production	NO	0.30	0.30	90%
Incineration of Waste	0.27	0.53	0.26	93%
All Other Categories			0.71	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 19.26 MMT CO_2 Eq., while net emissions are projected to be 12.61 MMT CO_2 Eq. The Projection Tool, which does not project emissions from LULUCF categories, projects total and net emissions in 2020 to be 17.79 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 L-3.

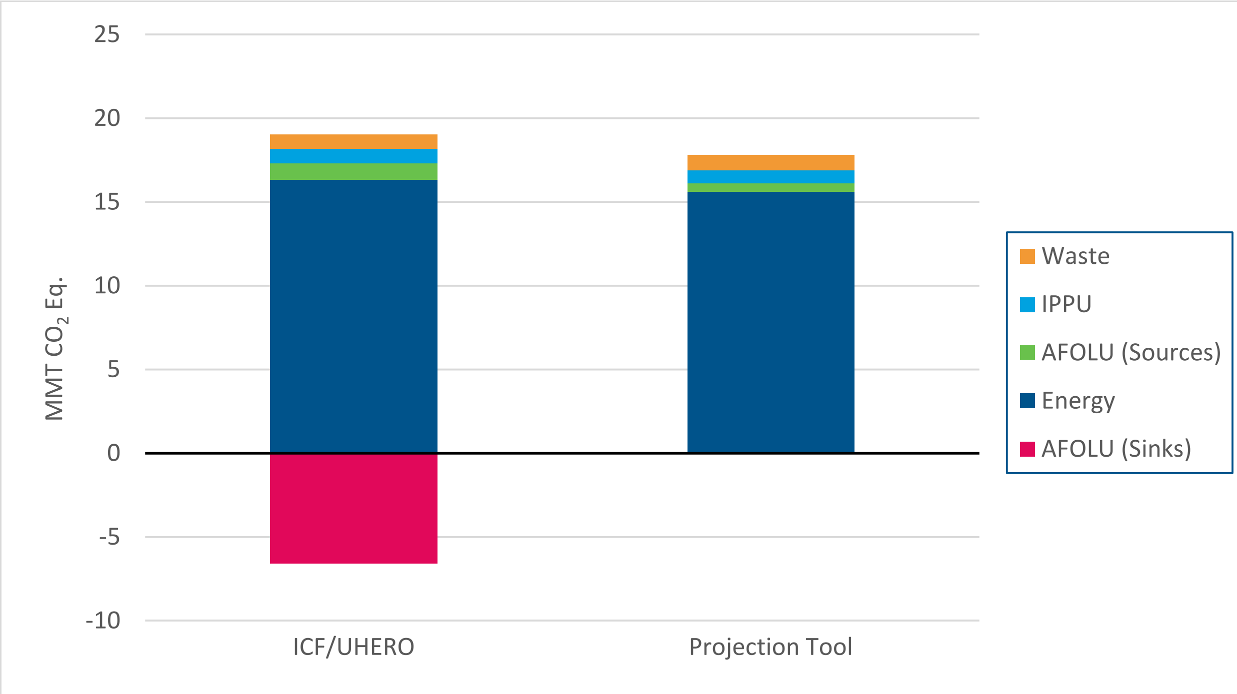
Table L-3: Comparison of 2020 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**16.31**	**15.61**	**(0.70)**	**(4%)**
Stationary Combustion	6.81	5.14	(1.68)	(25%)
Transportation	9.05	9.88	0.83	9%
Incineration of Waste	0.27	0.59	0.32	118%
Oil and Natural Gas Systems	0.19	0.01	(0.17)	(94%)
IPPU	**0.85**	**0.76**	**(0.10)**	**(11%)**
Electrical Transmission and Distribution	0.01	0.01	+	(22%)
Substitution of ODS	0.84	0.28	(0.56)	(66%)
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	0.46	0.46	NA
AFOLU[a]	**(5.56)**	**0.52**	**5.92**	**NA**
Enteric Fermentation	0.25	0.27	0.02	8%
Manure Management	0.03	0.05	0.01	31%
Agricultural Soil Management	0.17	0.21	0.04	24%
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]	0.04	NE	(0.04)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.05)	NE	0.05	NA
Urban Trees[a]	(0.35)	NE	0.35	NA
Forest Carbon[a]	(6.17)	NE	6.17	NA
Waste	**0.84**	**0.90**	**0.06**	**7%**
Landfills	0.75	0.74	(0.01)	(1%)
Composting[a]	0.02	N/A	(0.02)	NA
Wastewater Treatment	0.08	0.16	0.08	110%
Total Emissions (Excluding Sinks)	**19.02**	**17.79**	**(1.22)**	**(6%)**
Net Emissions (Including Sinks)	**12.45**	**17.79**	**5.35**	**43%**

+ 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 L-5.

Figure L-5: Comparison of 2020 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 93 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table L-4 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table L-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	(6.17)	NE	6.17	54%
Stationary Combustion	6.81	5.14	1.68	69%
Transportation	9.05	9.88	0.83	77%
Substitution of ODS	0.84	0.28	0.56	82%
Agricultural Soil Carbon	0.51	NE	0.51	86%
Iron & Steel Production	NO	0.46	0.46	90%
Urban Trees	(0.35)	NE	0.35	93%
All Other Categories			0.77	100%

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

2025 Projection Comparison

ICF, with support from UHERO, projects 2025 total GHG emissions to be 17.45 MMT CO_2 Eq., while net emissions are projected to be 10.80 MMT CO_2 Eq. The Projection Tool projects total and net emissions to be 16.94 MMT CO_2 Eq. in 2025. A summary of projected emissions and sinks by sector and category, as estimated by ICF/UHERO and the Projection Tool, are provided in Table L-5 for 2050.

Table L-5: Comparison of 2025 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**14.58**	**14.83**	**0.25**	**2%**
Stationary Combustion	4.77	4.61	(0.16)	(3%)
Transportation	9.33	9.55	0.22	2%
Incineration of Waste	0.29	0.65	0.36	122%
Oil and Natural Gas Systems	0.18	0.01	(0.17)	(93%)
IPPU	**0.99**	**0.88**	**(0.11)**	**(11%)**
Electrical Transmission and Distribution	0.01	0.01	(0.00)	(28%)
Substitution of ODS	0.98	0.36	(0.61)	(63%)
Limestone and Dolomite Use	NO	NO	NO	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.50	0.50	NA
AFOLU[a]	**(5.68)**	**0.47**	**6.15**	**NA**
Enteric Fermentation	0.24	0.22	(0.02)	(8%)
Manure Management	0.03	0.04	0.01	27%
Agricultural Soil Management	0.18	0.20	0.03	15%
Field Burning of Agricultural Residues	NO	NO	NA	NA
Urea Application[a]	+	NE	NA	NA
Agricultural Soil Carbon[a]	0.47	NE	(0.47)	NA
Forest Fires[a]	0.04	NE	(0.04)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.04)	NE	0.04	NA
Urban Trees[a]	(0.38)	NE	0.38	NA
Forest Carbon[a]	(6.22)	NE	6.22	NA
Waste	**0.92**	**0.77**	**(0.15)**	**(16%)**
Landfills	0.82	0.61	(0.21)	(26%)
Composting[a]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.08	0.17	0.08	100%
Total Emissions (Excluding Sinks)	**17.45**	**16.94**	**(0.51)**	**(3%)**
Net Emissions (Including Sinks)	**10.80**	**16.94**	**6.15**	**57%**

+ Does not exceed 0.005 MMT CO_2 Eq.

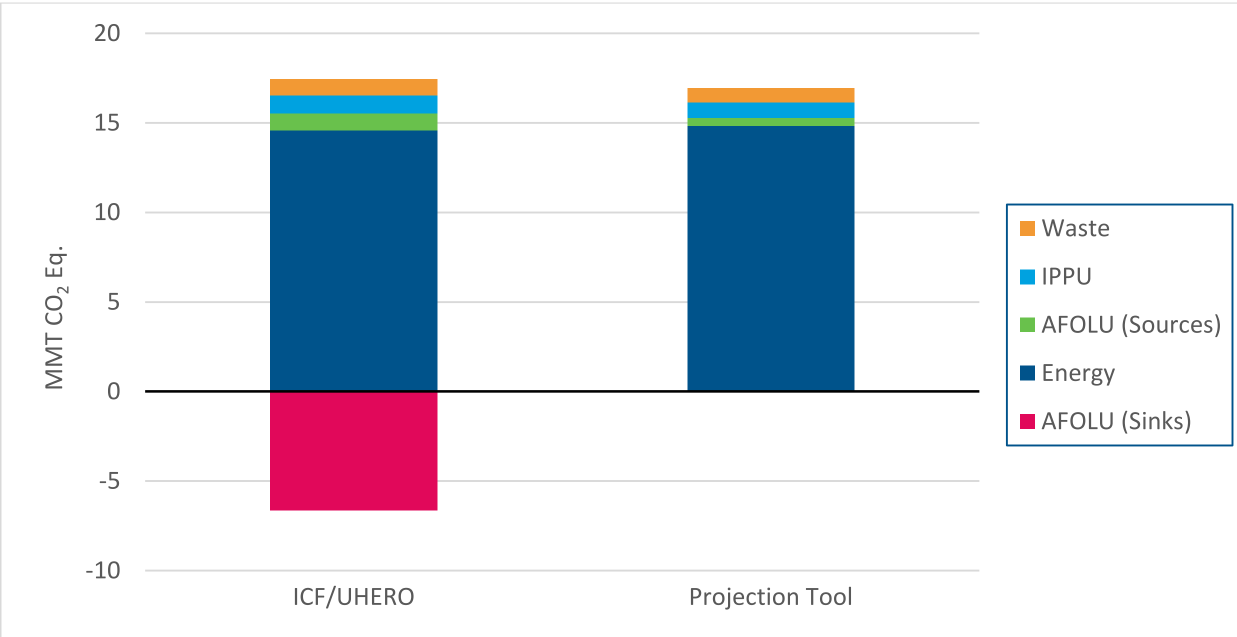
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[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 L-6.

Figure L-6: Comparison of 2025 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 90 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table L-6 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table L-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	(6.22)	N/A	6.22	65%
Substitution of ODS	0.98	0.36	0.61	72%
Iron & Steel Production	NO	0.50	0.50	77%
Agricultural Soil Carbon	0.47	N/A	0.47	82%
Urban Trees	(0.38)	N/A	0.38	86%
Incineration of Waste	0.29	0.65	0.36	89%
Transportation	9.33	9.55	0.22	92%
All Other Categories			0.79	100%

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

Methodology Comparison - 2016 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 2016 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 and activity data used by ICF and SIT to calculate emissions from stationary combustion and transportation are similar. 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 L-7.

Table L-7: Key Differences in Methodology and Data Sources for the Energy Sector

Source	ICF Inventory	SIT
Stationary Combustion	• Fuel consumption data is primarily taken from EIA's SEDS database, with biodiesel and fuel gas data for the energy industries sector coming from EPA's GHGRP. • ICF includes some industrial coal that is not included in the SIT to account for production of synthetic natural gas using naphtha. • ICF does not include petroleum coke consumption in its estimates as it was determined that it is not used in Hawaii.	• Fuel consumption data is taken from EIA's SEDS database and EIA's Natural Gas Annual report. • The SIT excludes some industrial coal consumption to avoid double-counting emissions from the production of synthetic natural gas. • The SIT includes petroleum coke consumption by allocating national consumption to states based on refinery capacity.
Transportation	• Fuel consumption data is taken from EIA's SEDS database. Fuel consumption data collected by DBEDT are used to apportion SEDS data to subsectors • ICF's methodology includes adjusting fuel consumption totals for domestic aviation and domestic marine to exclude bunker fuels from the inventory total.	• Fuel consumption data is taken from EIA's SEDS database. Emissions from alternative fuel vehicles are calculated separately. • Emissions from international bunker fuels are included in the total.
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 L-8.

Table L-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 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 L-9.

Table L-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. • Beef cow population data are taken from USDA NASS.	• Obtains sheep population data from the U.S. Inventory. • Beef cow population data are taken from USDA 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 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 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 2016 based on the historical five-year trend.	• Uses 2014 data from AAPFCO (2017) as a proxy for 2016 urea fertilization.
Agricultural Soil Carbon	• None.	• None.
Forest Fires	• Obtains forest area burned data from the USGS (Selmants et al. 2017).	• Does not include default data of forest area burned.
Landfilled Yard Trimmings	• Hawaii population data were obtained from the State of Hawaii Data Book.	• Hawaii population data were obtained from U.S. Census. • Uses 2015 waste generation data as a proxy for 2016.

Source	ICF Inventory	SIT
	• Extrapolates waste generation to 2016 based on the historical five-year trend.	
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.

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 L-10.

Table L-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- 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 and the Projection Tool to project emissions for each sector are presented in Table L-11. A more detailed description of the methodology and data sources used by ICF/UHERO can be found in Appendix K.

Table L-11: Key Differences in Methodology Used to Project Emissions

Sector	ICF/UHERO	Projection Tool
Energy	• For energy industries, emissions were projected based on direct communication with the utilities and the utility's PSIP. • 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 DBEDT'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 DBEDT'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 historical 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. • Emission sinks are not estimated.
Waste	• Emissions were projected using DBEDT's Macroeconomic Forecast.	• Forecasts activity data based on projected population.