Hawaii Greenhouse Gas Emissions Report for 2017

Final Report

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Prepared for:

HAWAII STATE DEPARTMENT OF HEALTH

Prepared by:

ICF

UHERO
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Acronyms and Abbreviations

AAPFCO	Association of American Plant Food Control Officials
ADI	Airline Data Inc.
AEO	Annual Energy Outlook
AFOLU	Agriculture, Forestry, and Other Land Use
BAU	Business-as-usual
Bbtu	Billion British Thermal Units
BE	Burning efficiency
BOD	Biochemical oxygen demand
BTS	Bureau of Transportation Statistics
CAFE	Corporate average fuel economy
CCAP	Coastal Change Analysis Program
CE	Combustion efficiency
CEFM	Cattle Enteric Fermentation Model
CF	Correction factor
CH_4	Methane
CO_2	Carbon dioxide
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
DSIRE	Database of State Incentives for Renewables & Efficiency
EIA	Energy Information Administration
EIIRP	Energy Industry Information Reporting Program
EPA	U.S. Environmental Protection Agency
EV	Electric vehicle
FE	Fuel Efficiency
FHWA	Federal Highway Administration
FOD	First Order Decay
FOFEM	First-Order Wildland Fire Effect Model
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
GJ	Gigajoules
GSP	Gross state product
GWh	Gigawatt hours

GWP	Global Warming Potential
ha	Hectares
HAR	Hawaii Administrative Rule
HDV	Heavy duty vehicles
HECO	Hawaiian Electric Company
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
IEA	International Energy Agency
IGP	Integrated Grid Plan
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IW	Incinerated waste
kg	Kilogram
KIUC	Kauai Island Utility Cooperative
Kt	Kilotons
kWh	Kilowatt hours
LDV	Light duty vehicles
LMOP	Landfill Methane Outreach Program
LTO	Landings and takeoffs
LULUCF	Land use, land use change, and forestry
MCF	Methane conversion factor
MECO	Maui Electric Company
MT	Metric tons
MT CO_2 Eq.	Metric tons of carbon dioxide equivalent
MMT	Million metric tons
MMT CO_2 Eq.	Million metric tons of carbon dioxide equivalent
MOVES	Motor Vehicle Emission Simulator
MSW	Municipal Solid Waste
MW	Megawatt
N	Nitrogen
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
PDF	Probability density function
PFCs	Perfluorocarbons
PHMSA	Pipeline and Hazardous Materials Safety Administration
PSIP	Power Supply Improvement Plan
PUC	Public Utilities Commission
QA/QC	Quality Assurance/Quality Control
RDF	Refuse-derived fuel
RECs	Residential Energy Consumption Survey
RNG	Renewable Natural Gas
RPS	Renewable Portfolio Standard
SEDS	State Energy Data System
SF_6	Sulfur hexafluoride
SIT	State Inventory Tool
SNAP	Significant New Alternatives Policy
SNG	Synthetic Natural Gas
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
WWTP	Wastewater treatment plant

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 (HAR), 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, 2015, and 2016 emission estimates;[1] inventory estimates for 2017; and emission projections for 2020, 2025, and 2030.

Based on the analysis presented in this report, net GHG emissions (excluding aviation) in 2020 are projected to be lower than net GHG emissions (excluding aviation) in 1990.[2,3] While the development of future inventory reports as well as ongoing quantitative assessment of uncertainties will further inform whether Hawaii met its 2020 statewide target, this report finds that Hawaii is expected to meet the 2020 target.

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.

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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] Net emissions account for both GHG emissions and carbon sinks.

[3] Complete data for 2020 were not available at the time that this report was developed. Therefore, 2020 emission estimates were projected as part of this analysis.

Inventory Scope and Methodology

The GHG emission estimates presented in this report include anthropogenic[4] GHG emissions and sinks for the state of Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017 from the following four sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture, Forestry, and Other Land Use (AFOLU); and Waste. As it is best practice to review GHG emission estimates for prior years, this report includes revised estimates for 1990, 2007, 2010, 2015, 2016 and newly developed estimates for 2017. 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 2020a). 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: 1990-2018*, 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.[5] 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.

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

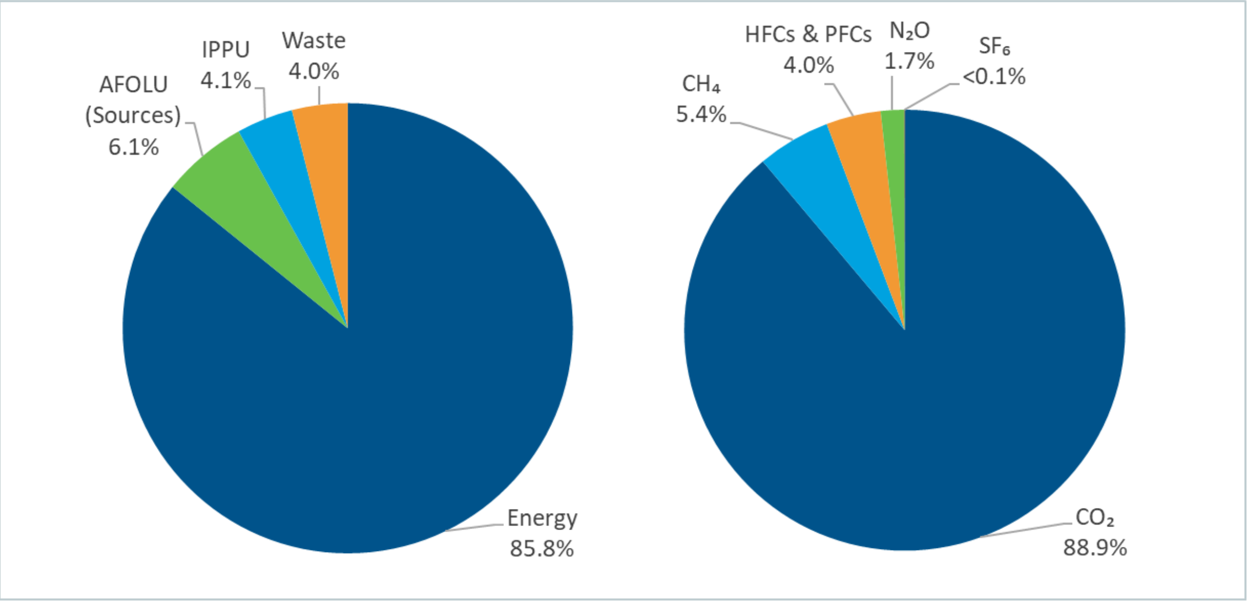
[5] The review team included representatives from the Hawaii Department of Business, Economic Development and Tourism (DBEDT), Division of Consumer Advocacy (DCA), and Public Utilities Commission (PUC).

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 2020a). For this report, quantitative 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. 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 2017, total GHG emissions in Hawaii were 20.56 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). Net emissions, which take into account carbon sinks, were 17.87 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (86 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 2017, 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), N_2O (2 percent), and SF_6 (less than 0.1 percent). Figure ES-1 shows emissions for 2017 by sector and gas.

Figure ES-1: Hawaii 2017 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 20 percent between 1990 and 2007 before falling 19 percent between 2007 and 2010 and another 3 percent between 2010 and 2015.[6] Between 2015 and 2017, emissions in Hawaii remained relatively constant, changing by less than 0.1 percent. Compared to 1990, total emissions in Hawaii in 2017 were roughly 6 percent lower, while net emissions were lower by roughly 8 percent. 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, 2016, and 2017)

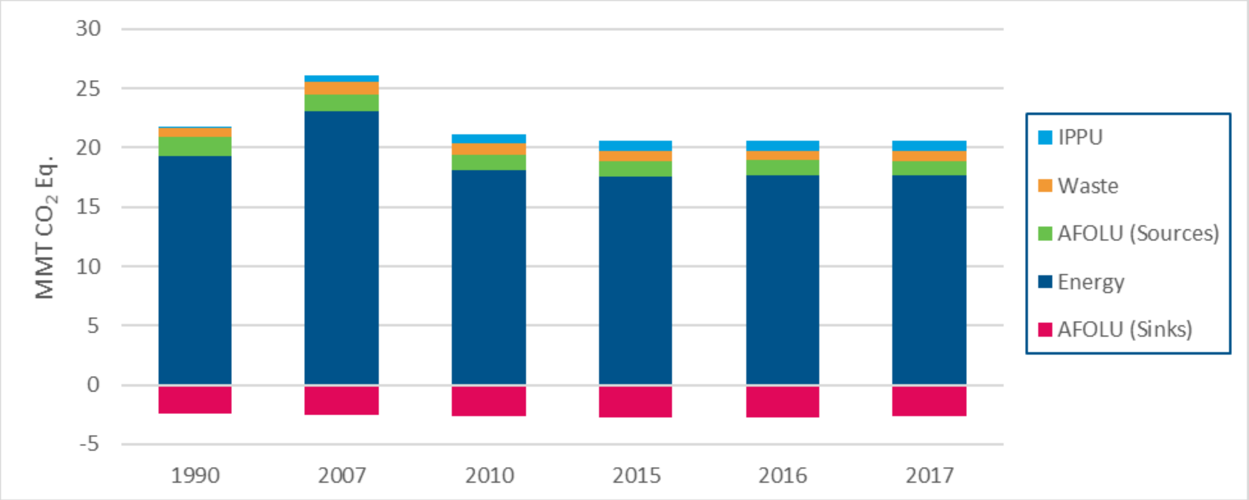


Table ES-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010, 2015, 2016, and 2017 (MMT CO₂ Eq.)

Sector/Category	1990	2007	2010	2015	2016	2017
Energy[a]	19.30	23.12	18.15	17.58	17.66	17.64
IPPU	0.17	0.59	0.71	0.83	0.83	0.83
AFOLU (Sources)	1.60	1.35	1.28	1.30	1.29	1.26
AFOLU (Sinks)	(2.44)	(2.58)	(2.62)	(2.73)	(2.71)	(2.69)
Waste	0.75	1.05	0.95	0.84	0.78	0.82
Total Emissions (Excluding Sinks)	**21.83**	**26.11**	**21.10**	**20.55**	**20.56**	**20.56**
Net Emissions (Including Sinks)	**19.39**	**23.53**	**18.48**	**17.81**	**17.86**	**17.87**
Aviation[b]	4.11	4.46	3.40	4.20	4.22	4.10
Net Emissions (Including Sinks, Excluding Aviation)[b]	**15.28**	**19.07**	**15.08**	**13.61**	**13.64**	**13.77**

[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 (2007).

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

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[6] 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).

As the largest source of emissions in Hawaii, the Energy sector is a major driver of the overall emissions trends, accounting for 89 percent of the emissions increase from 1990 to 2007 and 99 percent of reductions between 2007 and 2017. Relative to 1990, emissions from the Energy sector in 2017 were lower by 9 percent. Transportation emissions—which increased between 1990 and 2007, decreased between 2007 and 2010, and then increased again between 2010 and 2017—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 domestic aviation and ground transportation emissions, which together account for roughly 85 percent of transportation emissions. Stationary combustion emissions—which similarly increased between 1990 and 2007, before consistently decreasing between 2007 and 2016, and then slightly increasing again between 2016 and 2017—is the second largest share. This trend is driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial and commercial emissions. Overall, the decrease in Energy sector emissions between 1990 and 2017 is due to a decrease in stationary combustion emissions from commercial and industrial sources, a decrease in domestic marine, military aviation, and military non-aviation emissions, and a decrease in emissions from oil and natural gas systems. Together, these reductions outweigh overall increases in emissions from energy industries, ground transportation, and domestic aviation observed over the same period.

Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2017, falling by about 5 percent and 22 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 42 percent from 2007 to 2017. Relative to 1990, emissions from the IPPU sector in 2017 were more than three times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances (ODS).[7] Carbon removals from AFOLU sinks have also increased since 1990, growing by roughly 10 percent between 1990 and 2017.

Emission Projections

A combination of top-down and bottom-up approaches were used to develop baseline projections of statewide and county-level GHG emissions in the years 2020, 2025, and 2030.[8] For many sources (residential energy use, commercial energy use, industrial energy use, domestic aviation, incineration of waste, oil and natural gas systems, non-energy uses, and substitution of ozone depleting substances), a constructed long-range gross state product forecast was applied to project GHG emissions for 2020, 2025, and 2030, using the 2017 statewide GHG inventory as a starting point. For other sources (electrical transmission and distribution, composting, and wastewater treatment), population and electrical sales forecasts were used to project GHG emissions. For other smaller emission sources and sinks (AFOLU categories and landfill waste), emissions were projected by forecasting activity data using historical trends and published information available on future trends, and applying the same methodology used

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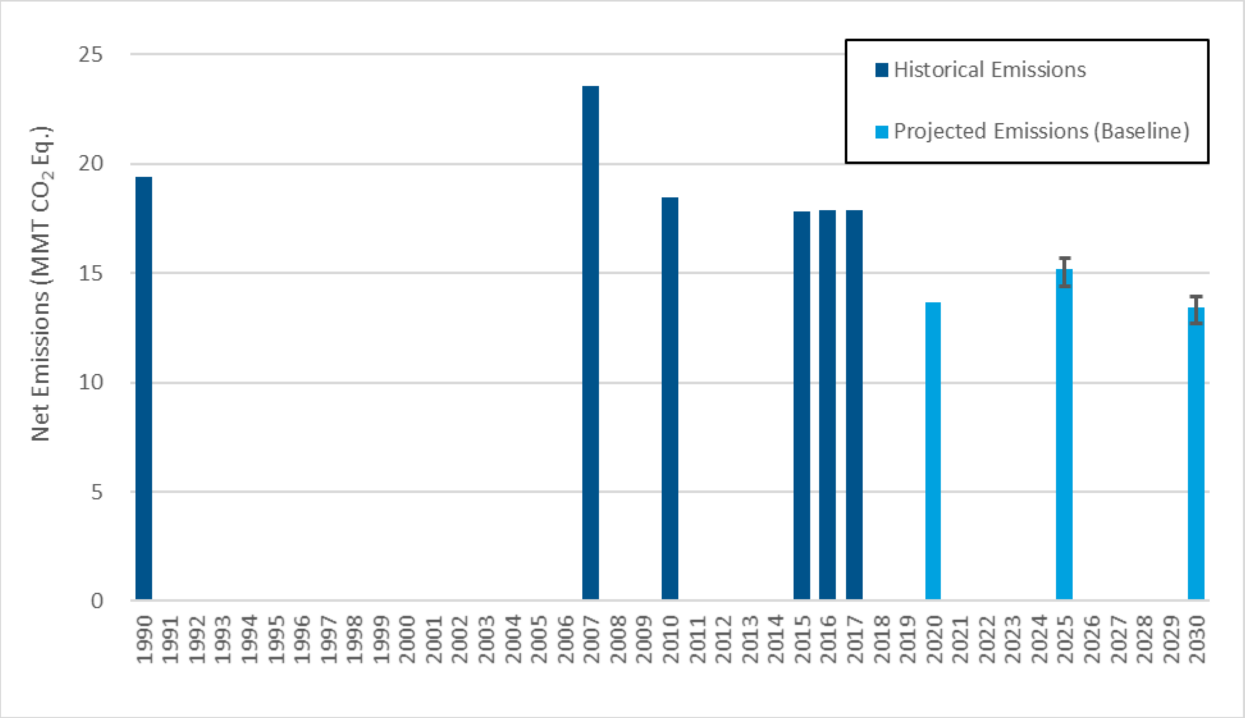
[7] Per IPCC (2006) guidelines, emissions of ODS, which are also GHGs, are not included in this inventory. For informational purposes, ODS emissions were estimated for the state of Hawaii and are presented in Appendix I.

[8] Complete data for 2020 were not available at the time that this report was developed. Therefore, 2020 emission estimates were projected as part of this analysis.

to estimate 2017 emissions. For large GHG emitting sources for which there has been substantial federal and state policy intervention (energy industries and transportation), a bottom-up approach was used to project GHG emissions. The team additionally quantitatively assessed three major points of uncertainty by modeling five alternative scenarios for statewide GHG emissions in 2025 and 2030.

Total GHG emissions are projected to be 16.32 MMT CO_2 Eq. in 2020, 17.80 MMT CO_2 Eq. in 2025, and 16.03 MMT CO_2 Eq. in 2030. Net emissions, which take into account carbon sinks, are projected to be 13.64 MMT CO_2 Eq. in 2020, 15.17 MMT CO_2 Eq. in 2025, and 13.44 MMT CO_2 Eq. in 2030. Relative to 2017, total emissions under the baseline scenario are projected to decrease by 21 percent by 2020, 13 percent by 2025 and 22 percent by 2030. Over the same period, net emissions are projected to decrease by 24 percent, 15 percent and 25 percent, respectively. This trend is largely driven by the recession and a reduction in air travel in 2020 caused by COVID-19, as well as the projected trend in emissions from energy industries (i.e., electric power plants and petroleum refineries), which are expected to decrease between 2017 and 2030. Figure ES-3 shows net GHG emissions for each historical and projected inventory year. Projections of statewide emissions and sinks by sector for 2020, 2025, and 2030 are summarized in Table ES-3.

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. Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, the technology and policy variation modeled under the alternative scenarios is not applicable.

Table ES-2: Hawaii GHG Emission Projections by Sector, 2020, 2025, and 2030 (MMT CO_2 Eq.)

Sector	2020	2025	2030
Energy[a]	13.50	15.06	13.33
IPPU	0.76	0.76	0.78
AFOLU (Sources)	1.25	1.19	1.12
AFOLU (Sinks)	(2.68)	(2.63)	(2.58)
Waste	0.81	0.80	0.80
Total Emissions (Excluding Sinks)	**16.32**	**17.80**	**16.03**
Net Emissions (Including Sinks)	**13.64**	**15.17**	**13.44**
Aviation[b]	1.98	4.22	4.56
Net Emissions (Including Sinks, Excluding Aviation)[b]	**11.66**	**10.96**	**8.88**

[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 (2007).

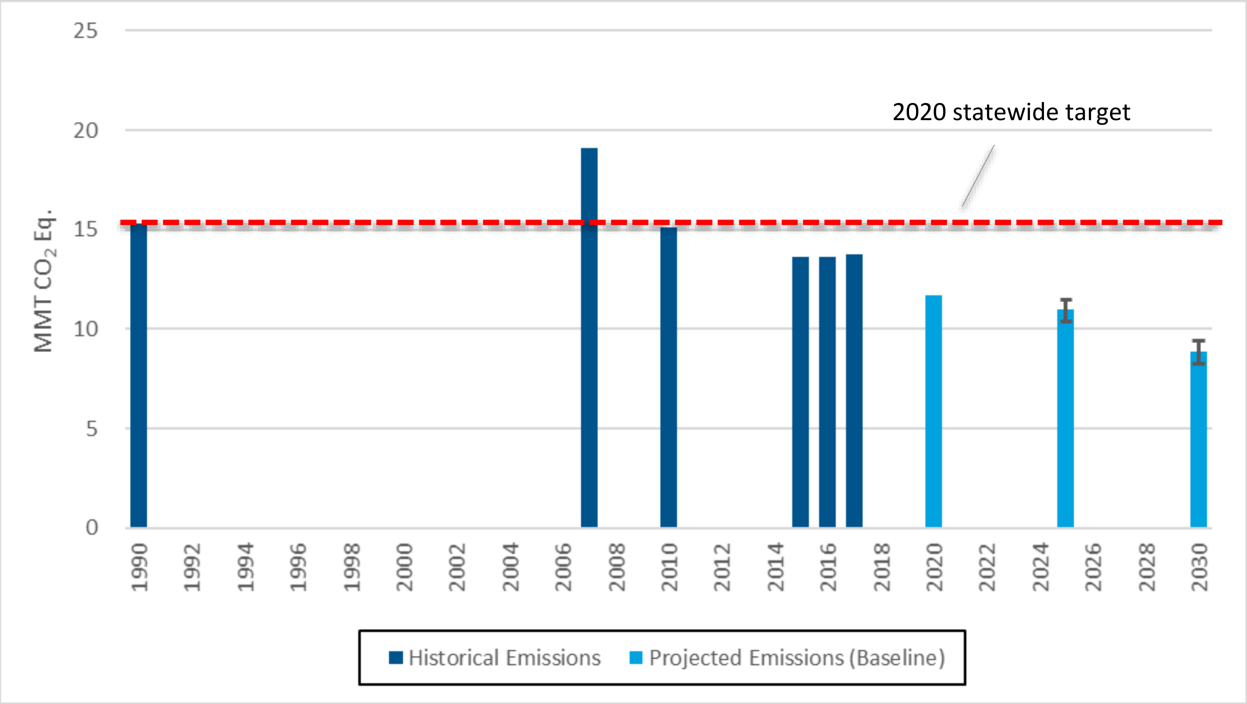
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Hawaii GHG Goal Progress

Excluding aviation, 1990 statewide emissions were estimated to be 15.28 MMT CO_2 Eq., which represents the 2020 emission target (statewide emissions must be at or below this amount). Net GHG emissions in 2017 (excluding aviation) were approximately 10 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, 2025, and 2030 and the 2020 statewide target, which is equal to 1990 emissions levels.

As net emissions excluding aviation are projected to be 11.66 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 future inventory reports as well as ongoing quantitative assessment of uncertainties will further inform whether Hawaii met 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. Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, the technology and policy variation modeled under the alternative scenarios is not applicable.

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 (HAR), 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, 2015, and 2016 emission estimates;[9] inventory estimates for 2017; and emission projections for 2020, 2025, and 2030.

Based on the analysis presented in this report, net GHG emissions (excluding aviation) in 2020 (excluding aviation) are projected to be lower than net GHG emissions (excluding aviation) in 1990.[10,11] While the development of future inventory reports as well as ongoing quantitative assessment of uncertainties will further inform whether Hawaii met its 2020 statewide target, this report finds that Hawaii is expected to meet the 2020 target.

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

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[9] 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.

[10] Net emissions account for both GHG emissions and carbon sinks.

[11] Complete data for 2020 were not available at the time that this report was developed. Therefore, 2020 emission estimates were projected as part of this analysis.

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 2020a, IPCC 2013). Black carbon also influences cloud development, but the direction and magnitude of this forcing is an area of active research (EPA 2020a). 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, 2016, and 2017 from the following four sectors:

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

This inventory was developed in accordance with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[12] 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, 2015, and 2016, and newly developed estimates for 2017. The 1990, 2007, 2010, 2015, and 2016 estimates were updated to account for updated activity data and methods, and to ensure time-series consistency across all inventory years.[13] Changes in emission estimates from the 2016 inventory report estimates are largely due to (1) updates to the forest carbon net sequestration rates based on new data from United States Geological Survey (USGS) (Selmants 2020), (2) updates to the method used to allocate aircraft aviation fuel consumption into domestic and international consumption, (3) inclusion of naphtha consumption by energy industries, (4) inclusion of emissions from hydrogen production in the oil and natural gas systems estimates, (5) updates to agricultural soil carbon emissions based on estimates obtained from the U.S. Inventory (EPA 2020a), and (6) updates to the net carbon sequestration factor per area of tree cover based on state-specific values obtained from the U.S. Inventory (EPA 2020a). These and other updates that impacted emission

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[12] 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.

[13] This report also includes updated emission projections for 2020 and 2025, and newly developed emission projections for 2030 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.

estimates are discussed on a source-by-source basis in the subsequent sections of this report. Appendix B summarizes updates that were made to historical emission estimates across all sectors. Appendix C additionally summarizes the effort undertaken to investigate and implement areas for improvement that were identified in the 2016 inventory 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 2020a).

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: 1990-2018* (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 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.

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 2017 inventory and the inventory projections for 2020 and 2025. The results of this comparison are presented and discussed in Appendix K. In addition, the results were reviewed by representatives from the Department of Health (DOH) as well as a group of other government entities.[14] 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 2020a).

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[14] The review team included representatives from the Hawaii Department of Business, Economic Development and Tourism (DBEDT), Division of Consumer Advocacy (DCA), and Public Utilities Commission (PUC).

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.[15] 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 information presented in these sections should be evaluated as potential focus areas for improvement for future inventory reports.

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

Sector	2017 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	17.64	17.30	18.11	-2%	2%	17.70	0.21
IPPU	0.83	0.81	0.89	-4%	5%	0.85	0.02
AFOLU (Sources)	1.26	(2.09)	4.52	-289%	309%	1.13	1.72
AFOLU (Sinks)	(2.69)	(3.09)	(2.32)	15%	-14%	(2.70)	0.20
Waste	0.82	0.60	0.97	-25%	21%	0.80	0.10
Total Emissions	**20.56**	**17.24**	**23.87**	**-16%**	**17%**	**2.48**	**1.73**
Net Emissions	**17.87**	**14.54**	**21.18**	**-18%**	**19%**	**17.79**	**1.74**
Net Emissions (Excl. Aviation)	**13.77**	**10.42**	**17.08**	**-24%**	**25%**	**13.68**	**1.74**

[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.

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[15] 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.

1.6. Organization of Report

The remainder of this report is organized as follows:

- **Chapter 2: Emission Results** – Summarizes 2017 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.
- **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.
- **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.
- **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.
- **Chapter 7: Emission Projections** – Presents projections for statewide GHG emissions and sinks for 2020, 2025, and 2030 under a baseline and three alternate scenarios. County-level GHG emissions and sinks for 2020, 2025, and 2030 under the baseline scenario are also provided.
- **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.

<u>Appendices</u>

- **Appendix A: Source and Sink Categories** – Provides a summary of all IPCC source and sink categories and the reason for any exclusions from this analysis as well as a summary of which source and sink categories are included in the inventory totals.
- **Appendix B: Updates to the Historical Emission Estimates Presented in the 2016 Inventory Report** – Summarizes changes in emission estimates relative to the 2016 inventory report.
- **Appendix C: Inventory Improvements** – Summarizes the effort undertaken to investigate and implement areas for improvement that were identified in the 2016 inventory report.
- **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 2017 and projections for 2020, 2025, and 2030.
- **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: ODS Emissions** – Summarizes for informational purposes estimated emissions from ozone depleting substances (ODS) for the state of Hawaii.
- **Appendix J: Emission Projections Methodology** – Summarizes the methodology used to project emissions for 2020, 2025, and 2030 by source and sink category, and includes a discussion of key uncertainties and areas for improvement.
- **Appendix K: 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 2017 inventory and the emission projections for 2020 and 2025.

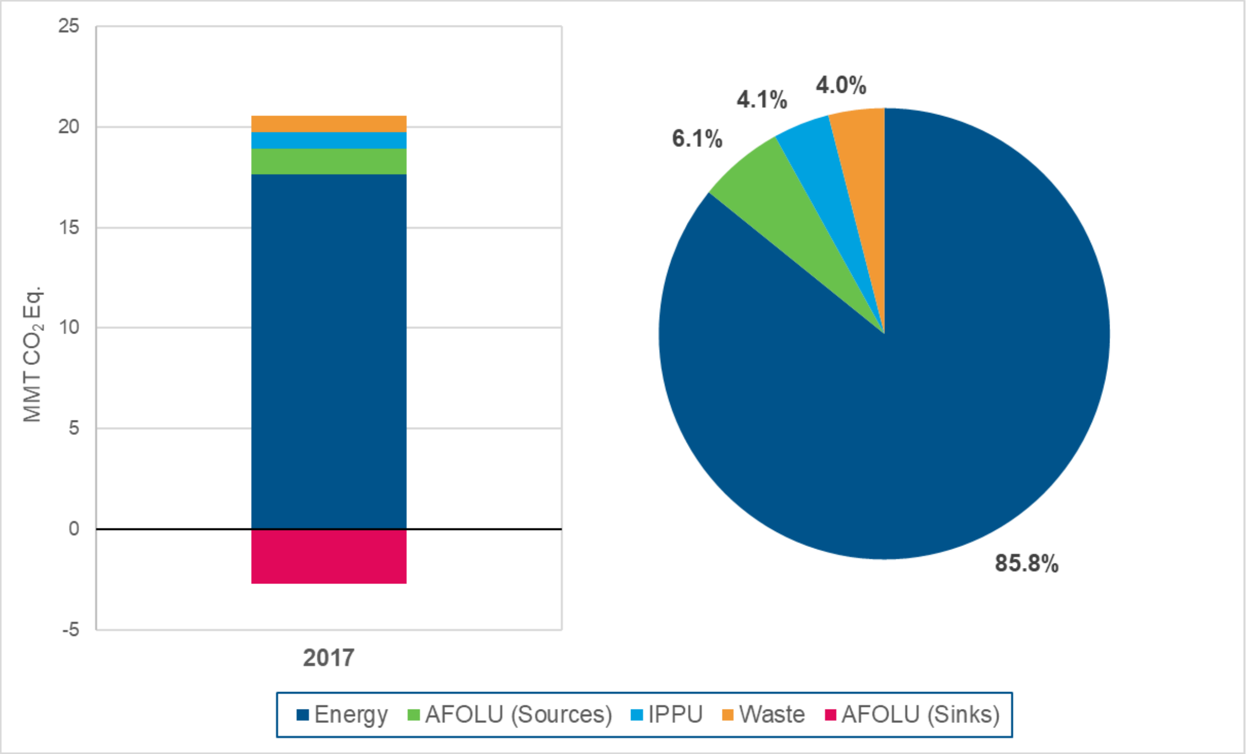
2. Emission Results

This section summarizes 2017 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 2017 Emissions

In 2017, total GHG emissions in Hawaii were 20.56 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 17.87 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (86 percent) of total emissions in Hawaii, followed by the AFOLU sector (6 percent), the IPPU sector (4 percent), and the Waste sector (4 percent). Figure 2-1 shows emissions for 2017 by sector.

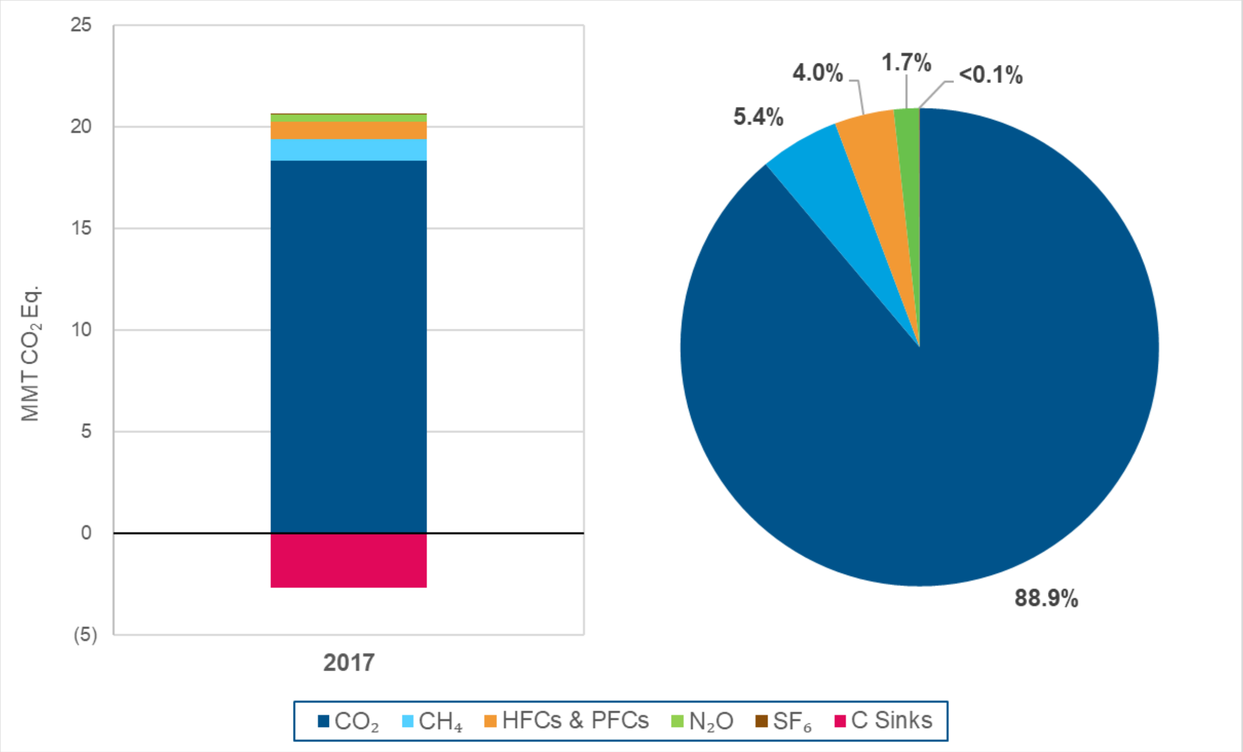
Figure 2-1: Hawaii 2017 GHG Emissions by Sector



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 2017, 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 2017 by gas.

Figure 2-2: Hawaii 2017 GHG Emissions by Gas



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

2.2. Emission Trends

Total GHG emissions in Hawaii grew by 20 percent between 1990 and 2007 before falling 19 percent between 2007 and 2010 and another 3 percent between 2010 and 2015.[16] Between 2015 and 2017, emissions in Hawaii remained relatively constant, changing by less than 0.1 percent. Compared to 1990, total emissions in Hawaii in 2017 were roughly 6 percent lower, while net emissions were lower by roughly 8 percent. Figure 2-3 below shows total and net GHG emissions for each inventory year.

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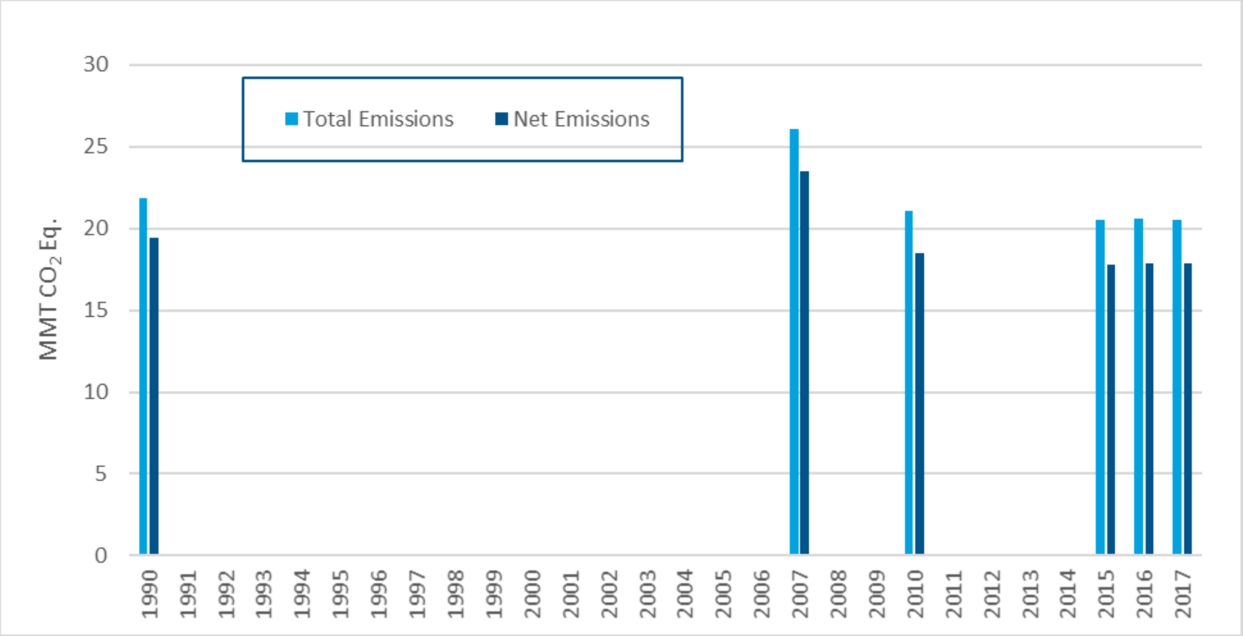
[16] The historical trend in total emissions from 1990 through 2010 is consistent with the trend seen at the national level. Specifically, between 1990 and 2007, U.S. emissions increased by roughly 17 percent before falling 6 percent between 2007 and 2010 (EPA 2012). The decrease in U.S. emissions from 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 (including aviation)



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, 2016, and 2017)

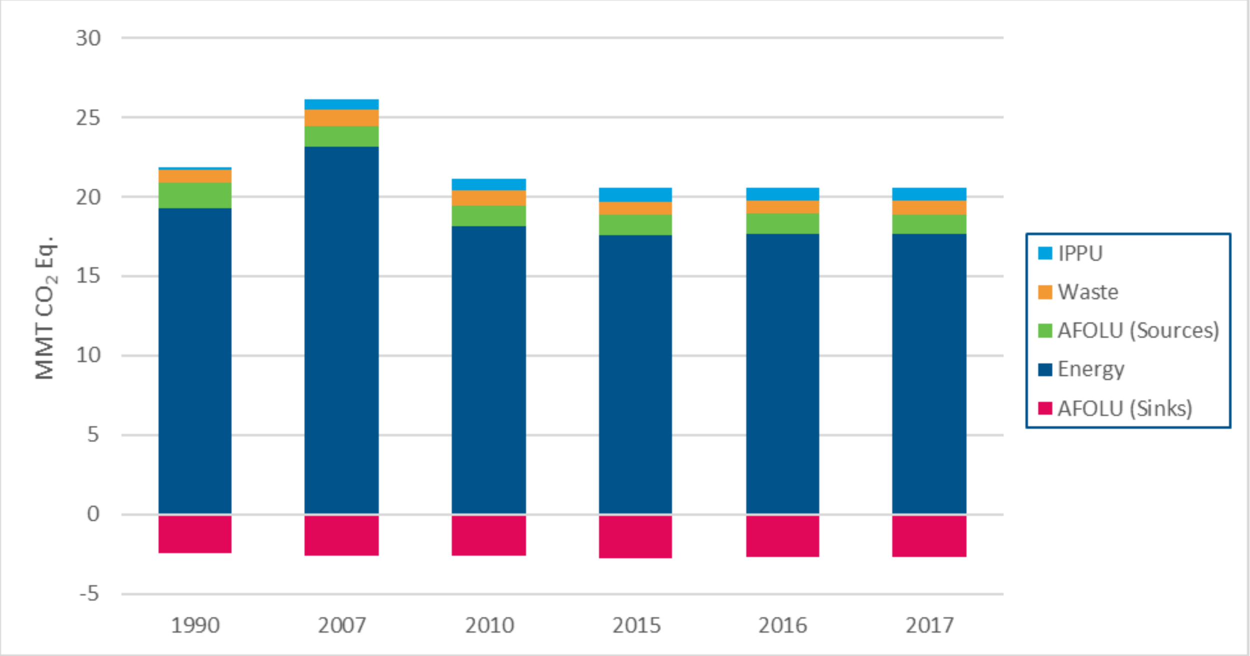


Table 2-1: Hawaii GHG Emissions by Sector/Category for 1990, 2007, 2010, 2015, 2016, and 2017 (MMT CO$_2$ Eq.)

Sector/Category	1990	2007	2010	2015	2016	2017
Energy	**19.30**	**23.12**	**18.15**	**17.58**	**17.66**	**17.64**
Stationary Combustion	8.47	9.37	8.89	8.16	8.01	8.09
Transportation	10.18	13.18	8.70	8.86	9.05	8.98
Incineration of Waste[a]	0.18	0.15	0.19	0.20	0.27	0.23
Oil and Natural Gas Systems	0.43	0.39	0.32	0.31	0.29	0.31
Non-Energy Uses	0.04	0.04	0.05	0.05	0.04	0.04
International Bunker Fuels[b]	*1.18*	*0.88*	*1.07*	*1.30*	*1.25*	*1.35*
CO$_2$ from Wood Biomass and Biofuel Consumption[b]	*2.43*	*0.88*	*1.24*	*1.40*	*1.49*	*0.75*
IPPU	**0.17**	**0.59**	**0.71**	**0.83**	**0.83**	**0.83**
Cement Production	0.10	NO	NO	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	+	0.57	0.70	0.82	0.82	0.82
AFOLU (Sources)	**1.60**	**1.35**	**1.28**	**1.30**	**1.29**	**1.26**
Enteric Fermentation	0.32	0.30	0.27	0.24	0.25	0.26
Manure Management	0.14	0.04	0.03	0.03	0.03	0.03
Agricultural Soil Management	0.18	0.17	0.16	0.16	0.17	0.17
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01	0.01	+
Urea Application	+	+	+	+	+	+
Agricultural Soil Carbon	0.83	0.72	0.80	0.82	0.81	0.79
Forest Fires	0.10	0.12	0.01	0.04	0.02	0.01
AFOLU (Sinks)	**(2.44)**	**(2.58)**	**(2.62)**	**(2.73)**	**(2.71)**	**(2.69)**
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Urban Trees	(0.51)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)
Forest Carbon	(1.80)	(1.90)	(1.98)	(2.08)	(2.06)	(2.03)
Waste	**0.75**	**1.05**	**0.95**	**0.84**	**0.78**	**0.82**
Landfills	0.65	0.92	0.87	0.75	0.69	0.73
Composting	+	0.02	0.01	0.02	0.02	0.02
Wastewater Treatment	0.10	0.12	0.07	0.07	0.07	0.07
Total Emissions (Excluding Sinks)	**21.83**	**26.11**	**21.10**	**20.55**	**20.56**	**20.56**
Net Emissions (Including Sinks)	**19.39**	**23.53**	**18.48**	**17.81**	**17.86**	**17.87**
Aviation[c]	4.11	4.46	3.40	4.20	4.22	4.10
Net Emissions (Including Sinks, Excluding Aviation)[c]	**15.28**	**19.07**	**15.08**	**13.61**	**13.64**	**13.77**

+ 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 (2007).

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 89 percent of the emissions increase from 1990 to 2007 and 99 percent of reductions between 2007 and 2017. Relative to 1990, emissions from the Energy sector in 2017 were lower by 9 percent. Transportation emissions—which increased between 1990 and 2007, decreased between 2007 and 2010, and then increased again between 2010 and 2017—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 domestic aviation and ground transportation emissions, which together account for roughly 85 percent of transportation emissions. Stationary combustion emissions—which similarly increased between 1990 and 2007, before consistently decreasing between 2007 and 2016, and then slightly increasing again between 2016 and 2017—is the second largest share. This trend is driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial and commercial emissions. Overall, the decrease in Energy sector emissions between 1990 and 2017 is due to a decrease in stationary combustion emissions from commercial and industrial sources, a decrease in domestic marine, military aviation, and military non-aviation emissions, and a decrease in emissions from oil and natural gas systems. Together, these reductions outweigh overall increases in emissions from energy industries, ground transportation, and domestic aviation observed over the same period.

Emissions from AFOLU sources and the Waste sector also contributed to the overall reduction in emissions from 2007 to 2017, falling by about 5 percent and 22 percent, respectively, during that period. These reductions more than offset growing emissions from the IPPU sector, which increased by 42 percent from 2007 to 2017. Relative to 1990, emissions from the IPPU sector in 2017 were more than three times higher, due entirely to the growth in HFC and PFC emissions from substitution of ozone depleting substances (ODS).[17] Carbon removals from AFOLU sinks have also increased since 1990, growing by roughly 10 percent between 1990 and 2017.

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 2017. Methane and emissions also increased between 1990 and 2007 and decreased between 2007 and 2017. Emissions of HFCs and PFCs grew substantially from 1990 to 2017, while SF_6 emissions decreased over the same period. Emissions of N_2O similarly decreased between 1990 and 2015 but increased slightly between 2015 and 2017, largely due to forest fires. Figure 2-5 shows emissions for each inventory year by gas.

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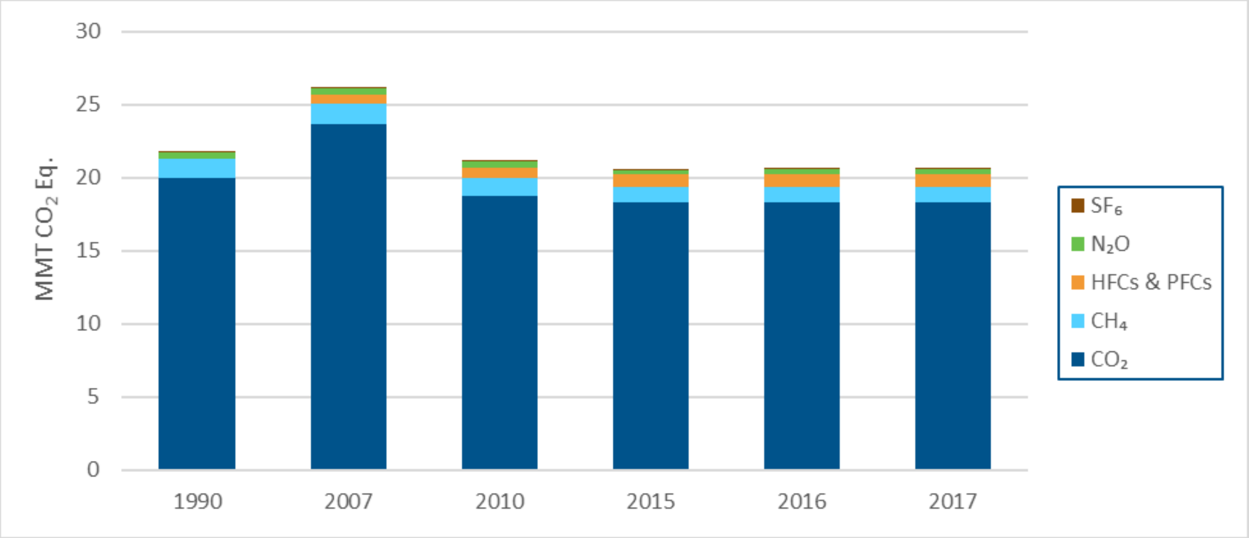
[17] Per IPCC (2006) guidelines, emissions of ODS, which are also GHGs, are not included in this inventory. For informational purposes, ODS emissions were estimated for the state of Hawaii and are presented in Appendix I.

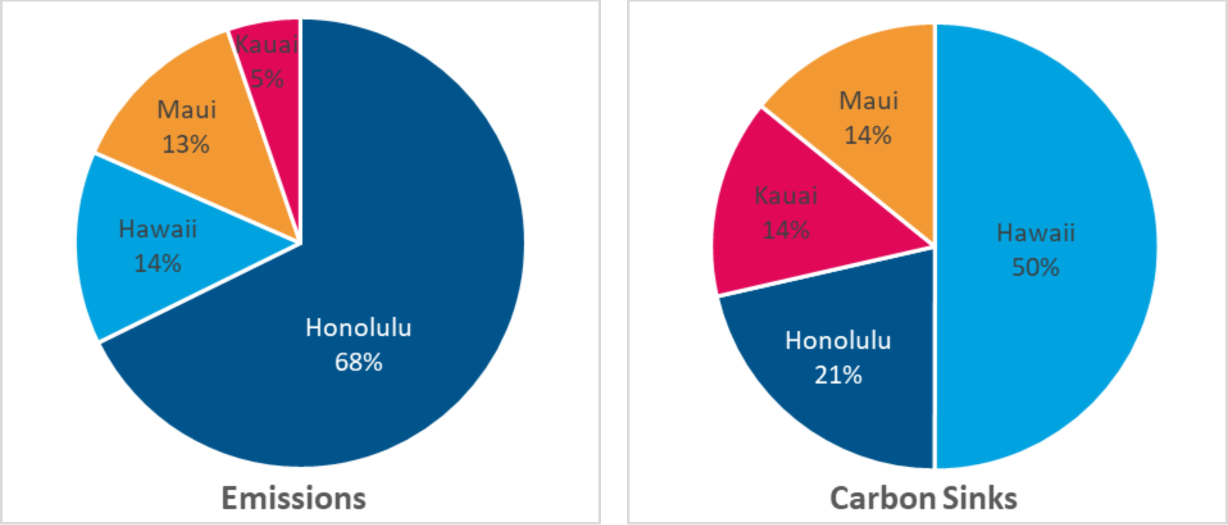
Figure 2-5: Hawaii GHG Emissions by Gas (1990, 2007, 2010, 2015, 2016, and 2017)



2.3. Emissions by County

In 2017, Honolulu County, which is home to roughly 65 percent of Hawaii's population, accounted for the largest share of GHG emissions (68 percent), followed by Hawaii County (14 percent), Maui County[18] (13 percent), and Kauai County (5 percent). Hawaii County, where more than half of the forested land in the state is found, accounted for the largest share of carbon removals from AFOLU sinks in 2017 (50 percent), followed by Honolulu County (21 percent), Kauai County (14 percent), and Maui County (14 percent). Figure 2-6 shows the breakout of emissions and carbon removals (sinks) by county in 2017.

Figure 2-6: 2017 GHG Emissions and Carbon Removals by County (MMT CO_2 Eq.)



Note: Totals may not sum due to independent rounding.

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[18] 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 2017, emissions from the Energy sector accounted for 92 percent of emissions from Honolulu County, 82 percent of emissions from Maui County, 77 percent of emissions from Kauai County, and 62 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 2017 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 vehicle miles traveled (VMT). Appendix E summarizes the methodology used to quantify Hawaii's GHG emissions by county.

Figure 2-7: Hawaii 2017 GHG Emissions by Sector and County

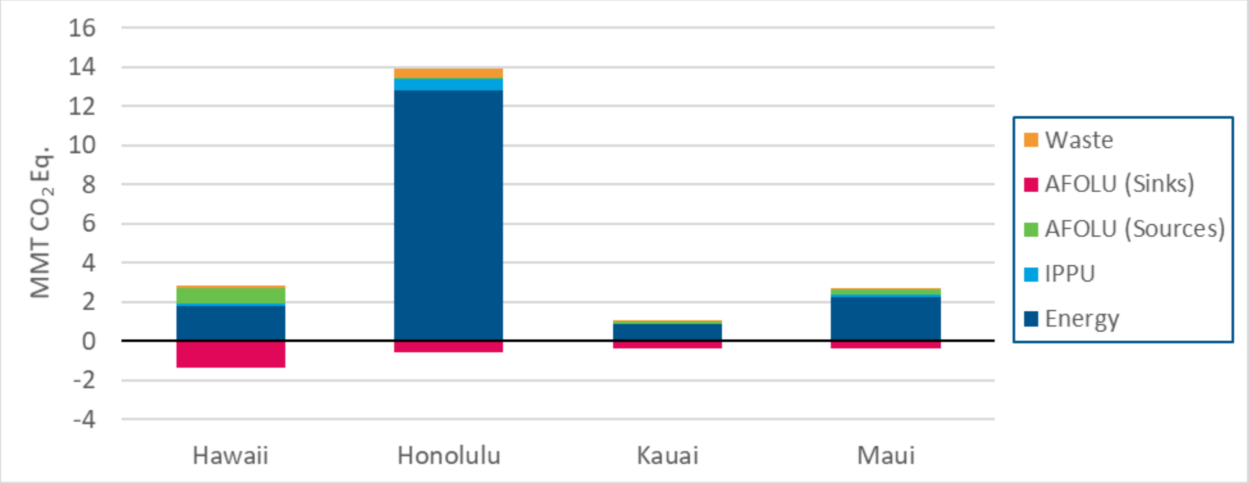


Figure 2-8 Net GHG Emissions by County (1990, 2007, 2010, 2015, 2016, and 2017)

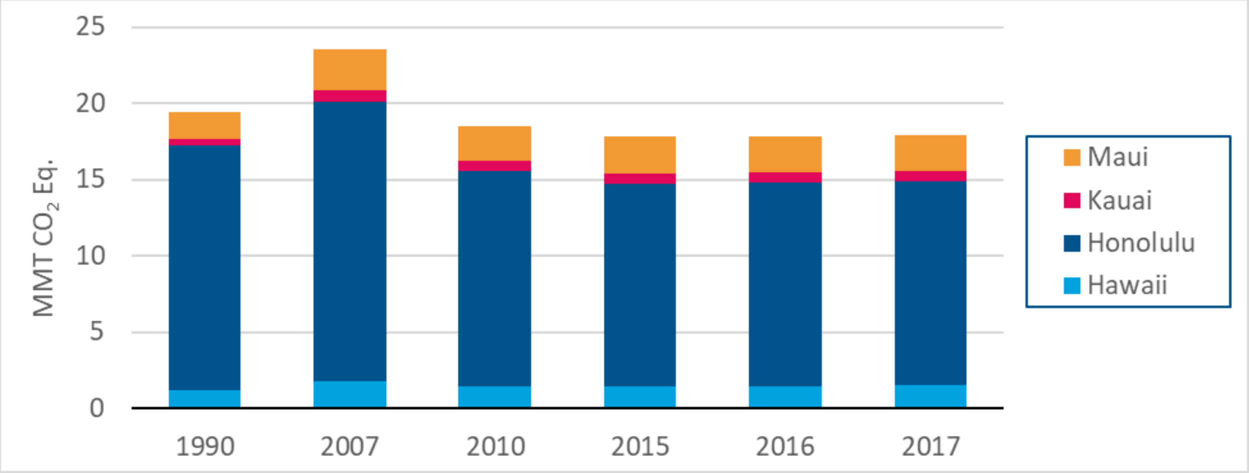


Table 2-2: GHG Emissions by Sector and County for 1990, 2007, 2010, 2015, 2016, and 2017 (MMT CO_2 Eq.)

Sector	1990	2007	2010	2015	2016	2017
Honolulu County						
Energy	15.63	17.74	13.53	12.72	12.81	12.82
IPPU	0.16	0.39	0.47	0.55	0.56	0.55
AFOLU (Sources)	0.21	0.10	0.09	0.10	0.10	0.10
AFOLU (Sinks)	(0.57)	(0.55)	(0.51)	(0.57)	(0.58)	(0.57)
Waste	0.57	0.65	0.59	0.47	0.43	0.46
Total Emissions	**16.58**	**18.89**	**14.68**	**13.84**	**13.90**	**13.93**
Net Emissions	**16.01**	**18.33**	**14.17**	**13.27**	**13.32**	**13.36**
Hawaii County						
Energy	1.39	1.98	1.67	1.72	1.73	1.76
IPPU	0.01	0.09	0.10	0.12	0.12	0.12
AFOLU (Sources)	0.93	0.87	0.81	0.81	0.80	0.79
AFOLU (Sinks)	(1.21)	(1.34)	(1.34)	(1.37)	(1.35)	(1.34)
Waste	0.08	0.16	0.17	0.17	0.17	0.17
Total Emissions	**2.41**	**3.10**	**2.75**	**2.81**	**2.82**	**2.84**
Net Emissions	**1.20**	**1.77**	**1.41**	**1.44**	**1.46**	**1.50**
Maui County						
Energy	1.67	2.53	2.17	2.28	2.28	2.23
IPPU	0.01	0.08	0.09	0.11	0.11	0.11
AFOLU (Sources)	0.33	0.26	0.27	0.28	0.27	0.27
AFOLU (Sinks)	(0.38)	(0.38)	(0.41)	(0.39)	(0.39)	(0.38)
Waste	0.06	0.16	0.12	0.12	0.10	0.10
Total Emissions	**2.07**	**3.03**	**2.66**	**2.78**	**2.77**	**2.71**
Net Emissions	**1.69**	**2.65**	**2.24**	**2.40**	**2.38**	**2.33**
Kauai County						
Energy	0.60	0.86	0.78	0.86	0.83	0.83
IPPU	+	0.04	0.04	0.05	0.05	0.05
AFOLU (Sources)	0.14	0.11	0.11	0.12	0.11	0.11
AFOLU (Sinks)	(0.28)	(0.31)	(0.36)	(0.40)	(0.39)	(0.39)
Waste	0.03	0.08	0.08	0.08	0.09	0.09
Total Emissions	**0.78**	**1.09**	**1.01**	**1.11**	**1.08**	**1.08**
Net Emissions	**0.49**	**0.78**	**0.66**	**0.71**	**0.69**	**0.69**

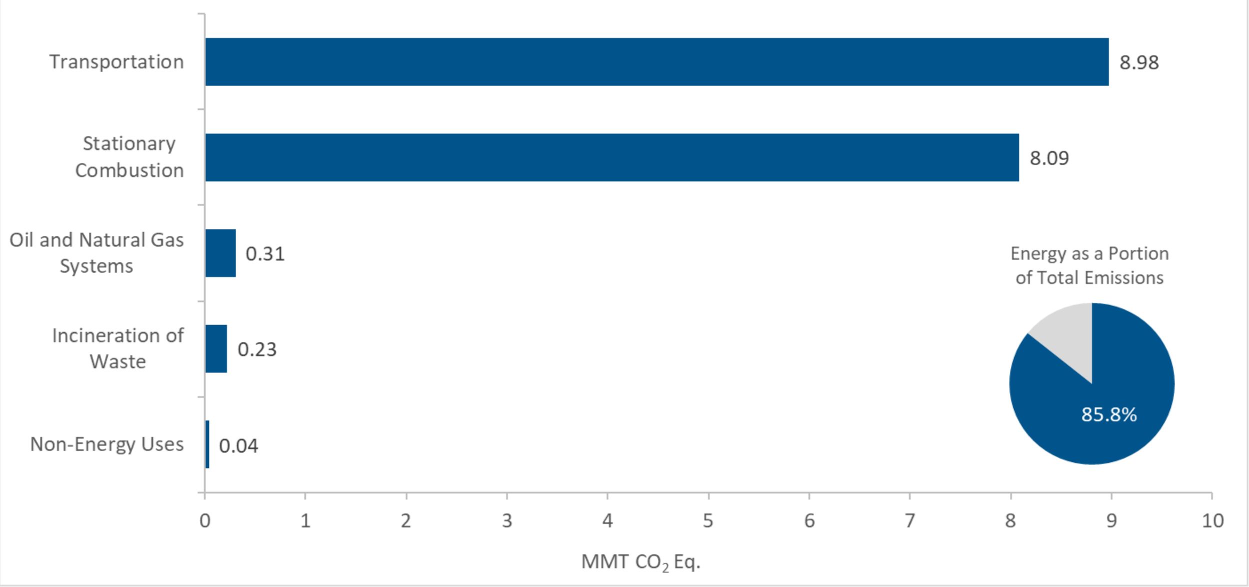
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.
+ Does not exceed 0.005 MMT CO_2 Eq.

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), oil and natural gas systems (IPCC Source Category 1B2), and non-energy uses[19] (IPCC Source Category 2D).[20] 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 2017, emissions from the Energy sector were 17.64 MMT CO_2 Eq., accounting for 86 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 oil and natural gas systems, waste incineration, and non-energy uses comprised a relatively small portion of Energy sector emissions (3 percent). Figure 3-1 and Figure 3-2 show emissions from the Energy sector by source for 2017.

Figure 3-1: 2017 Energy Emissions by Source



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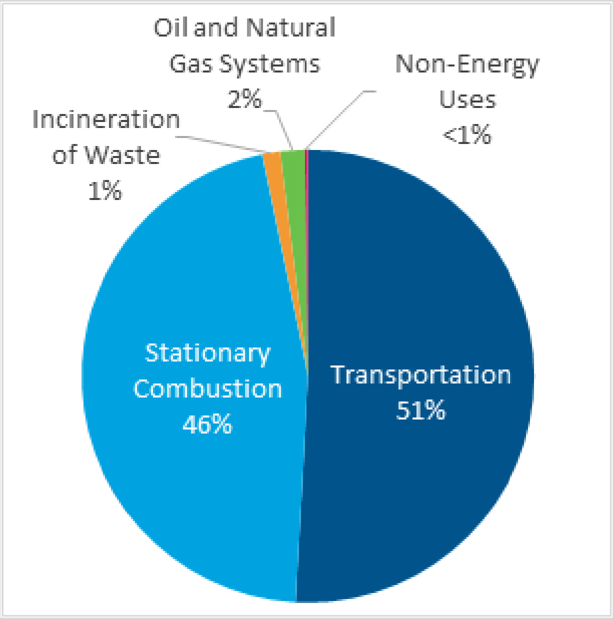
[19] Non-energy uses of fuels include use of fossil fuel feedstocks for industrial and transportation applications that do not involve combustion, including production of lubricants, asphalt, and road oil.

[20] 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.

Figure 3-2: 2017 Energy Emissions by Source



Relative to 1990, emissions from the Energy sector in 2017 were lower by roughly 9 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 again between 2010 and 2017, is largely driven by domestic aviation and ground transportation emissions, which together account for roughly 85 percent of transportation emissions. The trend in stationary combustion emissions, which similarly increased between 1990 and 2007, before consistently decreasing between 2007 and 2016, and then slightly increasing again between 2016 and 2017, is largely driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial and commercial emissions. Emissions by source and year are also summarized in Table 3-1.

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

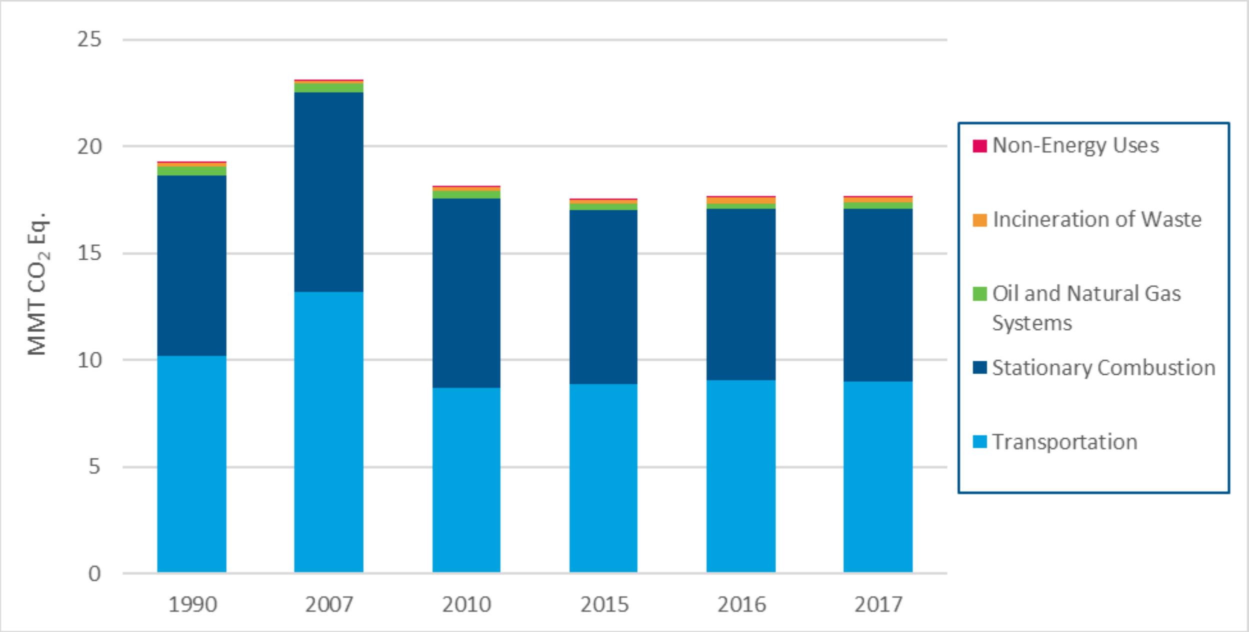


Table 3-1: GHG Emissions from the Energy Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016	2017
Stationary Combustion[a]	**8.47**	**9.37**	**8.89**	**8.16**	**8.01**	**8.09**
Energy Industries[b]	6.38	8.31	7.86	7.11	7.07	7.00
Residential	0.05	0.06	0.09	0.06	0.07	0.07
Commercial	0.76	0.30	0.37	0.47	0.48	0.54
Industrial	1.29	0.69	0.56	0.51	0.39	0.48
Transportation[a]	**10.18**	**13.18**	**8.70**	**8.86**	**9.05**	**8.98**
Ground	3.73	5.12	4.21	4.32	4.25	4.19
Domestic Marine	1.55	2.81	0.58	0.29	0.41	0.49
Domestic Aviation	2.73	3.83	2.91	3.54	3.57	3.46
Military Aviation	1.38	0.63	0.49	0.66	0.65	0.64
Military Non-Aviation	0.79	0.78	0.51	0.05	0.17	0.20
Incineration of Waste	**0.18**	**0.15**	**0.19**	**0.20**	**0.27**	**0.23**
Oil and Natural Gas Systems	**0.43**	**0.39**	**0.32**	**0.31**	**0.29**	**0.31**
Non-Energy Uses	**0.04**	**0.04**	**0.05**	**0.05**	**0.04**	**0.04**
International Bunker Fuels[c]	*1.18*	*0.88*	*1.07*	*1.30*	*1.25*	*1.35*
CO_2 from Wood Biomass and Biofuel Consumption[c]	*2.43*	*0.88*	*1.24*	*1.40*	*1.49*	*0.75*
Total	**19.30**	**23.12**	**18.15**	**17.58**	**17.66**	**17.64**

[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. Facility-level data for HAR affected facilities are provided in Appendix F.[21,22] Activity data and emission factors used in the analysis are summarized in Appendix G and Appendix H, respectively.

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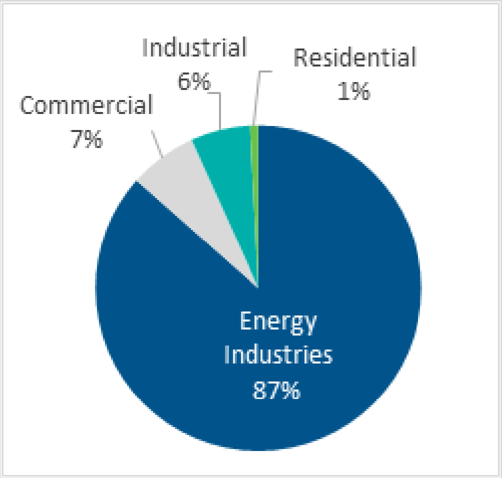
[21] HAR affected facilities refers to large existing stationary sources with potential GHG emissions at or above 100,000 tons of CO_2 Eq. per year. Hawaii Administrative Rules, Chapter 11-60.1, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.

[22] 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. For example, diesel consumption at the refineries is reported by SEDS under the industrial sector.

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

Fossil fuels are burned to generate energy from a variety of stationary sources, including electric power plants, industrial facilities, commercial businesses, and homes. When fossil fuels are combusted, they release CO_2, CH_4, and N_2O emissions. Stationary combustion emissions can be broken out by economic sector (i.e., energy industries,[23] residential,[24] commercial,[25] and industrial[26]), based on where the fuel is combusted. In 2017, emissions from stationary combustion in Hawaii were 8.09 MMT CO_2 Eq., accounting for 46 percent of Energy sector emissions. The vast majority of these emissions are from energy industries (87 percent), which includes both electric power plants and petroleum refineries. The commercial sector accounted for the next largest portion of stationary combustion emissions (7 percent), followed by the industrial (6 percent) and residential sectors (1 percent). Figure 3-4 shows the breakout of stationary combustion emissions by economic sector for 2017.

Figure 3-4: 2017 Stationary Combustion Emissions by Economic Sector



Relative to 1990, emissions from stationary combustion in 2017 were lower by roughly 5 percent. This trend is largely driven by emissions from energy industries, which increased from 1990 to 2007, decreased from 2007 to 2016, and then increased slightly from 2016 to 2017. Emissions from the industrial sector consistently decreased from 1990 to 2016, before increasing from 2016 to 2017. 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, increased from 2015 to 2016, and then decreased again from 2016 to 2017. Emissions from the commercial sector decreased from 1990 to 2007, and then consistently increased from 2007 to 2017. Figure 3-5 presents emissions

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[23] 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 plants whose primary business is to sell electricity or heat to the public (EIA 2020a).

[24] 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 2020a).

[25] 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 2020a).

[26] 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 2020a).

from stationary combustion in Hawaii by economic sector for 1990, 2007, 2010, 2015, 2016, and 2017. Table 3-2 summarizes emissions from stationary combustion in Hawaii by economic sector and gas for 1990, 2007, 2010, 2015, 2016, and 2017.

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

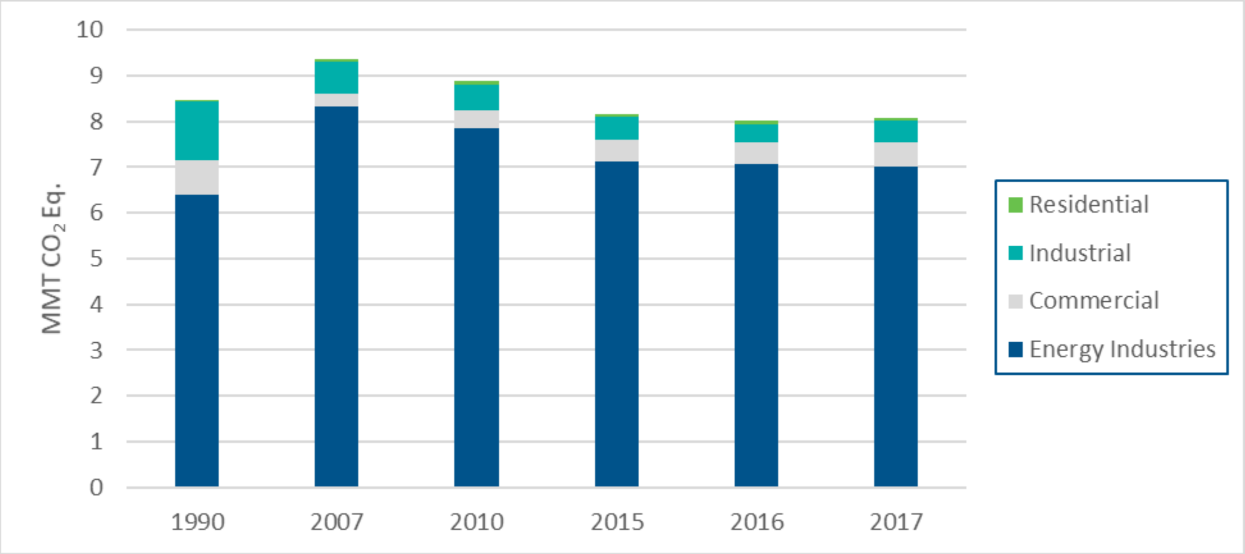

Table 3-2: GHG Emissions from Stationary Combustion by Economic Sector and Gas (MMT CO_2 Eq.)

Economic Sector/Gas	1990	2007	2010	2015	2016	2017
Energy Industries	**6.38**	**8.31**	**7.86**	**7.11**	**7.07**	**7.00**
CO_2	6.35	8.28	7.83	7.09	7.04	6.97
CH_4	0.01	0.01	0.01	0.01	0.01	0.01
N_2O	0.02	0.02	0.02	0.02	0.02	0.02
Residential	**0.05**	**0.06**	**0.09**	**0.06**	**0.07**	**0.07**
CO_2	0.05	0.06	0.09	0.06	0.07	0.07
CH_4	+	+	+	+	+	+
N_2O	+	+	+	+	+	+
Commercial	**0.76**	**0.30**	**0.37**	**0.47**	**0.48**	**0.54**
CO_2	0.76	0.28	0.34	0.45	0.44	0.51
CH_4	+	0.02	0.02	0.02	0.03	0.03
N_2O	+	+	+	+	0.01	0.01
Industrial	**1.29**	**0.69**	**0.56**	**0.51**	**0.39**	**0.48**
CO_2	1.25	0.68	0.55	0.50	0.39	0.48
CH_4	0.01	+	+	+	+	+
N_2O	0.02	0.01	0.01	0.01	+	+
Total	**8.47**	**9.37**	**8.89**	**8.16**	**8.01**	**8.09**

+ 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 2020a). 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 2020a) for ethanol.

Fuel consumption data by end-use sector were obtained from the Energy Information Administration's (EIA) State Energy Data System (SEDS) (EIA 2020a) for all years.[27] For some fuel types, consumption data were not available in SEDS and were obtained from additional data sources. Specifically, fuel gas and naphtha consumption were collected by the Hawaii Department of Business, Economic Development, and Tourism (DBEDT 2008a) for 2007.[28] For 2010, 2015, and 2016, CO_2, CH_4, and N_2O emissions from fuel gas and naphtha consumption were obtained directly from EPA's GHGRP (EPA 2020b). Methane and N_2O emissions from biodiesel consumption at the Hawaiian Electric Company (HECO), Hawaii Electric Light Company (HELCO), and the Maui Electric Company (MECO) were estimated based on biodiesel consumption data obtained from DBEDT's Data Warehouse (DBEDT 2020a) and Hawaii DOH (2020a).[29]

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[27] Motor gasoline consumption obtained from EIA (2020a) includes blended ethanol. Pure ethanol consumption obtained from EIA (2020a) was subtracted from motor gasoline prior to estimating emissions.
[28] 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.
[29] Carbon dioxide emissions from Wood Biomass and Biofuels Consumption are reported in Section 3.7.

Changes in Estimates since the Previous Inventory Report

In the 2016 inventory report, naphtha consumption was assumed to be accounted for in the SEDS data. However, based on a further review of SEDS data against other available data sets (see Appendix C), it was concluded that naphtha consumption is not accounted for in the SEDS data. Therefore, emissions from naphtha consumption, based on data obtained from DBEDT (2008a) and EPA's GHGRP (EPA 2020b), were incorporated into this inventory. In addition, in the 2016 inventory report, CH_4 and N_2O emissions from biodiesel consumption were obtained directly from EPA's GHGRP for 2015 and 2016. For all other inventory years, no biodiesel consumption was assumed. For this inventory report, biodiesel consumption estimates were updated based on consumption data obtained from the DBEDT Economic Data Warehouse (2020a) and Hawaii DOH (2020a). Finally, fuel-specific emission factors were updated based on the most recent version of the U.S. Inventory (EPA 2020a). The resulting changes in historical emission estimates are presented in Table 3-3.

Table 3-3: Change in Emissions from Stationary Combustion Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
Energy Industries					
2016 Inventory Report (MMT CO_2 Eq.)	6.66	8.29	7.79	6.88	6.83
This Inventory Report (MMT CO_2 Eq.)	6.38	8.31	7.86	7.11	7.07
Percent Change	-4.2%	0.3%	0.9%	3.4%	3.5%
Residential					
2016 Inventory Report (MMT CO_2 Eq.)	0.05	0.06	0.09	0.06	0.08
This Inventory Report (MMT CO_2 Eq.)	0.05	0.06	0.09	0.06	0.07
Percent Change	+	0.1%	0.8%	-3.6%	-2.5%
Commercial					
2016 Inventory Report (MMT CO_2 Eq.)	0.78	0.30	0.37	0.47	0.45
This Inventory Report (MMT CO_2 Eq.)	0.76	0.30	0.37	0.47	0.48
Percent Change	-2.2%	0.5%	0.4%	0.2%	5.4%
Industrial					
2016 Inventory Report (MMT CO_2 Eq.)	1.32	0.70	0.57	0.52	0.43
This Inventory Report (MMT CO_2 Eq.)	1.29	0.69	0.56	0.51	0.39
Percent Change	-2.8%	-1.2%	-1.6%	-1.1%	-7.7%
Total					
2016 Inventory Report (MMT CO_2 Eq.)	8.81	9.35	8.82	7.94	7.79
This Inventory Report (MMT CO_2 Eq.)	8.47	9.37	8.89	8.16	8.01
Percent Change	-3.8%	0.2%	0.7%	2.8%	2.9%

+ Does not exceed 0.05%

Uncertainties

Uncertainties associated with stationary consumption estimates include the following:

- Emissions from fuel gas and naphtha consumption were only available from EPA's GHGRP starting in 2010. Data on fuel gas and naphtha consumption in 2007 were collected by DBEDT. As DBEDT is the conduit of this data but not the source, there is uncertainty associated with data collected by DBEDT.
- Emissions from fuel gas and naphtha consumption in the energy industries sector for 2010, 2015, 2016, and 2017 that were obtained from EPA's GHGRP (EPA 2020b) do not include emissions from facilities that are below the reporting threshold of 25,000 metric tons of carbon dioxide equivalent (MT CO_2 Eq.) per year.
- The differences between the SEDS consumption data and data collected by DBEDT, as highlighted in Appendix C, indicate that there are uncertainties around the data collected by DBEDT and SEDS data; while significant effort has been made to validate each dataset and make a determination regarding which dataset has lower uncertainty, this remains an area of uncertainly.

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. 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 coal consumption in the energy industries sector, (2) CO_2 emission factor for residual fuel consumption in the energy industries sector, and (3) residual fuel consumption in the energy industries sector. The results of the quantitative uncertainty analysis are summarized in Table 3-4. Emissions from stationary combustion were estimated to be between 8.00 and 8.24 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 1 percent below and 2 percent above the emission estimate of 8.09 MMT CO_2 Eq.

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

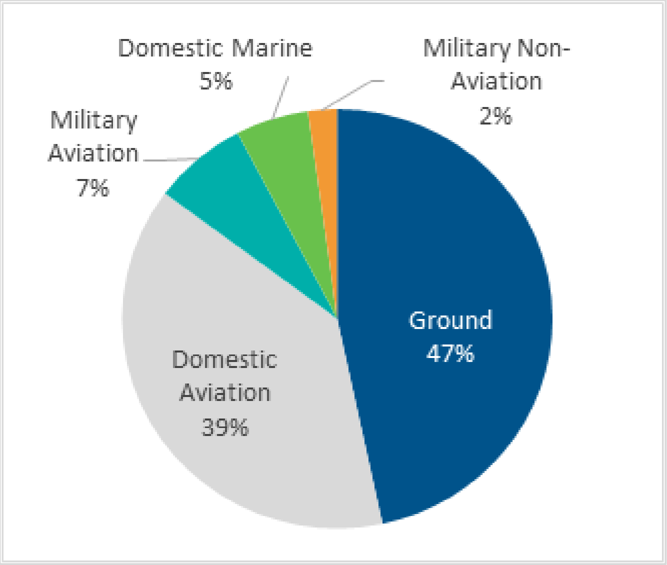
2017 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(%)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
8.09	8.00	8.24	-1%	+2%

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

3.2. Transportation (IPCC Source Category 1A3)

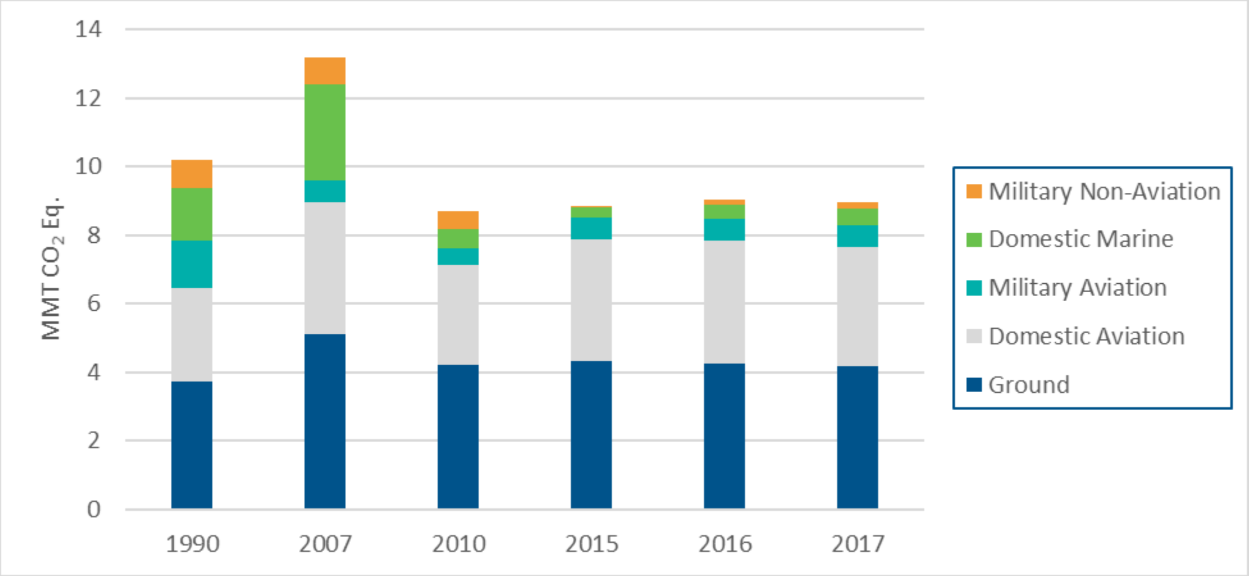
Emissions from transportation result from the combustion of fuel for ground, domestic marine, domestic aviation, military aviation, and military (non-aviation) transportation. Ground transportation includes passenger cars, light trucks, motorcycles, and heavy-duty vehicles (i.e., trucks and buses).[30] In 2017, emissions from transportation activities in Hawaii were 8.98 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 (39 percent), military aviation (7 percent), domestic marine (5 percent), and military non-aviation (2 percent). Figure 3-6 shows the breakout of transportation emissions by end-use sector for 2017.

Figure 3-6: 2017 Transportation Emissions by End-Use Sector



Relative to 1990, emissions from transportation in 2017 were lower by roughly 12 percent. While emissions from ground and domestic aviation transportation increased from 1990 to 2017, 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, 2016, and 2017. Table 3-5 summarizes emissions from transportation in Hawaii by end-use sector and gas for 1990, 2007, 2010, 2015, 2016 and 2017.

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



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[30] Emissions associated with charging electric vehicles (EVs), which currently represent a small share of vehicles on the road in Hawaii, are accounted for under the stationary combustion, energy industries source category.

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	2017
Ground	**3.73**	**5.12**	**4.21**	**4.32**	**4.25**	**4.19**
CO_2	3.56	5.02	4.13	4.28	4.21	4.15
CH_4	0.02	0.01	0.01	+	+	+
N_2O	0.14	0.10	0.08	0.04	0.04	0.04
Domestic Marine	**1.55**	**2.81**	**0.58**	**0.29**	**0.41**	**0.49**
CO_2	1.53	2.77	0.57	0.28	0.40	0.48
CH_4	+	+	+	+	+	+
N_2O	0.02	0.04	0.01	+	0.01	0.01
Domestic Aviation	**2.73**	**3.83**	**2.91**	**3.54**	**3.57**	**3.46**
CO_2	2.70	3.79	2.89	3.51	3.54	3.43
CH_4	+	+	+	+	+	+
N_2O	0.02	0.03	0.03	0.03	0.03	0.03
Military Aviation	**1.38**	**0.63**	**0.49**	**0.66**	**0.65**	**0.64**
CO_2	1.37	0.63	0.48	0.66	0.64	0.63
CH_4	+	+	+	+	+	+
N_2O	0.01	0.01	+	+	0.01	0.01
Military Non-Aviation	**0.79**	**0.78**	**0.51**	**0.05**	**0.17**	**0.20**
CO_2	0.75	0.77	0.50	0.05	0.16	0.19
CH_4	0.03	+	+	+	+	+
N_2O	0.01	0.01	0.01	+	+	+
Total	**10.18**	**13.18**	**8.70**	**8.86**	**9.05**	**8.98**

+ 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 (i.e., domestic aviation, domestic marine, military aviation):** 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 (i.e., international bunker fuels):** 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

Carbon content coefficients for estimating CO_2 emissions, which are specific to each fuel type, were taken from the U.S. Inventory (EPA 2020a). Fuel consumption data for transportation were obtained from EIA's SEDS (EIA 2020a) for all years.[31] These data were available at an aggregate level by fuel type. Disaggregated transportation data collected by DBEDT (2008a, 2020b) were used to allocate transportation fuel consumption from EIA (2020a) for diesel fuel, motor gasoline, propane, residual fuel, and natural gas into marine and ground transportation for each fuel type. Aviation gasoline and jet fuel kerosene are assumed to all be used for aviation.

Aviation gasoline, naphtha-type jet fuel, diesel fuel, and residual fuel consumption for military were obtained from EIA (2019a) for all years.[32] 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 (2020a) prior to estimating emissions for the other subcategories.[33]

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 (2020a) prior to estimating emissions for these years. For 2010, 2015, 2016 and 2017, the aggregate transportation jet fuel consumption data from EIA (2020a) were allocated to military transportation and non-military transportation using the 2007 data breakout.

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

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[31] Diesel fuel consumption data obtained from EIA (2020a) includes blended biodiesel. Biodiesel consumed by the transportation sector was subtracted from diesel fuel consumption from EIA to estimate pure diesel consumption.

[32] Unpublished military fuel consumption data from SEDS for 2017 were not available, therefore consumption for these fuel types were proxied to 2018 data.

[33] EIA SEDS (2020a) does not include any naphtha consumption for Hawaii, so naphtha-type jet fuel consumption in 1990 obtained from EIA (2020b) was assumed to be excluded from SEDS.

methodology and uncertainties associated with the methodology used to apportion aviation and marine fuel consumption into domestic or international consumption is discussed in Section 0.

Calculating CH_4 and N_2O emissions from highway vehicles

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

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

where,

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

For 2010, 2015, 2016, and 2017, 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; 2017). 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; 2017), 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 2020a).

Calculating CH_4 and N_2O emissions from non-highway vehicles

Methane and N_2O emissions from non-highway vehicles[34] were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:

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

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 U.S. Inventory (EPA 2020a). This source was used because the *2006 IPCC Guidelines* does not include updated emission factors for off-road vehicles.

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[34] 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.

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: [35]

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

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 2020a) for ethanol and biodiesel. Biodiesel consumption was estimated based on consumption data obtained from EIA (2020a). Biodiesel consumed by energy industries, as obtained from DBEDT's Economic Data Warehouse (DBEDT 2020a) and Hawaii DOH (2020a), was subtracted from the SEDS biodiesel consumption total to estimate the amount of biodiesel consumed by the transportation sector.

Changes in Estimates since the Previous Inventory Report

Changed that were implemented relative to the 2016 inventory report include the following:

- In the 2016 inventory report, data obtained directly from DBEDT (2008a) for 2007 were used to allocate fuel consumption for each fuel type into marine and ground transportation for all years. For this inventory report, data obtained from DBEDT (2020b) for 2010-2018 were used to allocate fuel consumption into marine and ground transportation for 2010 and 2015-2017.
- For the 2016 inventory report, flight mileage data from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database was used to allocate jet fuel consumption into domestic and international travel. For this inventory report, aircraft-specific fuel efficiency estimates and mileage data were instead used to calculate the ratio of domestic to international fuel consumption, and then allocate jet fuel consumption estimates from SEDS into domestic and international bunker fuel consumption (see Appendix C).
- Biodiesel consumption estimates were updated based on consumption data obtained from EIA (2020a). Biodiesel consumed by energy industries, as obtained from DBEDT's Economic Data Warehouse (DBEDT 2020a) and Hawaii DOH (2020a), was subtracted from the SEDS biodiesel consumption total to estimate the amount of biodiesel consumed by the transportation sector.
- Updated non-road emission factors for CH_4 and N_2O emissions (EPA 2020a) were incorporated into the inventory calculations.
- Fuels-specific emission factors were updated based on the most recent version of the U.S. Inventory (EPA 2020a).

The resulting changes in historical emission estimates are presented in Table 3-6.

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

Table 3-6: Change in Emissions from Transportation Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
Ground					
2016 Inventory Report (MMT CO_2 Eq.)	3.72	5.12	4.15	4.04	4.05
This Inventory Report (MMT CO_2 Eq.)	3.73	5.12	4.21	4.32	4.25
Percent Change	0.2%	+	1.3%	7.1%	4.9%
Domestic Marine					
2016 Inventory Report (MMT CO_2 Eq.)	1.58	2.90	0.60	0.56	0.64
This Inventory Report (MMT CO_2 Eq.)	1.55	2.81	0.58	0.29	0.41
Percent Change	-1.5%	-3.1%	-2.7%	-49.0%	-36.3%
Domestic Aviation					
2016 Inventory Report (MMT CO_2 Eq.)	2.41	3.48	2.67	3.33	3.20
This Inventory Report (MMT CO_2 Eq.)	2.73	3.83	2.91	3.54	3.57
Percent Change	13.3%	9.9%	9.0%	6.4%	11.6%
Military Aviation					
2016 Inventory Report (MMT CO_2 Eq.)	1.38	0.63	0.49	0.66	0.64
This Inventory Report (MMT CO_2 Eq.)	1.38	0.63	0.49	0.66	0.65
Percent Change	-	-	+	-0.9%	1.9%
Military Non-Aviation					
2016 Inventory Report (MMT CO_2 Eq.)	0.76	0.77	0.50	0.05	0.16
This Inventory Report (MMT CO_2 Eq.)	0.79	0.78	0.51	0.05	0.17
Percent Change	4.2%	1.7%	1.7%	1.6%	1.6%
Total					
2016 Inventory Report (MMT CO_2 Eq.)	9.84	12.91	8.41	8.64	8.69
This Inventory Report (MMT CO_2 Eq.)	10.18	13.18	8.70	8.86	9.05
Percent Change	3.4%	2.1%	3.4%	2.5%	4.1%

+ Does not exceed 0.05%

Uncertainties

Uncertainties associated with transportation estimates include the following:

- The differences between the SEDS consumption data and data collected by DBEDT, as highlighted in Appendix C, indicate that there are uncertainties around the data collected by DBEDT and SEDS data; while significant effort has been made to validate each dataset and make a determination regarding which dataset has lower uncertainty, this remains an area of uncertainty.
- Data collected by DBEDT were used to disaggregate fuel consumption data from EIA into ground and marine transportation. 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. 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.

- 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. As DBEDT is the conduit of this data but not the source, there is uncertainty associated with data 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, 2016, and 2017, which also resulted in some uncertainty.

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 kerosene, (2) motor gasoline consumption, (3) jet fuel kerosene 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. Emissions from transportation were estimated to be between 8.63 and 9.40 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 5 percent below and 5 percent above the emission estimate of 8.98 MMT CO_2 Eq.

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

2017 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
8.98	8.63	9.40	-5%	+5%

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

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

Municipal solid waste (MSW) emits CO_2, CH_4, and N_2O emissions when combusted. In 2017, emissions from the incineration of waste in Hawaii were 0.23 MMT CO_2 Eq., accounting for 1 percent of Energy sector emissions.[36] In 1990, MSW was combusted in Hawaii at two facilities: the Honolulu Program of Waste Energy Recovery (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; emissions then decreased from 2016 to 2017. Table 3-8 summarizes emissions from the incineration of waste in Hawaii by gas for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.17	0.15	0.18	0.19	0.26	0.21
CH_4	+	+	+	+	+	+
N_2O	+	+	0.01	0.01	0.01	0.01
Total	**0.18**	**0.15**	**0.19**	**0.20**	**0.27**	**0.23**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

2010, 2015, 2016, and 2017

Emissions for the H-POWER plant for 2010, 2015, 2016, and 2017 were obtained directly from EPA's GHGRP (EPA 2020b). 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
CF_i = fraction of carbon in the dry matter (total carbon content)
FCF_i = fraction of fossil carbon in the total carbon

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[36] Consistent with the U.S. Inventory (EPA 2020a), emissions from waste incineration are reported under the Energy sector because the waste is used to produce energy.

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 2020c).

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 Covanta 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 2016 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 2020a) 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. Emissions from waste incineration were estimated to be between 0.21 and 0.26 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 8 percent below and 13 percent above the emission estimate of 0.23 MMT CO_2 Eq.

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

2017 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
0.23	0.21	0.26	-8%	+13%

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

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

Petroleum refinery activities within the oil system release CO_2, CH_4, and N_2O to the atmosphere as fugitive emissions, vented emissions, and emissions from operational upsets. From 1990 through 2017, two refineries, Island Energy Services and Par Hawaii,[37] operated in Hawaii that contributed to these emissions (EIA 2020b).[38] In addition, CH_4 fugitive emissions occur from natural gas distribution and transmission pipelines. In 2017, emissions from oil and natural gas systems in Hawaii were 0.31 MMT CO_2 Eq., accounting for 2 percent of Energy sector emissions. Relative to 1990, emissions from oil and

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[37] 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.

[38] In 2018, Par Hawaii Inc. acquired Island Energy Services, LLC., which has since ceased its refinery operations and converted to an import terminal (Mai 2018).

natural gas systems in 2017 were lower by roughly 29 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, 2016, and 2017.[39]

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

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.42	0.37	0.31	0.30	0.29	0.30
CH_4	0.01	0.01	0.01	0.01	0.01	0.01
N_2O	+	+	+	+	+	+
Total	**0.43**	**0.39**	**0.32**	**0.31**	**0.29**	**0.31**

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

Note: Totals may not sum due to independent rounding.

Methodology

Refinery emissions for 2010, 2015, 2016, and 2017

Emissions from oil and gas systems for 2010, 2015, 2016, and 2017 were taken directly from EPA's GHGRP (EPA 2020b). This includes non-biogenic CO_2, CH_4, and N_2O fugitive emissions from petroleum refining and hydrogen production for Hawaii's two refineries.

Refinery emissions for 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 2020b) 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).

Fugitive emissions from natural gas distribution and transmission pipelines

Emissions from natural gas distribution and transmission pipelines for all inventory years were estimated using miles and services data by material from DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) database (2017) and applying pipeline leak factors obtained from the U.S. Inventory (EPA 2020a).

Changes in Estimates since the Previous Inventory Report

In the 2016 inventory report, emissions from hydrogen production were not included. This inventory report includes emissions from hydrogen production. In addition, fugitive emissions from natural gas pipelines were incorporated for the first time in this inventory report. The resulting changes in historical emission estimates are presented in Table 3-11.

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

Table 3-11: Change in Emissions from Oil and Natural Gas Systems Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.27	0.24	0.20	0.19	0.19
This Inventory Report (MMT CO_2 Eq.)	0.43	0.39	0.32	0.31	0.29
Percent Change	61.2%	62.2%	62.0%	59.4%	52.1%

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 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. Fugitive emissions from natural gas distribution and transmission are disaggregated by pipeline material. Data from DOT's PHMSA does not provide details on the material types included in the "other materials" category for gas distribution services. An average pipeline leak rate was applied to the distribution services, other materials, and as a result, there is uncertainty associated with these emissions.

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 3-12. Emissions from oil and natural gas systems were estimated to be between 0.30 and 0.31 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 2 percent below and 2 percent above the emission estimate of 0.31 MMT CO_2 Eq.

Table 3-12: Quantitative Uncertainty Estimates for Emissions from Oil and Natural Gas Systems

2017 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
0.31	0.30	0.31	-1.6%	+1.6%

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

3.5. Non-Energy Uses (IPCC Source Category 2D)

In addition to being combusted for energy, fossil fuels are also consumed for non-energy uses in Hawaii. Emissions may occur during the manufacture of a product or during the product's lifetime. Fuels used in non-energy uses include coal, diesel fuel, propane, asphalt and road oil, lubricants, and waxes. In 2017, emissions from non-energy uses of fuels in Hawaii were 0.04 MMT CO_2 Eq., accounting for less than 1 percent of Energy sector emissions. These emissions are included under the Energy sector, rather than the IPPU sector, consistent with the U.S. Inventory (EPA 2020a). Table 3-13 summarizes emissions from non-energy uses of fuels in Hawaii by gas for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 3-13: Emissions from Non-Energy Uses (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.04	0.04	0.05	0.05	0.04	0.04

Note: Totals may not sum due to independent rounding.

Methodology

Carbon dioxide emissions were estimated using the following equation, consistent with IPCC (2006):[40]

$$CO_2\ Emissions\ =\ [Fuel\ Consumption\ \times NEU\ Consumption\ \%\ ] \times C_{fuel}\ \times \frac{44}{12} \times [1 - C_{stored}]$$

where,

Fuel Consumption = total consumption by fuel type and end-use sector (Bbtu)
NEU Consumption % = percentage of non-energy use of fuel consumption (%)
C_{fuel} = total mass of carbon per unit of energy in each fuel (lbs C/Bbtu)
44/12 = conversion of carbon to CO_2
C_{stored} = carbon storage factor by fuel type (%)

The percentage of non-energy use consumption by fuel type were obtained from the U.S. Inventory (EPA 2020a) and applied to total consumption values for fuels by end use sector obtained from EIA's SEDS (EIA 2020a).[41] Carbon content coefficients for estimating CO_2 emissions, which are specific to each fuel type, were taken from the U.S. Inventory (EPA 2020a). The percentage of C stored in non-energy uses of fuels were also obtained from EPA (2020a).

Changes in Estimates since the Previous Inventory Report

Non-energy uses were newly estimated in the 2017 inventory report.

Uncertainties

Uncertainties associated with non-energy use estimates include the following:

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[40] Methane and N_2O emissions from non-energy uses are not estimated, consistent with IPCC Guidance (2006) and the U.S. Inventory (EPA 2020a).

[41] Consumption values for fuels included in the stationary combustion source category from EIA's SEDS (EIA 2020a) were adjusted to subtract non-energy uses.

- Non-energy use CO_2 emission factors are not available from the U.S. Inventory (EPA 2020a), therefore industrial sector emission factors, by fuel type are used.
- Non-energy use estimates are based on U.S.-specific storage factors. The storage factor for feedstocks is based on an analysis of long-term storage and emissions. Rather than modeling the total uncertainty around each process, the current analysis addresses only the storage rates, and assumes that all C that is not stored is emitted. Further analysis may investigate Hawaii-specific non-energy use storage factors and processes.

To estimate uncertainty associated with emissions from non-energy uses, 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) industrial lubricant consumption, (2) transportation lubricant consumption, and (3) industrial LPG consumption.

The results of the quantitative uncertainty analysis are summarized in Table 3-14. Emissions from non-energy uses were estimated to be between 0.03 and 0.04 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 24 percent below and 1 percent above the emission estimate of 0.04 MMT CO_2 Eq.

Table 3-14: Quantitative Uncertainty Estimates for Emissions from Non-Energy Uses

2017 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	0.04	-24%	+1.4%

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

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

International bunker fuels are defined as marine and aviation travel originating in Hawaii and ending in a foreign country. According to IPCC (2006), emissions from the combustion of fuels used for international transport activities, or international bunker fuels, should not be included in emission totals, but instead should be reported separately. International bunker fuel combustion produces CO_2, CH_4, and N_2O emissions from both marine and aviation fuels. In 2017, emissions from international bunker fuels in Hawaii were 1.35 MMT CO_2 Eq., which is 14 percent higher than 1990 levels. Table 3-15 summarizes emissions from international bunker fuels in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 3-15: Emissions from International Bunker Fuels by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
International Marine	**0.09**	**0.05**	**0.39**	**0.10**	**0.06**	**0.12**
CO_2	0.09	0.05	0.39	0.10	0.06	0.12
CH_4	+	+	+	+	+	+
N_2O	+	+	+	+	+	+
International Aviation	**1.09**	**0.83**	**0.68**	**1.20**	**1.20**	**1.23**
CO_2	1.08	0.82	0.67	1.19	1.19	1.22
CH_4	NO	NO	NO	NO	NO	NO
N_2O	0.01	0.01	0.01	0.01	0.01	0.01
Total	**1.18**	**0.88**	**1.07**	**1.30**	**1.25**	**1.35**

+ 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 (metric tons, MT/Bbtu)

Carbon dioxide emission factors were obtained from the U.S. Inventory (EPA 2020a), while CH_4 and N_2O emission factors were obtained from IPCC (2006). The following sections describe how international bunker fuel (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. Aircraft-specific fuel efficiency estimates (miles/gal) and mileage data were used to calculate the ratio of domestic to international fuel consumption to allocate jet fuel consumption estimates from SEDS (EIA 2020a) into domestic and international bunker fuel consumption. The annual fuel efficiency for each aircraft type for both domestic and international flights were calculated using Airline Data Inc.'s (ADI) Form 41 Fuel Statistics dataset (ADI 1990 through 2017). The calculated year-specific fuel efficiencies by aircraft type were then multiplied by the total distance traveled by year for domestic and international flights originating in Hawaii (ADI 1990 through 2017). That ratio was multiplied by total non-military jet fuel consumption in Hawaii, as derived from EIA (2020a and 2019a), to calculate aviation international bunker fuel consumption.

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

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)
Gallons_I = gallons consumed for international trips originating in Hawaii
Gallons_D = gallons consumed 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 applying the average of 2006 and 2007 Hawaii marine bunker fuel consumption (the earliest available years for Hawaii marine bunker fuel) to apportion U.S. consumption in 1990. An average of the two years was used to account for annual fluctuations in consumption. National marine bunker fuel consumption was obtained from the U.S. Inventory (EPA 2020a).

Changes in Estimates since the Previous Inventory Report

In the 2016 inventory report, flight mileage data from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database was used to allocate jet fuel consumption into domestic and international travel. For this inventory report, aircraft-specific fuel efficiency estimates and mileage data were instead used to calculate the ratio of domestic to international fuel consumption, and then allocate jet fuel consumption estimates from SEDS (EIA 2020a) into domestic and international bunker fuel consumption (see Appendix C).

In addition, for the 2016 inventory report 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). Since marine bunker fuel consumption for Hawaii varies year-to-year, to improve the Hawaii marine bunker fuel consumption estimate in 1990, the average of 2006 and 2007 Hawaii marine bunker fuel consumption was instead used to apportion U.S.

consumption in 1990 (see Appendix C). The resulting changes in historical emission estimates are presented in Table 3-16.

Table 3-16: Change in Emissions from International Bunker Fuels Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	1.53	1.22	1.31	1.65	1.54
This Inventory Report (MMT CO_2 Eq.)	1.18	0.88	1.07	1.30	1.25
Percent Change	-22.8%	-28.3%	-18.9%	-21.3%	-18.4%

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 that there are uncertainties around the data collected by DBEDT and SEDS data; while significant effort has been made to validate each dataset and make a determination regarding which dataset has lower uncertainty, this remains an area of uncertainty.
- There is some uncertainty associated with estimating jet fuel consumption for international trips based on the international flight to total flight fuel efficiency ratio. This approach was used because data on jet fuel consumption for international trips originating in Hawaii were not available.
- There is some uncertainty with estimating marine bunker fuel consumption in 1990 due to a lack of available data and use of the average of 2006 and 2007 data to apportion total U.S. consumption.
- Uncertainties exist with the reliability of 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 2020a).

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 3-17. Emissions from international bunker fuels were estimated to be between 1.20 and 1.51 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 1.35 MMT CO_2 Eq.

Table 3-17: Quantitative Uncertainty Estimates for Emissions from International Bunker Fuels

2017 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
1.35	1.20	1.51	-11%	+12%

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

3.7. 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.[42,43] 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 2017, CO_2 emissions from wood biomass and biofuel consumption in Hawaii were 0.75 MMT CO_2 Eq. Table 3-18 summarizes CO_2 emissions from wood biomass and biofuel consumption in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 3-18: Emissions from Wood Biomass and Biofuel Consumption by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	2.43	0.88	1.24	1.40	1.49	0.75

Methodology

Biofuel

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

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

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

[43] 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.

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)

Wood Biomass

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

$$CO_2\ Emissions\ =\ Wood\ Biomass\ Consumption\ \times\ EF_{wood\ biomass}$$

where,

Wood Biomass Consumption = total amount of wood biomass combusted (Bbtu)
$EF_{wood\ biomass}$ = Wood biomass default CO_2 emission factor (lb CO_2/MMBtu)

Ethanol, biodiesel, and wood biomass consumption data were obtained from SEDS (EIA 2020a) for all years. Carbon dioxide combustion emission factors were obtained from the U.S. Inventory (EPA 2020a).

Changes in Estimates since the Previous Inventory Report

In the 2016 inventory report, CO_2 emissions from biodiesel consumption were based on data obtained from EPA's GHGRP and DBEDT. For this inventory report, biodiesel consumption estimates were updated based on consumption data obtained from EIA (2020a) (see Appendix C). The resulting changes in historical emission estimates are presented in Table 3-19.

Table 3-19: Change in CO_2 Emissions from Wood Biomass and Biofuel Consumption Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	2.43	0.87	1.27	1.47	1.53
This Inventory Report (MMT CO_2 Eq.)	2.43	0.88	1.24	1.40	1.49
Percent Change	0.0%	1.5%	-1.9%	-4.9%	-2.3%

Uncertainties

The differences between the SEDS consumption data and data collected by DBEDT, as highlighted in Appendix C, indicate that there are uncertainties around the data collected by DBEDT and SEDS data; while significant effort has been made to validate each dataset and make a determination regarding which dataset has lower uncertainty, this remains an area of uncertainly.

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 quantitatively around each input variable based on IPCC (2006) and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) H-Power plant biogenic CO_2 emissions, (2) transportation ethanol consumption, and (3) CO_2 emission factor for ethanol.

The results of the quantitative uncertainty analysis are summarized in Table 3-20. Carbon dioxide emissions from wood biomass and biofuel consumption were estimated to be between 0.69 and 0.83 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 9 percent below and 10 percent above the emission estimate of 0.75 MMT CO_2 Eq.

Table 3-20: Quantitative Uncertainty Estimates for Emissions from Wood Biomass and Biofuel Consumption

2017 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
0.75	0.69	0.83	-9%	+10%

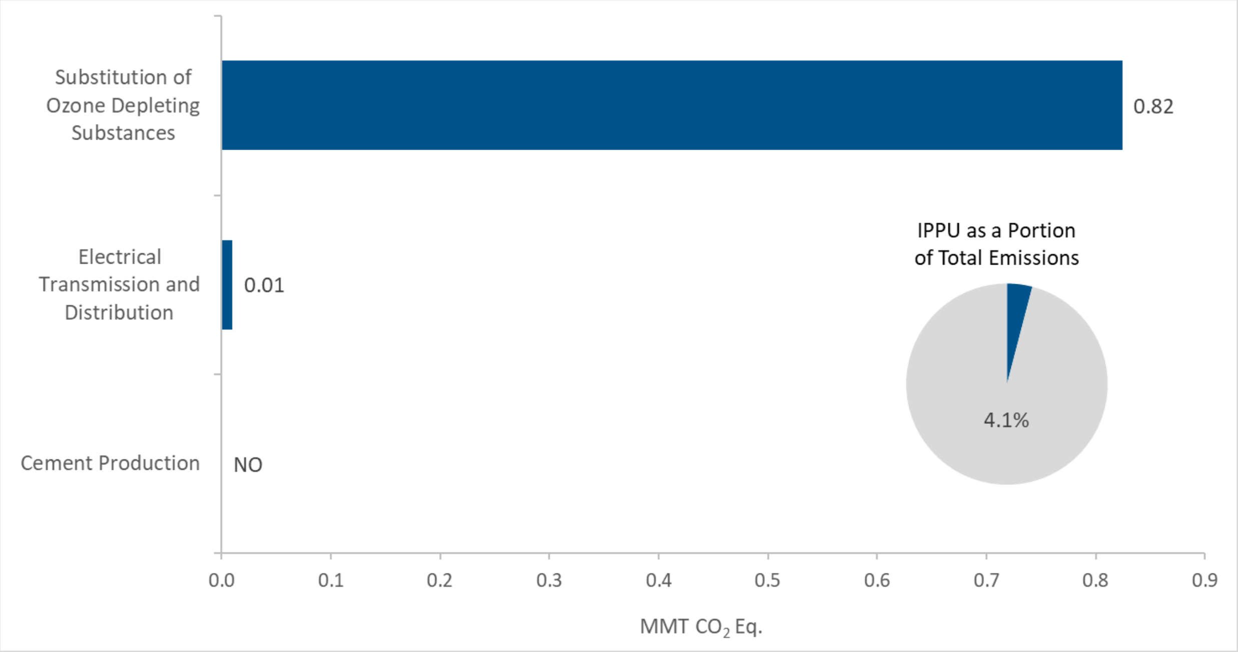
[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

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 2017, emissions from the IPPU sector were 0.83 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 2017 were zero. Figure 4-1 and Figure 4-2 show emissions from the IPPU sector by source for 2017.

Figure 4-1: 2017 IPPU Emissions by Source (MMT CO_2 Eq.)



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[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 2017 were nearly five 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 2020a). Sulfur hexafluoride emissions from electrical transmission and distribution decreased by 86 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 2020a). 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: 2017 IPPU Emissions by Source

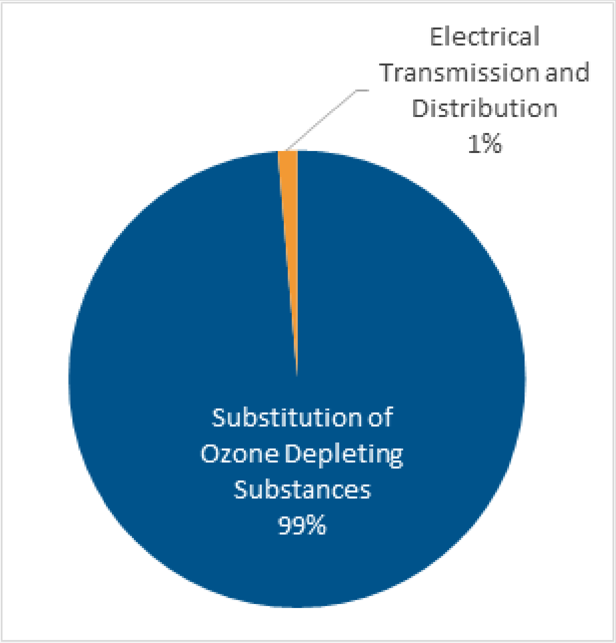


Figure 4-3: IPPU Emissions by Source and Year

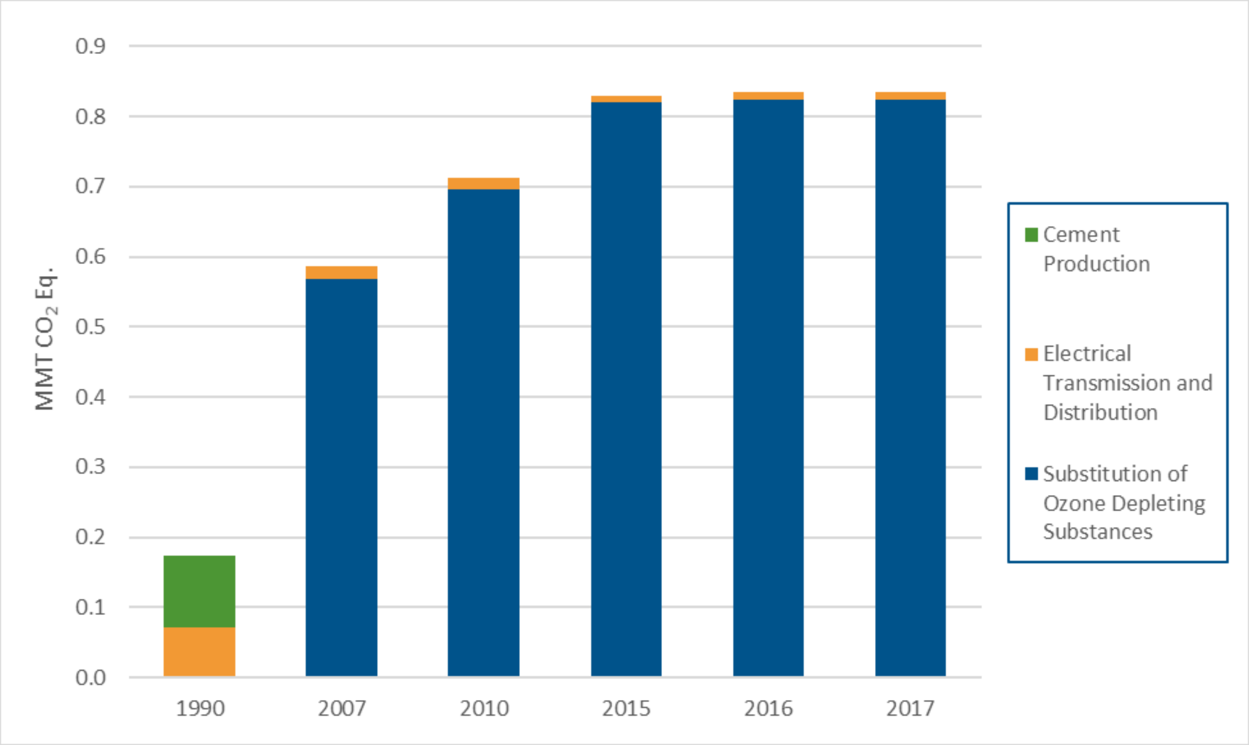


Table 4-1: GHG Emissions from the IPPU Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016	2017
Cement Production	0.10	NO	NO	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	+	0.57	0.70	0.82	0.82	0.82
Total	**0.17**	**0.59**	**0.71**	**0.83**	**0.83**	**0.83**

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

Note: Totals may not sum due to independent rounding.

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

4.1. Cement Production (IPCC Source Category 2A1)

Carbon dioxide emissions are released as a by-product of the clinker production process, an intermediate product used primarily to make portland cement. In Hawaii, clinker was produced on-site in Oahu until production ceased in 1996, after which clinker was imported (Wurlitzer 2008). Portland cement production ended in Hawaii in 2001 (Wurlitzer 2008). As a result, in 2017, emissions from cement production in Hawaii were zero. Table 4-2 summarizes emissions from cement production in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.10	NO	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:

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

where:

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

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from cement production since the 2016 inventory report.

Uncertainties

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

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 2017, 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 2017 were lower by 86 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 2020a). Table 4-3 summarizes emissions from electrical transmission and distribution systems in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
SF_6	0.07	0.02	0.02	0.01	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 2020a). National electricity sales data come from the U.S. Department of Energy, Energy Information Administration (EIA 2019b). Hawaii electricity sales data come from the State of Hawaii Data Book (DBEDT 2019).

Changes in Estimates since the Previous Inventory Report

National emissions data were updated based on updated values published by EPA (2020a). 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 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01	0.01
This Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01	0.01
Percent Change	0.4%	1.6%	-3.4%	-11.6%	-4.7%

+ 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. Emissions from electrical transmission and distribution systems were estimated to be between 0.008 MMT CO_2 Eq. and 0.013 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 21 percent below and 27 percent above the emission estimate of 0.010 MMT CO_2 Eq.

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

2017 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
0.010	0.008	0.013	-21%	+27%

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

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 2017, emissions from

ODS substitutes in Hawaii were 0.82 MMT CO_2 Eq., accounting for 99 percent of IPPU sector emissions. Nationally, emissions from ODS substitutes have risen dramatically since 1990, and now represent one of the largest sources of GHG emissions from the IPPU sector (EPA 2020a). Table 4-6 summarizes emissions from HFCs and PFCs that are used as substitutes of ODS in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017. While not included in the inventory totals, estimated emissions from ODS in Hawaii are presented in Appendix I.[45]

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

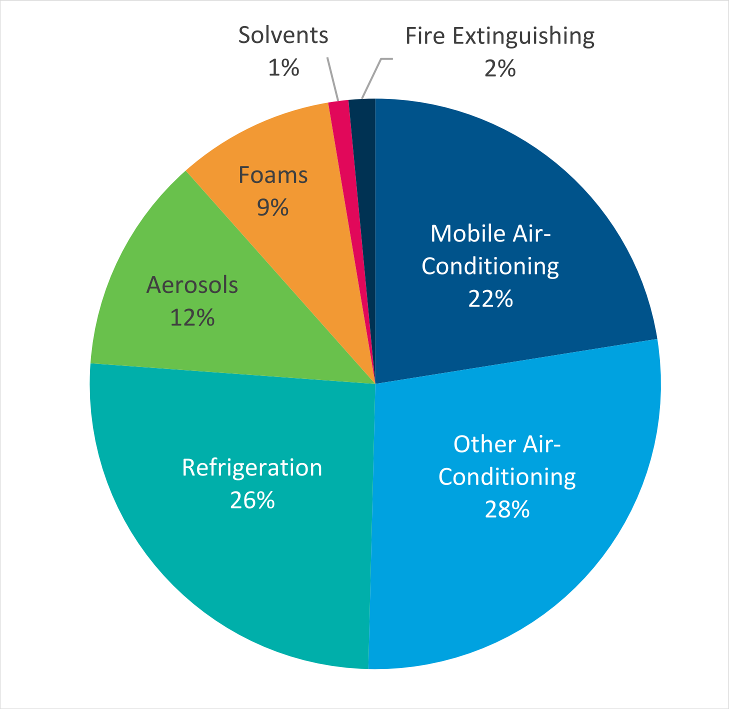
Gas	1990	2007	2010	2015	2016	2017
HFC/PFC	+	0.57	0.70	0.82	0.82	0.82

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

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

Figure 4-4: 2017 Emissions from ODS Substitutes by Sub-Category



At the national level, these emissions are estimated using EPA's Vintaging Model, which tracks the use characteristics of equipment currently in use for more than 50 different end-use categories, and applies HFC and PFC leak rates to estimate annual emissions. In the U.S. Inventory (EPA 2020a), emissions are presented for the following sub-categories:

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

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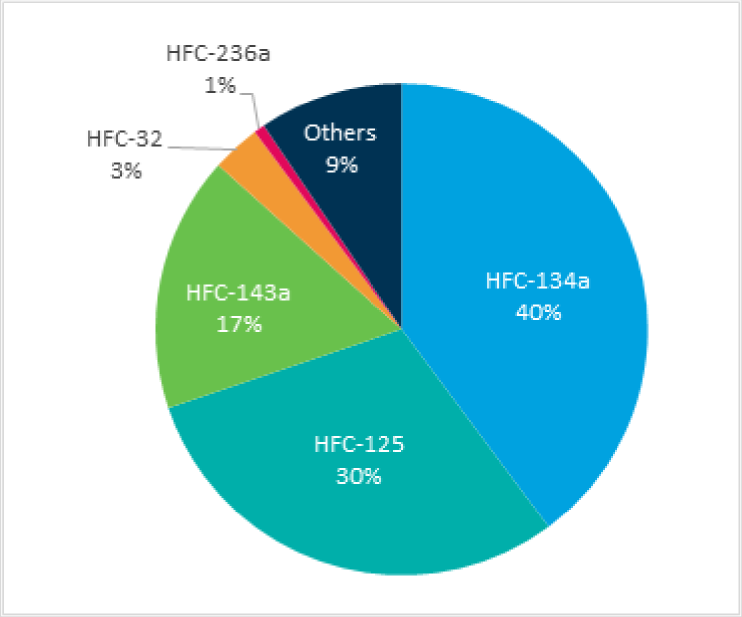
[45] Per IPCC (2006) guidelines, emissions of ODS, which are also GHGs, are not included in this inventory. For informational purposes, ODS emissions were estimated for the state of Hawaii and are presented in Appendix I.

Hawaii emissions from mobile air-conditioning systems were estimated by apportioning national emissions from the U.S. Inventory (EPA 2020a) to Hawaii based on the ratio of Hawaii vehicle registrations from the State of Hawaii Data Book (DBEDT 2019) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2017). Hawaii emissions from other air-conditioning systems (i.e., air conditioning systems excluding mobile air conditioners) were estimated by apportioning national emissions from the U.S. Inventory (EPA 2020a) to Hawaii based on the ratio of the number of houses with air conditioners in Hawaii to the number of houses with air conditioners in the United States.

The number of houses in Hawaii with air conditioners was estimated by apportioning the total number of houses with air conditioners in hot and humid climate regions in the United States using EIA's 2009 and 2015 Residential Energy Consumption Survey (RECS) (EIA 2013; EIA 2018). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2020a) were apportioned to Hawaii based on the ratio of Hawaii population from DBEDT (2019) to U.S. population from the U.S. Census Bureau (2019). Emissions by gas are shown in Figure 4-5.

Figure 4-5: 2017 Emissions from ODS Substitutes by Gas



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 (2019). National emissions data were also updated based on updated values published by EPA (2020a). 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 in the refrigeration and air conditioning and fire protection sectors. Updates were made to various assumptions for integral skin foam, consumer aerosols (previously non-metered dose inhalers), and low-pressure two-component spray foam (previously polyurethane rigid spray foam). Additionally, two new end-uses were added to the model: technical aerosols and low pressure two-component spray foam (EPA 2020a).

In the 2016 inventory report, national emissions from 'other air conditioners' were apportioned to Hawaii based on population. For this inventory report, national emissions were instead apportioned to Hawaii based on number of houses with air conditioners. 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 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	+	0.54	0.65	0.76	0.77
This Inventory Report (MMT CO_2 Eq.)	+	0.57	0.70	0.82	0.82
Percent Change	-24.3%	6.3%	7.6%	8.4%	7.5%

+ 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 2020c). 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. homes in hot and humid climates with air conditioners, and (3) U.S. emissions from substitutes of ODS from aerosols.

The results of the quantitative uncertainty analysis are summarized in Table 4-8. Emissions from substitutes of ODS were estimated to be between 0.80 and 0.88 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 0.82 MMT CO_2 Eq.

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

2017 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
0.82	0.80	0.88	-2%	+7%

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

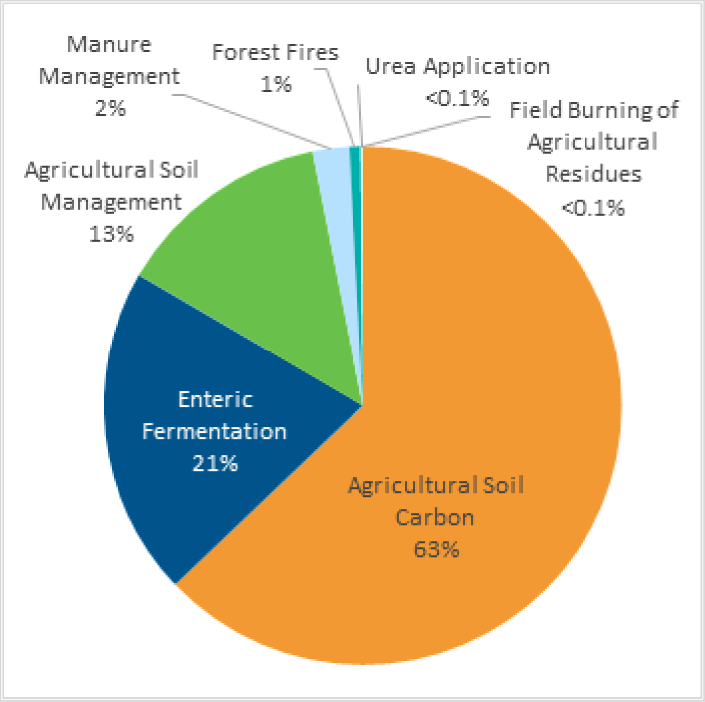
5. Agriculture, Forestry and Other Land Uses (AFOLU)

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 2017, total emissions (excluding sinks) from the AFOLU sector were 1.28 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, manure management, forest fires, urea application, and field burning of agricultural residues. Figure 5-1 and Figure 5-2 show emissions from the AFOLU sector by source for 2017.

Figure 5-1: 2017 AFOLU Emissions by Source



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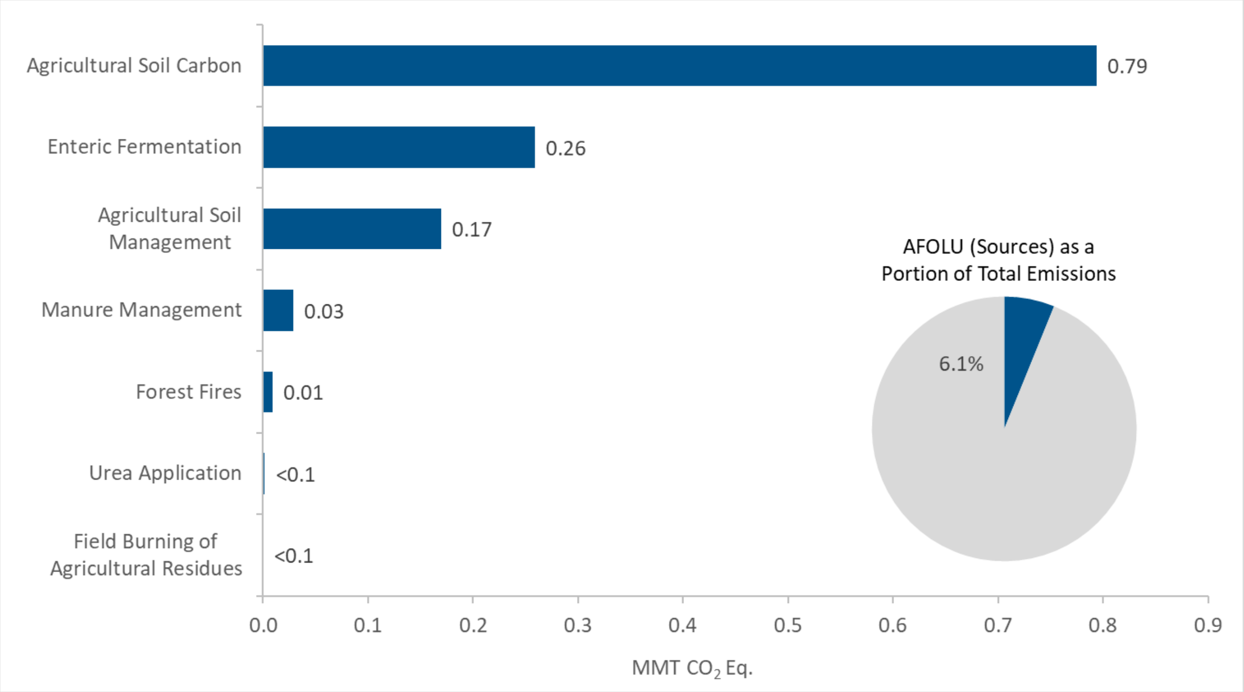
[46] IPCC Source and Sink Categories for which emissions were not estimated for the state of Hawaii include: Land Converted to Forest Land (3B1b), Wetlands (3B4), Land Converted to Settlements (3B5b), Other Land (3B6), Biomass Burning in Grassland (3C1c), Biomass Burning in All Other Land (3C1d), Liming (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: 2017 AFOLU Emissions by Source (MMT CO_2 Eq.)



Carbon removals by sinks were 2.69 MMT CO_2 Eq. in 2017. Therefore, the AFOLU sector resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 1.41 MMT CO_2 Eq. in 2017. 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 2017.

Relative to 1990, emissions from AFOLU sources in 2017 were lower by roughly 20 percent. Carbon removals from AFOLU sinks in 2017 were higher by roughly 10 percent relative to 1990 sinks. As a result, net removals from AFOLU increased by 68 percent in 2017 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: 2017 AFOLU Removals by Carbon Sink

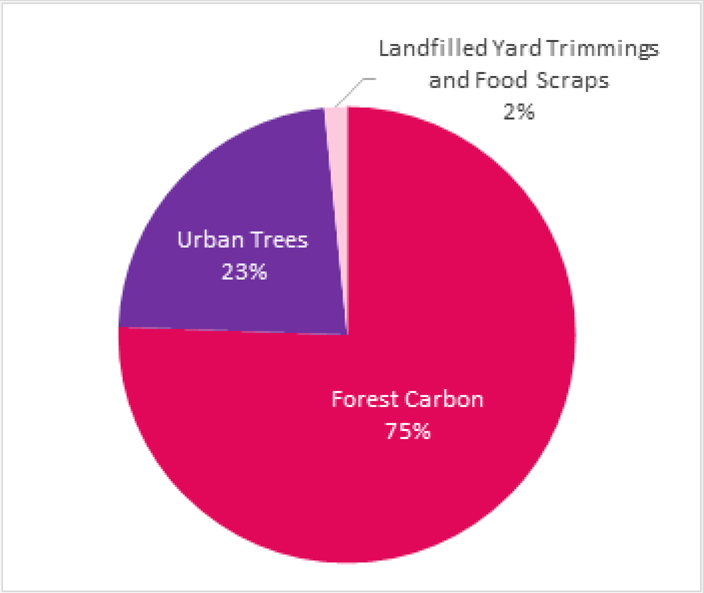


Figure 5-4: AFOLU Emissions and Removals by Source and Sink Category and Year

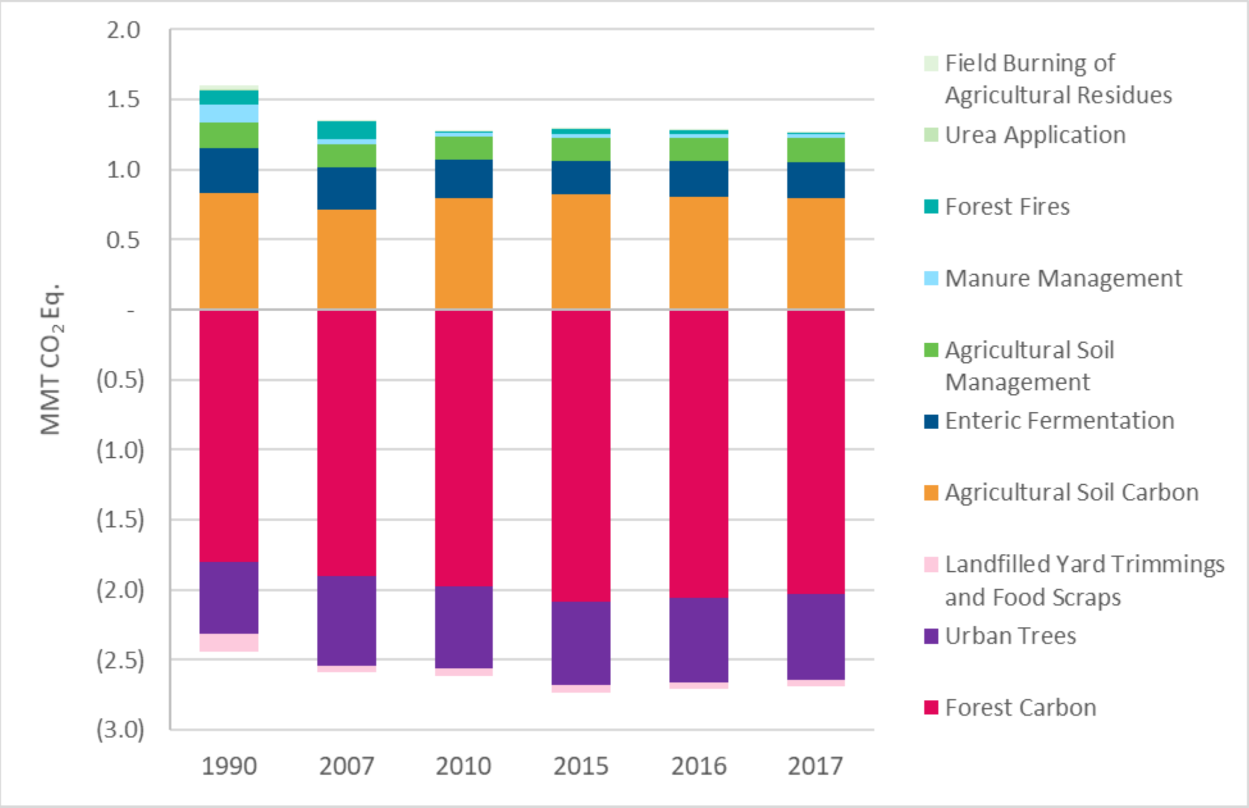


Table 5-1: GHG Emissions from the AFOLU Sector by Category (MMT CO$_2$ Eq.)

Category	1990	2007	2010	2015	2016	2017
Agriculture	**0.67**	**0.51**	**0.47**	**0.44**	**0.46**	**0.46**
Enteric Fermentation	0.32	0.30	0.27	0.24	0.25	0.26
Manure Management	0.14	0.04	0.03	0.03	0.03	0.03
Agricultural Soil Management	0.18	0.17	0.16	0.16	0.17	0.17
Field Burning of Agricultural Residues	0.03	0.01	0.01	0.01	0.01	+
Urea Application	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry	**(1.50)**	**(1.74)**	**(1.81)**	**(1.87)**	**(1.88)**	**(1.88)**
Agricultural Soil Carbon	0.83	0.72	0.80	0.82	0.81	0.79
Forest Fires	0.10	0.12	0.01	0.04	0.02	0.01
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Urban Trees	(0.51)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)
Forest Carbon	(1.80)	(1.90)	(1.98)	(2.08)	(2.06)	(2.03)
Total (Sources)	**1.60**	**1.35**	**1.28**	**1.30**	**1.29**	**1.26**
Total (Sinks)	**(2.44)**	**(2.58)**	**(2.62)**	**(2.73)**	**(2.71)**	**(2.69)**
Total Net Emissions	**(0.84)**	**(1.23)**	**(1.33)**	**(1.43)**	**(1.42)**	**(1.42)**

+ 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. Activity data and emission factors used in the analysis are summarized in Appendix G and Appendix H, respectively.

5.1. Enteric Fermentation (IPCC Source Category 3A1)

Methane is produced as part of the digestive processes in animals, a microbial fermentation process referred to as enteric fermentation. The amount of CH_4 emitted by an animal depends upon the animal's digestive system, and the amount and type of feed it consumes (EPA 2020a). This source includes CH_4 emissions from dairy and beef cattle, sheep, goats, swine, and horses. In 2017, CH_4 emissions from enteric fermentation were 0.26 MMT CO_2 Eq., accounting for 20 percent of AFOLU sector emissions. Table 5-2 summarizes emissions from enteric fermentation in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CH_4	0.32	0.30	0.27	0.24	0.25	0.26

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:

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

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, 1999a, 2004a, 2009, 2014, and 2019), which is compiled every five years. Specifically, population data for 2007 were obtained directly from USDA (2009) while population estimates for 1990, 2010, 2015, 2016 and 2017 were interpolated and extrapolated based on 1987, 1992, 2007, and 2012 data. Cattle population data from USDA NASS were further disaggregated into subgroups based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA for 1990 through 2018 (Steller 2020).

Yearly emission factors for all cattle types available for the state of Hawaii for all years were obtained from the U.S. Inventory (EPA 2020a).[47] Constant emission factors for sheep, goats, horses, and swine were also obtained from the U.S. Inventory (EPA 2020a).

Changes in Estimates since the Previous Inventory Report

To improve emission estimates from enteric fermentation, cattle population data were further disaggregated to allow for the application of more granular emission factors. For the 2016 inventory report, population data and emission factors were applied to the following animal groupings: Dairy Cows, Dairy Replacement Heifers, Other Dairy Heifers, Bulls, Beef Cows, Beef Replacement Heifers, Steers, Other Beef Heifers and Calves. Based on Hawaii-specific cattle population data obtained from the EPA for 1990 through 2018 (Steller 2020), population data were further disaggregated as follows:

- Calves into Beef and Dairy Calves;
- Beef Replacement Heifers into the 7-11 months and 12-23 months age ranges;
- Dairy Replacement Heifers into 7-11 months and 12-23 month age ranges;
- Steer into Steer Feedlot and Steer Stockers; and
- Other Beef Heifers into Heifer Feedlot and Heifer Stockers.

More granular annual enteric emission factors for the new cattle groups from the U.S. Inventory (EPA 2020a) were then applied to estimate emissions. In addition to the cattle updates, the goat population estimates were updated to reflect all goats, as reported by the USDA Census of Agriculture; previously, only emissions from milk and angora goats were reflected in the inventory estimates. The resulting changes in historical emissions estimates, which are not visibly significant, are presented in Table 5-3.

Table 5-3: Change in Emissions from Enteric Fermentation Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.32	0.29	0.27	0.24	0.25
This Inventory Report (MMT CO_2 Eq.)	0.32	0.30	0.27	0.24	0.25
Percent Change	0.4%	0.6%	0.7%	1.0%	0.9%

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

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[47] The U.S. Inventory includes annually variable emission factors for the following cattle types: dairy cows, beef cows, dairy replacement heifers 7-11 months, dairy replacement heifers 12-23 months, other dairy heifers, beef replacement heifers 7-11 months, beef replacement heifers 12-23 months, heifer stockers, heifer feedlot, steer stockers, steer feedlot, beef calves and dairy calves.

available in 2017. As a result, population data for these animals were interpolated between years 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.
- Population data for further disaggregated animal groupings (by age, class, and diet) are not available from USDA NASS and therefore are apportioned based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA (Steller 2020).
- 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 2020a). 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 bulls. 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 5-4. Emissions from enteric fermentation were estimated to be between 0.22 and 0.30 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 14 percent below and 14 percent above the emission estimate of 0.26 MMT CO_2 Eq.

Table 5-4: Quantitative Uncertainty Estimates for Emissions from Enteric Fermentation

2017 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
0.26	0.22	0.30	-14%	+14%

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

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 2020a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. In 2017, emissions from manure management were 0.03 MMT CO_2 Eq., accounting for 2 percent of AFOLU sector emissions. Table 5-5 summarizes emissions from manure management in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CH_4	0.12	0.04	0.03	0.03	0.02	0.03
N_2O	0.01	+	+	+	+	+
Total	**0.14**	**0.04**	**0.03**	**0.03**	**0.03**	**0.03**

+ Does not exceed 0.005 MMT CO_2 Eq.

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 were obtained from various sources, as described below.

- Animal population data for cattle and swine for all years were obtained directly from the USDA NASS (USDA 2018a, 2018b). Cattle population data from USDA NASS were further disaggregated into subgroups based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA for 1990 through 2018 (Steller 2020).
- Chicken population data for 1990 through 2010, for all subgroups except broilers, were obtained from USDA NASS (USDA 2018c). Chicken population data for 2012 and 2017 were obtained from USDA Census of Agriculture (USDA 2014 and 2019) and population data for 2015 and 2016 were estimated by extrapolating data available from 2012 and 2017.
- Population data for sheep, goats, horses, and broiler chickens were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999a, 2004a, 2009, 2014, and 2019), which is compiled every five years. Specifically, population data for 2007 and 2017 were obtained directly from USDA (2009) and USDA (2019), respectively, while population estimates for 1990, 2010, 2015, and 2016 were interpolated based on 1987, 1992, 2007, 2012 and 2017 data.

To develop CH_4 emissions from manure management, typical animal mass (TAM) and maximum potential emissions (B_O) by animal for all animal types were obtained from the U.S. Inventory (EPA 2020a). Weighted methane conversion factors (MCFs) for all cattle types, sheep, goats, horses, swine, and chicken were obtained from the U.S. Inventory (EPA 2020a). Volatile solids (VS) excretion rates were obtained from the U.S. Inventory (EPA 2020a).

To develop N_2O emissions from manure management, nitrogen excretion (Nex) rates for all animal types were obtained from the U.S. Inventory (EPA 2020a). The distributions of waste by animal in different waste management systems (WMS) were obtained from the U.S. Inventory (EPA 2020a). 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).

The weighted averages of chicken and broiler VS rates, Nex rates, TAM and B_O factors, based on the percentage of Hawaii-specific chicken and broiler population data, were applied to total Hawaii chicken and broiler population data. Similarly, the weighted averages of swine VS rates, Nex rates, TAM and B_O factors, based on the percentage of each swine type from the U.S. Inventory (EPA 2020a) were applied to total Hawaii swine population data.

Changes in Estimates since the Previous Inventory Report

Changes that were implemented relative to the 2016 inventory report are summarized below.

- Cattle population data were further disaggregated, as described in Section 5.1, to allow for the application of more granular emission factors.
- Chicken population data were obtained for years 2012 and 2017 from the USDA Census of Agriculture and used to back calculate population estimates after 2010 (USDA 2014 and 2019). For the 2016 inventory report, only chicken population data through 2010 as obtained from USDA NASS were used to prepare the inventory.

- Broiler chicken population data were not included in previous estimates because these data are not available from USDA NASS. For this inventory report, broiler chicken population data were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999a, 2004a, 2009, 2014, and 2019).
- For the 2016 inventory report, goat population data included milk and angora goats but did not include goats reported in the "other goats" category of the USDA Census of Agriculture. For this inventory report, other goat population data were obtained from the USDA Census of Agriculture (USDA 1989, 1994, 1999a, 2004a, 2009, 2014, and 2019).
- For the 2016 inventory report, VS rates, Nex rates, TAM and B_O factors for swine were calculated by averaging the factors for all swine types. For this inventory report, the weighted averages of swine VS rates, Nex rates, TAM and B_O factors, based on the percentage of each swine type from the U.S. Inventory (EPA 2020a) were instead used.

The resulting changes in historical emissions estimates are presented in Table 5-6.

Table 5-6: Change in Emissions from Manure Management Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.15	0.05	0.04	0.04	0.04
This Inventory Report (MMT CO_2 Eq.)	0.14	0.04	0.03	0.03	0.03
Percent Change	-6.2%	-15.8%	-20.8%	-26.3%	-30.0%

Uncertainties

Uncertainties associated with manure management estimates include the following:

- There is uncertainty associated with animal population data. Population data for sheep, goats, horses, and broiler chickens are reported every five years in the USDA Census of Agriculture, with the latest data available in 2017. As a result, population data for these animals were interpolated between years to obtain estimates for 1990, 2010, 2015, and 2016. Similarly, chicken population data, excluding broilers, which are available through 2010 from USDA NASS and then from the USDA Census of Agriculture for years 2012 and 2017, were interpolated 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.
- Population data for further disaggregated animal groupings (by age, class, and diet) are not available from USDA NASS and therefore are apportioned based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA (Steller 2020).
- 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 2020a).

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 methane conversion factor for dairy cows, (2) the maximum methane producing capacity for animal waste (B_0) for dairy cows, and (3) the volatile solids conversion rate for dairy cows.

The results of the quantitative uncertainty analysis are summarized in Table 5-7. Emissions from manure management were estimated to be between 0.02and 0.04 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 19 percent below and 23 percent above the emission estimate of 0.03 MMT CO_2 Eq.

Table 5-7: Quantitative Uncertainty Estimates for Emissions from Manure Management

2017 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
0.03	0.02	0.04	-19%	+23%

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

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 2020a). This category includes N_2O emissions from synthetic fertilizer, organic fertilizer, manure N, as well as crop residue inputs from sugarcane,[48] pineapples, sweet potatoes, ginger root, taro, corn for grain, and seed production. In 2017, emissions from agricultural soil management were 0.17 MMT CO_2 Eq., accounting for 13 percent of AFOLU sector emissions. Table 5-8 summarizes emissions from agricultural soil management in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-8: Emissions from Agricultural Soil Management by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
N_2O	0.18	0.17	0.16	0.16	0.17	0.17

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[48] The Hawaiian Commercial & Sugar Company plant closed in December 2016; as a result, sugarcane crop area and production in Hawaii decreased significantly after 2016.

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 (MT/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, 1999a, 2004a, 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, 2016, and 2017 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, 2016 and 2017 were estimated by extrapolating data for 1997 and 2002 (USDA 2004a). Sweet potato production was not available for 2012, so sweet potato production data for 2010, 2015, 2016 and 2017 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 2020a).

Seed crop acreage for 1990 through 2017 were obtained from the USDA (USDA 2004b, 2015, 2016, and 2018e). According to the USDA, seed corn accounts for over 95 percent of the value of Hawaii's seed industry (USDA 2018). Therefore, corn for grain crop residue factors from IPCC (2006) were applied to seed production data to estimate emissions from nitrogen applied from crop residues. Seed crop acreage data were used to estimate total seed production by using the average production per acre of corn for grain as a proxy.

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 2008, 2011, 2013, 2014, 2017; TVA 1991). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[49] Historical usage patterns were used to apportion these sales to the inventory calendar years (January through December). Synthetic fertilizer N application data were not available after 2014, so 2015 through 2017 data were extrapolated based on 2010-2014 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 were obtained from the following sources:

- 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 were estimated by interpolating data available from the USDA Census of Agriculture for years 2012 and 2017 (USDA 2014 and 2019). Cattle population data from USDA NASS were further disaggregated into subgroups based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA for 1990 through 2018 (Steller 2020).
- Broiler chicken population data were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999a, 2004a, 2009, 2014, and 2019).
- Population data for sheep, goats, and horses were obtained directly from and estimated using the USDA Census of Agriculture (USDA 1989, 1994, 1999a, 2004a, 2009, 2014, and 2019), which is compiled every five years. Specifically, population data for 2007 and 2017 were obtained directly from USDA (2009) and USDA (2019), respectively, while population estimates for 1990, 2010, 2015, and 2016 were interpolated based on 1987, 1992, 2007, 2012, and 2017 data.

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[49] Fertilizer sales are reported by fertilizer year, corresponding to the growing season. The 2017 fertilizer year, for example, runs from July 2016 to June 2017.

Changes in Estimates since the Previous Inventory Report

Relative to the 2016 inventory report, cattle population data were further disaggregated, as described in Section 5.1, to allow for the application of more granular emission factors. Emissions from seed production were estimated for all inventory years. For the 2016 inventory report, emissions from seed production in Hawaii were not estimated. The resulting changes in historical emissions estimates are presented in Table 5-9.

Table 5-9: Change in Emissions from Agricultural Soil Management Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.17	0.16	0.16	0.16	0.16
This Inventory Report (MMT CO_2 Eq.)	0.18	0.17	0.16	0.16	0.17
Percent Change	3.7%	0.6%	1.2%	1.5%	1.5%

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, horses, and broiler chickens are reported every five years in the USDA Census of Agriculture, with the latest data available in 2017. As a result, population data for these animals were interpolated between years to obtain estimates for 1990, 2010, 2015, and 2016. Similarly, chicken population data, excluding broilers, which are available through 2010 from USDA NASS and then from the USDA Census of Agriculture for years 2012 and 2017, were interpolated to obtain estimates for 2015 and 2016. Population data for further disaggregated animal groupings (by age, class, and diet) are not available from USDA NASS and therefore are apportioned based on the relative ratios of cattle animal groupings of Hawaii-specific cattle population data obtained from EPA (Steller 2020).
- 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 2017 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.
- There is uncertainty associated with seed production data since the USDA provides seed production data only for out-shipments of seed. Data on out-shipments of seed are not

representative of total seed production in Hawaii because the majority of the seeds produced are not sold but instead are used for ongoing research or for further propagation before sale (USDA 1999b). Therefore, seed crop acreage data were used to estimate total seed production by using the average production per acre of corn for grain as a proxy. 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 2020a), 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 5-10. Emissions from agricultural soil management were estimated to be between 0.11 and 0.30 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 33 percent below and 78 percent above the emission estimate of 0.17 MMT CO_2 Eq.

Table 5-10: Quantitative Uncertainty Estimates for Emissions from Agricultural Soil Management

2017 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
0.17	0.11	0.30	-33%	+78%

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

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 2020a).[50] 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). The Hawaiian Commercial & Sugar Company plant closed in December 2016, so sugarcane crop area and production decreased significantly from 2016 to 2017. In 2017, emissions from field burning of agricultural residues were 0.000002 MMT CO_2 Eq., accounting for less than 1 percent of AFOLU sector

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[50] 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).

emissions. Table 5-11 summarizes emissions from field burning of agricultural residues in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-11: Emissions from Field Burning of Agricultural Residues Emissions by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
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.

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 2020a). Emissions were calculated using the following equation:

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

where,

Crop = crop production; annual weight of crop produced (kg)

R_{RC} = residue-crop ratio; amount of residue produced per unit of crop production

DMF = dry matter fraction; amount of dry matter per unit of biomass

$Frac_{BURN}$ = fraction of crop residue burned amount of residue which is burned per unit of total residue

BE = burning efficiency; the proportion of pre-fire fuel biomass consumed

CE = combustion efficiency; the proportion of C or N released with respect to the total amount of C or N available in the burned material

C or N content of residue = amount of C or N per unit of dry matter

$R_{emissions}$ = emissions ratio; g CH_4-C/g C released or g N_2O-N/g N release (0.0055 and 0.0077, respectively)

$F_{conversion}$ = conversion factor; conversion of CH_4-C to C or N_2O-N to N (16/12 and 44/28, respectively)

Annual sugarcane area and production estimates were obtained directly from USDA NASS (USDA 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 2016 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 for sugarcane, (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 5-12. Emissions from field burning of agricultural residues were estimated to be between 0.000001 and 0.000003 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 36 percent below and 40 percent above the emission estimate of 0.000002 MMT CO_2 Eq.

Table 5-12: Quantitative Uncertainty Estimates for Emissions from Field Burning of Agricultural Residues

2017 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
0.000002	+	+	-36%	+40%

+ 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.

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 2017, emissions from urea application were 0.002 MMT CO_2 Eq., accounting for less than 1 percent of AFOLU sector emissions. Table 5-13 summarizes emissions from urea application in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-13: Emissions from Urea Application by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
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 2008, 2011, 2013, 2014, 2017; TVA 1991). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[51] 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 through 2017 data were estimated based on 2010-2014 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

No changes were made to emissions from urea application since the 2016 inventory report.

Uncertainties

There is uncertainty associated with the extrapolation of urea fertilizer application data to 2017 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

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[51] Fertilizer sales are reported by fertilizer year, corresponding to the growing season. The 2017 fertilizer year, for example, runs from July 2016 to June 2017.

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. 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 43 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

2017 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
0.002	+	+	-43%	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.

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 2020a). 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 2017, emissions from agricultural soils were 0.79 MMT CO_2 Eq., accounting for 63 percent of AFOLU sector emissions. Table 5-15 summarizes emissions from agricultural soils in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.83	0.72	0.80	0.82	0.81	0.79

Methodology

Emission estimates from Hawaii's agricultural soils are based on state-level data obtained from the 1990-2018 U.S. Inventory (EPA 2020a). State-level emission estimates from agricultural soils are only available for 2015 in the 1990-2018 U.S. Inventory (EPA 2020a).[52] The 1990-2015 U.S. Inventory provides a full timeseries of state-level emission estimates from 1990 through 2015 (EPA 2017). These estimates were developed by EPA using a Tier 2 IPCC methodology. This Tier 2 methodology incorporated country-specific carbon storage factors and activity data from the USDA National Resources Inventory, among other sources (EPA 2017).

To estimate emissions from Hawaii's agricultural soils for 1990 through 2015, the percent change between the 2015 estimates obtained from the 1990-2018 U.S. Inventory and the 1990-2015 U.S. Inventory were applied to the entire timeseries from the 1990-2015 U.S. Inventory. To estimate emissions for 2016 and 2017, 2015 emissions estimates from the 1990-2018 U.S. Inventory (EPA 2020a) were projected based on projected changes in Hawaii land cover by the U.S. Geological Survey (USGS) (Selmants et al. 2017, Selmants 2020). Specifically, the projected percent change in land cover for grassland and agricultural lands were annualized and applied to the 2015 emission estimates for grassland and cropland, respectively, to estimate 2016 and 2017 emissions.

Changes in Estimates since the Previous Inventory Report

Relative to the 2016 inventory report, agricultural soil emissions were revised based on the latest state-level estimates for 2015, and national-level estimates for 1990, 2007, 2010, 2015, 2016, and 2017, as obtained from the 1990-2018 U.S. Inventory (EPA 2020a). The updated 2015 emission estimates from the 1990-2018 U.S. Inventory (EPA 2020a) were 36 percent higher for cropland soils and 54 percent higher for grassland soils than the 2015 estimates obtained from the 1990-2015 U.S. Inventory (EPA 2017). Additionally, the methodology used to extrapolate grassland soil emissions for 2016 was updated based on land cover projections for grassland from USGS (Selmants et al. 2017); previously, projected changes in carbon stored in grassland was used to extrapolate emissions from grassland. The resulting changes in historical emissions estimates are presented in Table 5-16.

Table 5-16: Change in Emissions from Agricultural Soil Carbon Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.57	0.48	0.53	0.56	0.55
This Inventory Report (MMT CO_2 Eq.)	0.83	0.72	0.80	0.82	0.81
Percent Change	47.5%	50.8%	50.7%	47.2%	47.1%

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 2017. The methodology used to

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[52] State-level estimates from the U.S. Inventory do not include the change in carbon stocks due to the application of sewage sludge to soils, which are only estimated at the national scale (EPA 2020a).

project 2015 emissions from agricultural soil carbon to 2017 is based on USGS projections of land cover types 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 to the quantified uncertainty estimates: (1) carbon stock changes in mineral soils in grassland (from 1990-2015 U.S. Inventory estimates), (2) carbon stock changes in organic soils in grassland (from 1990-2018 U.S. Inventory estimates), and (3) carbon stock changes in organic soils in cropland (from 1990-2018 U.S. Inventory estimates).

The results of the quantitative uncertainty analysis are summarized in Table 5-17. Emissions from agricultural soil carbon were estimated to be between -2.61 and 4.02 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 428 percent below and 407 percent above the emission estimate of 0.79 MMT CO_2 Eq.

Table 5-17: Quantitative Uncertainty Estimates for Emissions from Agricultural Soil Carbon

2017 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
0.79	(2.61)	4.02	-428%	+407%

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

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).[53] In 2017, emissions from forest fires were 0.01 MMT CO_2 Eq., accounting for 1 percent of AFOLU sector emissions. Table 5-18 summarizes emissions from forest fires in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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[53] 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 5-18: Emissions from Forest Fires by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	0.09	0.11	0.01	0.03	0.02	0.01
CH_4	0.01	0.01	+	+	+	+
N_2O	+	0.01	+	+	+	+
Total	**0.10**	**0.12**	**0.01**	**0.04**	**0.02**	**0.01**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

Emissions from forest fires were estimated by multiplying the area burned for each vegetation class (in hectares) by an emission factor specific to that vegetation class and moisture scenario. These emission factors are based on USGS data, which generated emission factors for each vegetation class, moisture scenario, and biomass pool using the First-Order Wildland Fire Effect Model (FOFEM) (Selmants 2017). 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, 2016, and 2017 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; DBEDT 2019). 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 2019). 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, 2002 data were used as a proxy for 2007, and 2016 data were used as a proxy for 2017.

Managed forestland area data were obtained from the State of Hawaii Data Book (DBEDT 2019). 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, 2016 and 2017. Unmanaged forests are not included in this analysis per IPCC guidelines because the majority of anthropogenic GHG emissions occurs on managed land (IPCC 2006).

To break down the total forest/shrubland burned into vegetation classes, annual percentages of area burned by vegetation class and moisture scenario were obtained from USGS (Selmants 2020). These percentages were available for 1999 to 2019. The average for each vegetation class from this timeseries was applied to the years 1990 through 1998. The total area burned for each vegetation class and moisture scenario was then multiplied by the associated emission factor to calculate CO_2 emissions. 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 2016 inventory report, the formula used to calculate emissions from forest fires was updated to account for new emission factors from the U.S. Geological Survey (Selmants 2020). These emission factors directly estimate CO_2 emissions based on the area burned for each vegetation class and moisture scenario. Previously, the methodology included an assumption regarding available fuel or combustion factors for each land category. In addition, this inventory reflects updated totals of area burned by vegetation class and moisture scenario for 1999 to 2019. These data are used to calculate the percentage breakdown of area burned, and to apportion total burned area to each vegetation class (Selmants 2020). The resulting changes in historical emissions estimates are presented in Table 5-19.

Table 5-19: Change in Emissions from Forest Fires Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.08	0.12	0.01	0.02	0.07
This Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.01	0.04	0.02
Percent Change	24.9%	-1.5%	-6.8%	60.4%	-68.3%

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 proxied based on the available data. There is significant annual variability in wildfire acres burned data, so 1994 data may not accurately represent wildfire acres burned in 1990.
- The ratio of forest and shrubland area is also a source of uncertainty for all inventory years because the ratios are estimated based on land cover data for years 1999 through 2019.
- The carbon emissions from each vegetation class and moisture scenario are a source of uncertainty because they are used to calculate the emission factors for each land class (in CO_2 Eq.) by taking an average of each moisture scenario.
- According to the United States Forest Service (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 1.92 MMT CO_2 Eq. in 2014 and 0.08 MMT CO_2 Eq. in 2017.[54] 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. (See Appendix C for additional discussion.)

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

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), Selmants (2017, 2020), IPCC (2006), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) reported forest area burned, (2) methane emission factor, and (3) land under wildland fire protection.

The results of the quantitative uncertainty analysis are summarized in Table 5-20. Emissions from forest fires were estimated to be between 0.007 and 0.011 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 26 percent below and 27 percent above the emission estimate of 0.009 MMT CO_2 Eq.

Table 5-20: Quantitative Uncertainty Estimates for Emissions from Forest Fires

2017 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
0.009	0.007	0.011	-26%	+27%

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

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 2017, landfilled yard trimmings sequestered 0.05 MMT CO_2 Eq., accounting for 2 percent of carbon sinks. Table 5-21 summarizes changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-21: CO_2 Flux from Landfilled Yard Trimmings and Food Scraps (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)

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 2020c). 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 2020c) 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 2020c), were used to calculate the national-level estimates. Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2019).

Changes in Estimates since the Previous Inventory Report

Relative to the 2016 inventory report, waste generation and incineration data were updated for 2016 based on the most recent version of EPA's *Advancing Sustainable Materials Management* Fact Sheet, as referenced in EPA's State Inventory Tool (EPA 2020c). The resulting changes in historical sink estimates are presented in Table 5-22.

Table 5-22: Change in Sinks from Landfilled Yard Trimmings and Food Scraps Relative to the 2016 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)
This Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)
Percent Change	0%	0%	0%	+	-5.8%

+ Does not exceed 0.05%.

Note: Parentheses indicate negative values or sequestration.

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, (2) yard trimming recovery, and (3) the proportion of carbon stored permanently in food scraps.

The results of the quantitative uncertainty analysis are summarized in Table 5-23. Sinks from landfilled yard trimmings and food scraps were estimated to be between -0.08 and -0.02 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 88 percent below and 63 percent above the sink estimate of -0.04 MMT CO_2 Eq.

Table 5-23: Quantitative Uncertainty Estimates for Sinks from Landfilled Yard Trimmings and Food Scraps

2017 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)	(0.08)	(0.02)	+88%	-63%

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

Note: Parentheses indicate negative values or sequestration.

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 2018). In 2017, urban trees sequestered 0.61 MMT CO_2 Eq., accounting for 23 percent of carbon sinks. Table 5-24 summarizes carbon flux from urban trees in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-24: CO_2 Flux from Urban Trees (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	(0.51)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)

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 2020a) 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 1990-2018 U.S. Inventory provides state-level carbon sequestration rates from trees in *Settlements Remaining Settlements*, a land-use category that includes urban areas (EPA 2020a). Using the Hawaii-specific estimates, 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.[55] 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 2017 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, 2016, and 2017.

Nowak and Greenfield (2012) developed a study to determine percent tree cover by state. According to Nowak and Greenfield (2012), 39.9 percent of urban areas in Hawaii were covered by trees circa 2005.

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[55] 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 2020a).

With an estimate of total urban tree cover for Hawaii, the Hawaii-specific sequestration factor (MT C/km^2 tree cover) was applied to this area to calculate total C sequestration by urban trees (MT C/year).

Changes in Estimates since the Previous Inventory Report

Relative to the 2016 inventory report, the net carbon sequestration factor per area of tree cover was updated using state-specific values from the U.S. Inventory (EPA 2020a). The resulting changes in historical sink estimates are presented in Table 5-25.

Table 5-25: Change in Sinks from Urban Trees Relative to the 2016 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	(0.28)	(0.35)	(0.32)	(0.33)	(0.33)
This Inventory Report (MMT CO_2 Eq.)	(0.51)	(0.64)	(0.58)	(0.60)	(0.60)
Percent Change	82.8%	82.8%	82.8%	82.8%	82.8%

Note: Parentheses indicate negative values or sequestration.

Uncertainties

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

- The methodology used to estimate urban area in 2015, 2016, and 2017 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.
- The average and net sequestration rates are based on estimates of the settlement area in Hawaii and the associated percent tree cover in developed land. This methodology has associated uncertainty resulting from the land cover data used to generate the area and tree cover estimates.

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 and 2012), Selmants et al. (2017), U.S. Census (2012), EPA (2020a), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) net carbon sequestration per area of urban tree cover in Hawaii , (2) 2010 urban area in Honolulu, and (3) the percent of urban area in Hawaii covered by trees. The quantified uncertainty estimated for net carbon sequestration per area of urban tree cover 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 5-26. Sinks from urban trees were estimated to be between -0.86 and -0.38 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 40 percent below and 38 percent above the sink estimate of -0.61MMT CO_2 Eq.

Table 5-26: Quantitative Uncertainty Estimates for Sinks from Urban Trees

2017 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
(0.61)	(0.86)	(0.38)	+40%	-38%

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

Note: Parentheses indicate negative values or sequestration.

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.[56] In 2017, forests and shrubland sequestered 2.03 MMT CO_2 Eq., accounting for 75 percent of carbon sinks. Table 5-27 summarizes carbon flux from forests and shrubland in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 5-27: CO_2 Flux from Forest Carbon (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CO_2	(1.80)	(1.90)	(1.98)	(2.08)	(2.06)	(2.03)

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

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[56] 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.

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 2019). 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, 2016, and 2017.

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

According to NOAA-CCAP, roughly half of Hawaii's forestland in 2000 was shrub/scrubland, defined as land with vegetation less than 20 feet tall (NOAA-CCAP 2000). In 2014, the share of shrubland in Hawaii 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, 2016, and 2017. 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).

Net ecosystem production for forest and shrubland in Hawaii were obtained from USGS for 2011-2025 (Selmants 2020). Net C sequestration rates were calculated by dividing annual net ecosystem production for each land class by the associated area to obtain a yearly rate (MT C/hectares or ha/year). Each year's net C sequestration rate for forest and shrubland were applied to the respective land area. For years prior to 2011, the average sequestration rates across the entire timeseries was used.

Changes in Estimates since the Previous Inventory Report

Relative to the 2016 inventory report, net sequestration rates for the entire time series were updated to reflect new Hawaii-specific values from USGS (Selmants 2020). The USGS net sequestration rates are based on Hawaii-specific biomass and soil organic carbon data, aboveground carbon density maps, and climate data (Selmants 2020). The new USGS net sequestration rates are lower than the sequestration rates previously obtained from USGS (Selmants et al. 2017). The resulting changes in historical emission estimates are presented in Table 5-28. Additional information on uncertainties associated with the revised factors are discussed below.

Table 5-28: Change in Sinks from Forest Carbon Relative to the 2016 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	(6.30)	(6.13)	(6.18)	(6.12)	(6.13)
This Inventory Report (MMT CO_2 Eq.)	(1.80)	(1.90)	(1.98)	(2.08)	(2.06)
Percent Change	-71.4%	-69.0%	-68.0%	-66.0%	-66.5%

Note: Parentheses indicate negative values or sequestration.

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 for forest and shrubland are calculated based on the average net ecosystem production per year across four unique modeling scenarios for different land-use/climate change projections. Yearly forest and shrubland sequestration rates are only available after 2011; all years prior to 2011 use an average rate across the available timeseries (Selmants 2020).

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), Selmants (2020), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) annual forest net ecosystem production, (2) total forest area, and (3) annual shrubland net ecosystem production. The quantified uncertainty estimated for the forest net ecosystem production 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 5-29. Sinks from forest carbon were estimated to be between -2.33 and -1.75 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 15 percent below and 14 percent above the sink estimate of -2.03 MMT CO_2 Eq.

Table 5-29: Quantitative Uncertainty Estimates for Sinks from Forest Carbon

2017 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
(2.03)	(2.33)	(1.75)	+15%	-14%

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

Note: Parentheses indicate negative values or sequestration.

6. Waste

This chapter presents GHG emissions from waste management and treatment activities. For the state of 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). 57

In 2017, emissions from the Waste sector were 0.82 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 2017.

Figure 6-1: 2017 Waste Emissions by Source

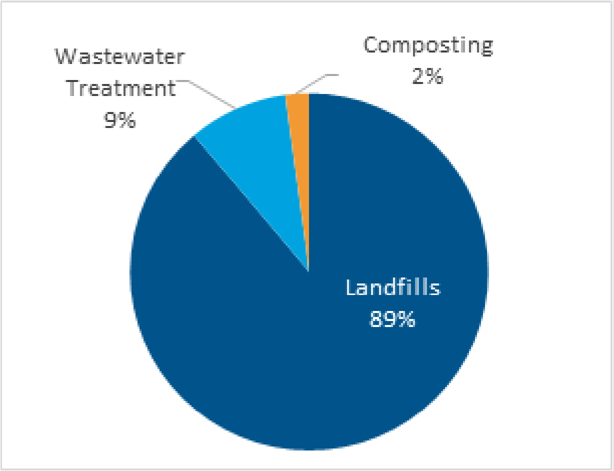
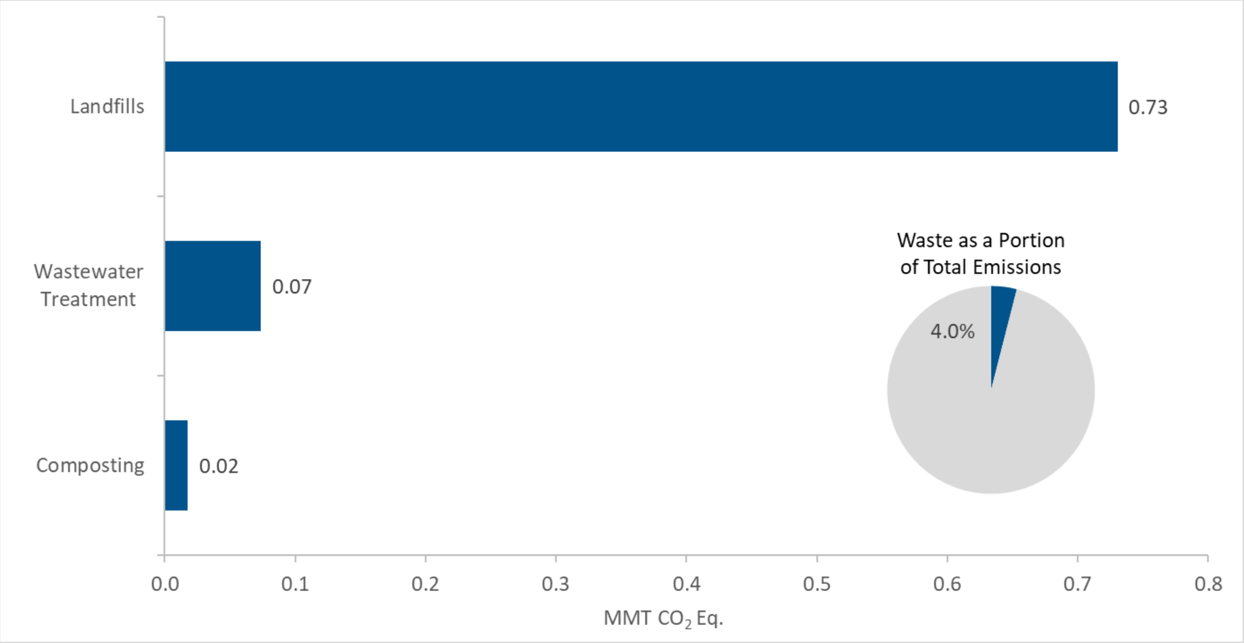


Figure 6-2: 2017 Waste Emissions by Source (MMT CO_2 Eq.)



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[57] In Hawaii, incineration of MSW has historically occurred at waste-to-energy facilities (i.e., the Waipahu Incinerator, which is no longer in operation, and the H-POWER plant, which remains in operation) 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 2017 were higher by 9 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. These emissions then increased between 2016 and 2017, driven by an increase in waste disposal and decrease in landfill gas recovery. 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

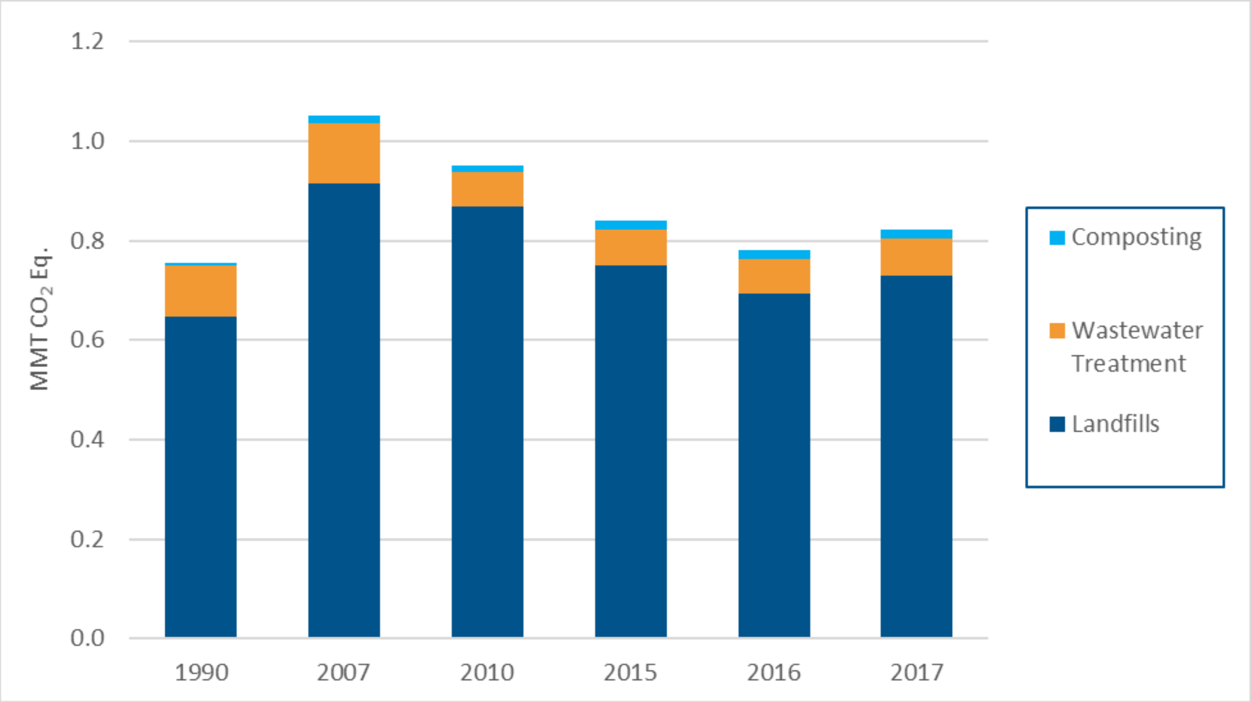

Table 6-1: GHG Emissions from the Waste Sector by Source (MMT CO_2 Eq.)

Source	1990	2007	2010	2015	2016	2017
Landfills	0.65	0.92	0.87	0.75	0.69	0.73
Composting	+	0.02	0.01	0.02	0.02	0.02
Wastewater Treatment	0.10	0.12	0.07	0.07	0.07	0.07
Total	**0.75**	**1.05**	**0.95**	**0.84**	**0.78**	**0.82**

+ 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. Activity data and emission factors used in the analysis are summarized in Appendix G and Appendix H, respectively.

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 2020a). Consistent with IPCC (2006), biogenic CO_2 from landfills is not reported under the Waste sector. In 2017, CH_4 emissions from landfills in Hawaii were 0.73 MMT CO_2 Eq., accounting for 89 percent of Waste sector emissions. Relative to 1990, emissions from landfills in 2017 were higher by roughly 13 percent, down from 42 percent above 1990 levels in 2007. This trend is attributed to a relative increase in the volume of landfill gas recovered for flaring in Hawaii between 2007 and 2017. At the same time, landfill emissions increased between 2016 and 2017, driven by an increase in waste disposal and decrease in landfill gas recovery. Table 6-2 summarizes CH_4 emissions from landfills in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CH_4	0.65	0.92	0.87	0.75	0.69	0.73

Methodology

Consistent with the methodology used for the U.S. Inventory (EPA 2020a), 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 2017 were provided by the Hawaii Department of Health (DOH), Solid & Hazardous Waste Branch (Hawaii DOH 2020b 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 2020c). 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 (m^3 CH_4)
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 (MT)
L_o = CH_4 generation potential (m^3 CH_4/MT waste)

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 2020c). 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 0.04 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 (MT CO_2 Eq.)
OR = methane oxidation rate (percent)
Flared = amount of methane flared in the inventory year (MT CO_2 Eq.)
Recovered = amount of methane recovered for energy in the inventory year (MT CO_2 Eq.)

For 2010, 2015, 2016, and 2017 volumes of landfill gas recovered for flaring and energy were obtained from EPA's GHGRP (EPA 2020b). 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 2019), 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 2020c).

Changes in Estimates since the Previous Inventory Report

This inventory report incorporated updated data from EPA's GHGRP for 2010, 2015, and 2016 on landfill operation and gas collection systems. The revised data led to decreases in the landfill gas capture efficiencies of several landfills in Hawaii. The resulting changes in historical emission estimates are presented in Table 6-3.

Table 6-3: Change in Emissions from Landfills Relative to the 2016 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.65	0.92	0.84	0.69	0.69
This Inventory Report (MMT CO_2 Eq.)	0.65	0.92	0.87	0.75	0.69
Percent Change	0%	0%	4.0%	9.6%	+

+ 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 2017. 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 2020c). 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 (2020a). 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. Emissions from landfills were estimated to be between 0.51 and 0.88 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 31 percent below and 21 percent above the emission estimate of 0.73 MMT CO_2 Eq.

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

2017 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
0.73	0.51	0.88	-31%	+21%

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

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 2020a). In 2017, 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 2017 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, 2016, and 2017.

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

Gas	1990	2007	2010	2015	2016	2017
CH_4	+	0.01	0.01	0.01	0.01	0.01
N_2O	+	0.01	0.01	0.01	0.01	0.01
Total	**+**	**0.02**	**0.01**	**0.02**	**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 2020a). MSW composting volumes for Hawaii were calculated using population data from the State of Hawaii Data Book (DBEDT 2019). 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

No changes were made to emissions from composting since the 2016 inventory report.

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 (2020a). 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 6-6. Emissions from composting were estimated to be between 0.01 and 0.04 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 62 percent below and 97 percent above the emission estimate of 0.02 MMT CO_2 Eq.

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

2017 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	0.04	-62%	+97%

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

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 2020a). 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 2017, 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 2017 were lower by 30 percent, down from 14 percent higher than 1990 levels in 2007. Table 6-7 summarizes emissions from wastewater treatment in Hawaii for 1990, 2007, 2010, 2015, 2016, and 2017.

Table 6-7: Emissions from Wastewater Treatment by Gas (MMT CO_2 Eq.)

Gas	1990	2007	2010	2015	2016	2017
CH_4	0.07	0.08	0.03	0.03	0.03	0.03
N_2O	0.04	0.04	0.04	0.05	0.05	0.05
Total	**0.10**	**0.12**	**0.07**	**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 2020a) and EPA's State Inventory Tools – Wastewater Module (EPA 2020c). 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:

$$CH4\,Emissions = BOD5 * EF * AD$$

where,

BOD_5 = total annual 5-day biochemical oxygen demand production (MT/year)
EF = emission factor for municipal wastewater treatment (MT CH_4/MT BOD_5)
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 population by region not using septic wastewater treatment (%)
EF = emission factor for municipal wastewater treatment (g N_2O/person/year)

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 (kg protein/person/year)
N_P = nitrogen content of protein (kg N/kg protein)
F_N = fraction of nitrogen not consumed
N_{Direct} = direct N_2O emissions (kg)
Biosolids = percentage of biosolids used as fertilizer (%)
EF = emission factor for municipal waste treatment (kg N_2O-N/kg sewage N-produced)

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 2017, 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 2019), 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, 2016 and 2017, 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, 2016, and 2017. Emission factors were obtained from EPA's State Inventory Tool (EPA 2020c).

Changes in Estimates since the Previous Inventory Report

For the 2016 inventory report, data on nitrogen emissions from wastewater were inadvertently excluded from the 2016 inventory estimate. These data were incorporated into the 2016 inventory estimates presented in this inventory report but have a negligible impact on emission totals. The resulting changes in historical emission estimates are presented in Table 6-8.

Table 6-8: Change in Emissions from Wastewater Treatment Relative to the 2016 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016
2016 Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.07	0.07	0.07
This Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.07	0.07	0.07
Percent Change	0%	0%	0%	0%	+

+ Does not exceed 0.05%

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, 2016, and 2017.

Data for two NPDES wastewater treatment plants were not available for the entire time series. Data for Honouliuli Water Recycling Facility was available for 1991, 2005, 2010, 2015, 2016, and 2017. Flow data for Sand Island Wastewater 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 6-9. 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 22 percent below and 22 percent above the emission estimate of 0.07 MMT CO_2 Eq.

Table 6-9: Quantitative Uncertainty Estimates for Emissions from Wastewater Treatment

2017 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	-22%	+22%

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

7. Emission Projections

This section presents projections for statewide GHG emissions and sinks for 2020, 2025, and 2030. The detailed methodology used to develop these projections and a discussion of uncertainties by source and sink category is provided in Appendix J.

Methodology Overview

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 on projections of economic activities as well as an understanding of policies and programs that impact the intensity of GHG emissions.

The Impact of COVID-19

The COVID-19 pandemic has led to a dramatic decline in economic activities, heavily impacted the transportation sector, and created extraordinary uncertainty of future economic activities related to recovery. To the extent possible, adjustments and qualifications were made to the GHG emission projections to account for the known and anticipated impacts of COVID-19.

For this analysis, a combination of top-down and bottom-up approaches were used to develop baseline projections of statewide and county-level GHG emissions in the years 2020, 2025, and 2030.[58] For many sources (residential energy use, commercial energy use, industrial energy use, domestic aviation, incineration of waste, oil and natural gas systems, non-energy uses, and substitution of ozone depleting substances), a constructed long-range gross state product forecast was applied to project GHG emissions for 2020, 2025, and 2030, using the 2017 statewide GHG inventory as a starting point (ICF 2020). For other sources (electrical transmission and distribution, composting, and wastewater treatment), population and electrical sales forecasts were used to project GHG emissions. For other smaller emission sources and sinks (agriculture, forestry, and other land use (AFOLU) categories and landfill waste), 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 2017 emissions. For large GHG emitting sources for which there has been substantial federal and state policy intervention (energy industries and transportation), a bottom-up approach was used to project GHG emissions. Due to policy that affects these sources, fluctuation in economic activities alone is only one component of future GHG emissions. Therefore, a more comprehensive sectoral approach was used to develop baseline projections for these emission sources.

There is uncertainty in forecasting GHG emissions due to economic, technology, and policy uncertainty. In addition to the **baseline scenario**, three major points of uncertainty—macroeconomic growth, renewable energy deployment, and transportation technologies—were assessed by modeling five

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[58] Complete data for 2020 were not available at the time that this report was developed. Therefore, 2020 emission estimates were projected as part of this analysis.

alternative scenarios for statewide GHG emissions in 2025 and 2030, as described below.[59] These alternative scenarios impact projected emissions from the stationary combustion, transportation, and substitution of ODS source categories.

Macroeconomic Forecast

The baseline macroeconomic forecast represents a combination of short-term outlooks of macroeconomic conditions due to the COVID-19 crisis with a return to more long-term conditions after 2025. There are several notable sources for short-term macroeconomic forecasts for Hawaii. The State of Hawaii Department of Business, Economic Development and Tourism (DBEDT) and the University of Hawaii Economic Research Organization (UHERO) both release quarterly outlook reports. DBEDT‘s third quarter 2020 report estimates that by the end of the forecast period, 2023, real gross state product will still be 8 percent lower than 2019 levels (DBEDT 2020c). UHERO‘s third quarter 2020 report similarly finds 2023 real gross state product will be 4 percent lower than 2019 levels (UHERO 2020).

The baseline macroeconomic forecast adopted for this report assumes that 2019 levels of real gross state product will be returned to by 2025, requiring an approximate 2 percent growth rate from 2023 to 2025 based on UHERO‘s forecast. Economic recovery in approximately five years is consistent with the trend of the Great Recession in Hawaii, in terms of gross state product and visitor arrivals (Tian 2020). After 2025 it is assumed that Hawaii‘s economy returns to steady-state conditions, estimated in DBEDT‘s long-run forecast. DBEDT (2018) estimated a 1.8 percent average annual growth rate in real gross state product from 2020 to 2025. This is assumed to be delayed until 2025 and to then guide growth through 2030.

- **Alternate Scenario 1A and 1B: Gross state product.** The COVID-19 pandemic impacts levels of economic activity and resulting GHG emissions. This scenario looks at alternative timelines to recovery. Whereas the baseline assumes that Hawaii‘s gross state product will return to 2019 levels by 2025, the *low* scenario (Alternate Scenario 1A) assumes that Hawaii‘s gross state product does not return to 2019 levels until 2030 and the *high* scenario (Alternate Scenario 1B) assumes that it is achieved by 2023. In all scenarios, after the return to 2019 levels, the growth in real gross state product is assumed to return to the levels forecasted in DBEDT‘s long-range forecast, 1.8 percent annually (DBEDT 2018).
- **Alternate Scenario 2: Renewable energy deployment.** Hawaii has adopted a 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 response, the utility‘s most recent long-range energy plan (the Power Supply Improvement Plan) goes beyond the RPS requirements to achieve 100% generation through renewable sources by the year 2045. While this plan serves as a baseline for 2020, 2025, and 2030 (adjusted for actual build-outs of renewable energy since the release of

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[59] Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, there is no technology or policy variation.

the plan and 2020), this scenario illustrates the GHG impacts of a slower renewable energy adoption pathway where the RPS is met to the standard of the law.

- **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). It is not yet clear the set of policy instruments that will be implemented to attain this goal, and there is considerable uncertainty in the emissions trajectory within the ground transportation sector. These scenarios create a *lower* (Alternate Scenario 3A) and *upper* (Alternate Scenario 3B) bound of possible ground transportation-based GHG emissions, building on scenarios 1A and 1B. Alternate scenarios 3A and 3B account for potential variations in (1) the adoption of electric vehicles; (2) the implementation of the U.S. Renewable Fuel Standard;[60] 3) the share of cars versus light trucks on the road; and (4) future VMT.[61] Whereas scenario 3A represents substantial progress toward the 100 percent renewable ground transportation by 2045 goal, including high levels of vehicle technology and fuel-switching, as well as more car sales and overall lower VMT, scenario 3B shows a more pessimistic pathway across all of the four levers.

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 J. The methodologies used to identify county-level estimates are also detailed in Appendix J.

Limitations of the Projections Analysis

The levels of economic uncertainty due to COVID-19 are unprecendented in recent times, with levels of decline in economic activities on par with the Great Depression. To the extent feasible, this study assessed scenarios to account for potential ranges in gross state product, as well as GHG impacts due to policy and planning within 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. Three additional key areas of uncertainty are:

- **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.

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[60] The U.S. Renewable Fuel Standard requires an increasing amount of biofuel to be blended with refined petroleum products in ground level transportation fuels (i.e., diesel and gasoline). The EPA has consistently granted compliance waivers so the baseline scenario assumes this policy will not be met. To comply, fuel producers will likely need to move more of their gasoline pool to E15 and diesel pool to B20.

[61] While this scenario 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; 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.

- **Fuel/Technology Prices:** Shifts in world fossil fuel prices, particularly oil, will impact consumer use of different fuels and resulting GHG emissions. In addition, break-throughs in technology like battery storage as well as declining renewable energy costs will change the relative cost-effectiveness of low carbon technologies.
- **Policy:** The impacts of other recently adopted policies such as Act 15 (2018), which focuses on increasing GHG sequestration in Hawaii's agricultural and natural environment, and Act 16 (2018), which establishes a framework for a carbon offset program, were not directly considered in this analysis as there is significant uncertainty in how these policies will ultimately impact carbon sinks. In addition, while this analysis accounts for the anticipated impact of Hawaii House Bill 2492 on emissions from the substitution of ozone depleting substances (e.g., hydrofluorocarbons or HFCs), due to the quantifiable impact of this state-specific policy, it does not consider the adoption of other international and federal programs and policies (e.g., The American Innovation and Manufacturing (AIM) Act of 2020, Kigali Amendment to the *Montreal Protocol*) that aim to reduce emissions from the substitution of ozone depleting substances.[62]

7.1. Projections Summary

Under the baseline scenario, total GHG emissions are projected to be 16.32 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.) in 2020, 17.80 MMT CO_2 Eq. in 2025, and 16.03 MMT CO_2 Eq. in 2030. Net emissions, which take into account carbon sinks, are projected to be 13.64 MMT CO_2 Eq. in 2020, 15.17 MMT CO_2 Eq. in 2025, and 13.44 MMT CO_2 Eq. in 2030. Net emissions excluding aviation, which is used for the statewide GHG target established under Act 234 (2007), are projected to be 11.66 MMT CO_2 Eq. in 2020, 10.96 MMT CO_2 Eq. in 2025, and 8.88 MMT CO_2 Eq. in 2030.

Under the alternate scenarios, total GHG emissions are projected to range from 17.05 to 18.30 MMT CO_2 Eq. in 2025 and 15.06 to 18.11 MMT CO_2 Eq. in 2030; net emissions are projected to range from 14.42 to 15.67 MMT CO_2 Eq. in 2025 and 12.48 to 15.53 MMT CO_2 Eq. in 2030; and net emissions excluding aviation are projected to range from 10.35 to 11.46 MMT CO_2 Eq. in 2025 and 8.11 to 10.97 MMT CO_2 Eq. in 2030. Emission projections under all alternate scenarios are equal to the baseline projections in 2020.[63] Table 7-1 summarizes emission projections of statewide emissions for 2020, 2025, and 2030 under the baseline and each alternate scenario.

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[62] The AIM Act, which was passed by Congress in December 2020, requires the United States to phaseout the production and consumption of HFCs by 85 percent by 2035. This law along with the Kigali Amendment, which has not yet been adopted by Congress, were not considered in this analysis due to the timing of when the analysis was completed and the uncertainty associated with the adoption of national policies that target HFCs at that time.

[63] Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, there is no technology or policy variation.

Table 7-1: Hawaii GHG Emission Projections by Sector for 2020, 2025, and 2030 (MMT CO_2 Eq.)

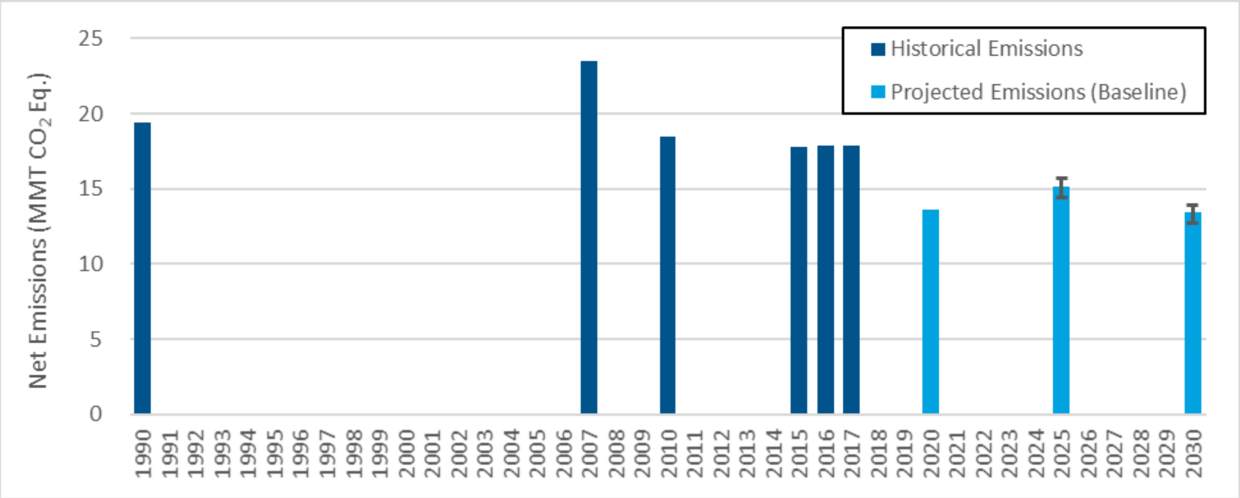
Sector	Total Emissions (Excluding Sinks)[a]			Net Emissions (Including Sinks)[a]			Net Emissions (Including Sinks, Excluding Aviation)[a,b]		
	2020	2025	2030	2020	2025	2030	2020	2025	2030
Baseline Scenario	**16.32**	**17.80**	**16.03**	**13.64**	**15.17**	**13.44**	**11.66**	**10.96**	**8.88**
Alternate Scenario 1A	16.32	17.05	15.06	13.64	14.42	12.48	11.66	10.50	8.35
Alternate Scenario 1B	16.32	18.17	16.40	13.64	15.54	13.82	11.66	11.18	9.12
Alternate Scenario 2	16.32	18.30	18.11	13.64	15.67	15.53	11.66	11.46	10.97
Alternate Scenario 3A	16.32	17.20	15.25	13.64	14.57	12.67	11.66	10.35	8.11
Alternate Scenario 3B	16.32	18.03	16.52	13.64	15.39	13.94	11.66	11.18	9.37

[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 (2007).

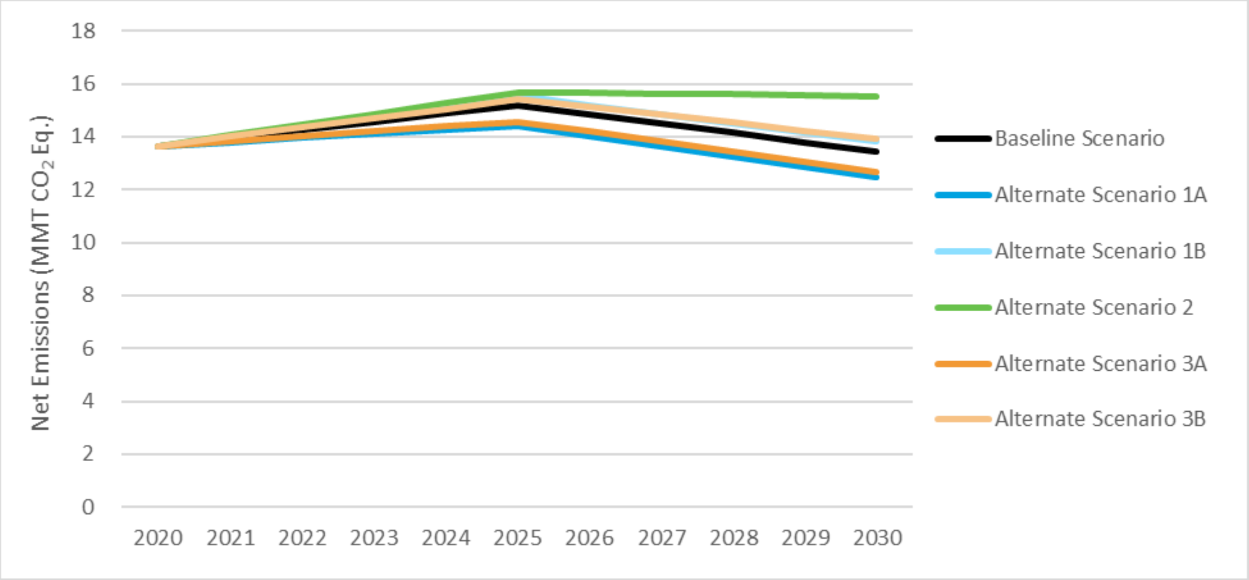
Relative to 2017, total emissions under the baseline scenario are projected to decrease by 21 percent by 2020, 13 percent by 2025 and 22 percent by 2030. Over the same period, net emissions are projected to decrease by 24 percent, 15 percent and 25 percent, respectively, and net emissions excluding aviation are projected to decrease by 15 percent, 20 percent and 36 percent, respectively. This trend is largely driven by the recession and a reduction in air travel in 2020 caused by COVID-19, as well as the projected trend in emissions from energy industries (i.e., electric power plants and petroleum refineries), which are expected to decrease between 2017 and 2030. 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)



Note: The uncertainty bars represent the range of emissions projected under the alternative scenarios. Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, the technology and policy variation modeled under the alternative scenarios is not applicable.

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

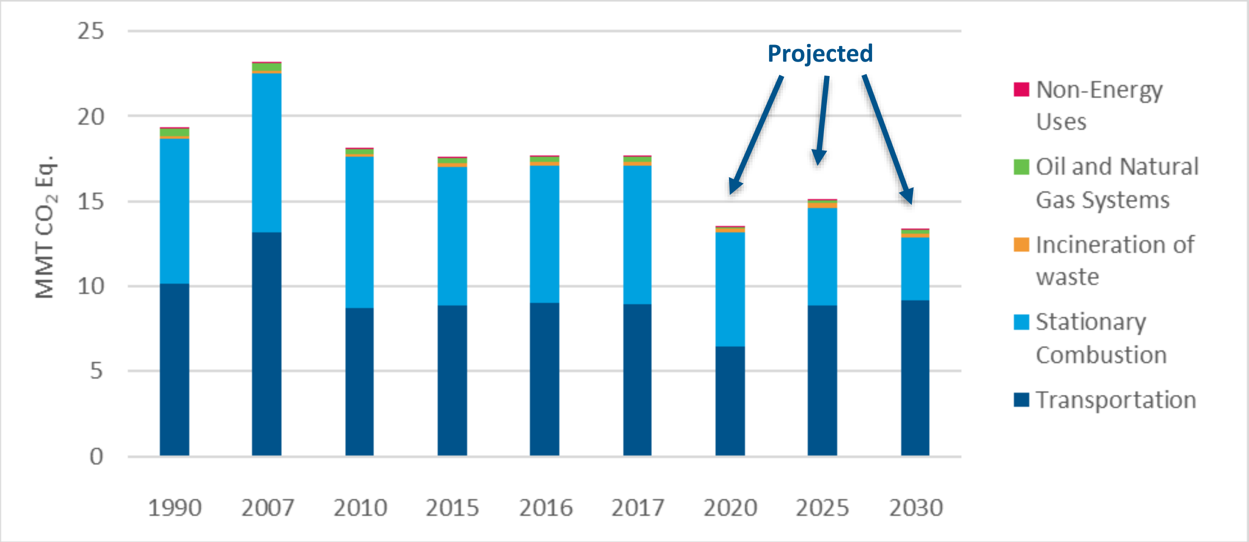


7.2. Energy

Baseline Scenario

Under the baseline scenario, emissions from the Energy sector are projected to be 13.50 MMT CO_2 Eq. in 2020, 15.06 MMT CO_2 Eq. in 2025, and 13.33 MMT CO_2 Eq. in 2030, accounting for 83 percent, 85 percent, and 75 percent of total projected statewide emissions, respectively. Projected emissions under the baseline scenario by source for 2020, 2025, and 2030 are summarized in Table 7-2. Figure 7-3 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



Relative to 2017, emissions from the Energy sector are projected to decrease by 23 percent by 2020, 15 percent by 2025, and 24 percent by 2030. 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. Emissions from the transportation sector are expected to decline substantially in 2020 due to the decrease in airline travel. Though aviation emissions are expected to rebound by 2025, transportation emission levels in 2030 are expected to be only 2 percent higher than 2017 due to increasing vehicle fuel efficiency.

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

Source[a]	2020	2025	2030
Stationary Combustion	**6.65**	**5.70**	**3.67**
Energy Industries[b]	*5.68*	*4.60*	*2.51*
Residential	*0.06*	*0.06*	*0.06*
Commercial	*0.48*	*0.53*	*0.57*
Industrial	*0.43*	*0.50*	*0.53*
Transportation	**6.49**	**8.87**	**9.15**
Ground	*3.82*	*3.97*	*3.90*
Domestic Marine[c]	*0.49*	*0.49*	*0.49*
Domestic Aviation	*1.34*	*3.58*	*3.93*
Military Aviation[d]	*0.64*	*0.64*	*0.64*
Military Non-Aviation[d]	*0.20*	*0.20*	*0.20*
Incineration of Waste	**0.27**	**0.30**	**0.30**
Oil and Natural Gas Systems	**0.05**	**0.14**	**0.16**
Non-Energy Uses	**0.04**	**0.04**	**0.05**
Total	**13.50**	**15.06**	**13.33**

[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 2017 emission estimates.

[d] Because decisions about military operations are generally external to Hawaii's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2017 emission estimates.

Notes: Totals may not sum due to independent rounding.

Alternate Scenarios

Under the alternate scenarios, emissions from the Energy sector are projected range from 14.37 to 15.56 MMT CO_2 Eq. in 2025 and 12.44 to 15.41 MMT CO_2 Eq. in 2030. Emission projections from the Energy sector under all alternate scenarios are equal to the baseline projections in 2020. Projected emissions under each scenario by source for 2025 and 2030 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

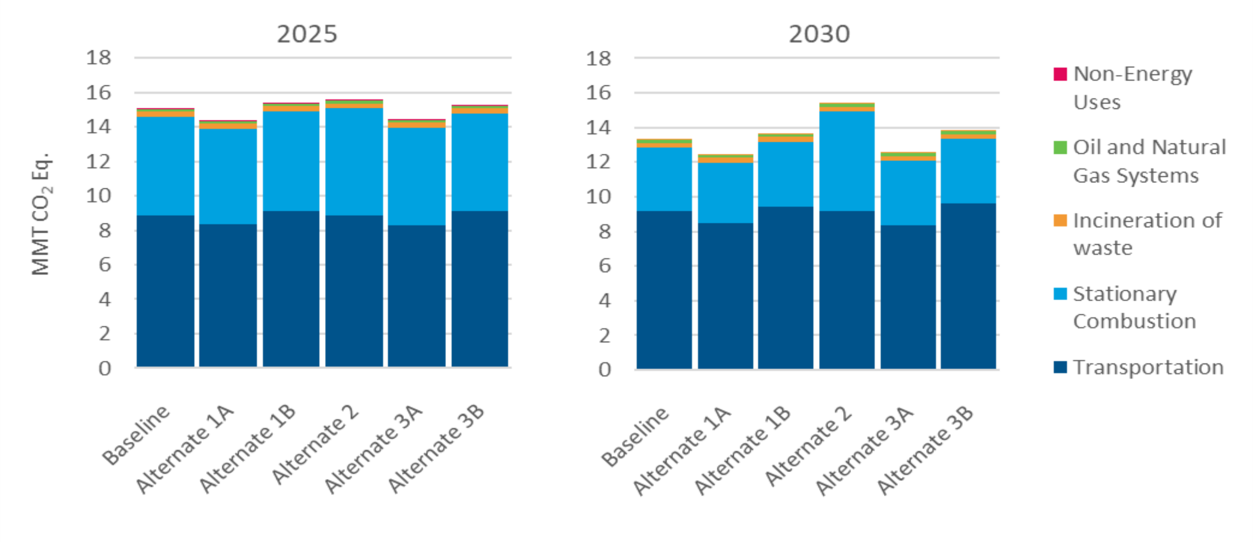


Table 7-3: Emission Projections from the Energy Sector under the Alternate Scenarios by Source (MMT CO_2 Eq.)

Source[a]	Alternate Scenario 1A		Alternate Scenario 1B		Alternate Scenario 2		Alternate Scenario 3A		Alternate Scenario 3B	
	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
Stationary Combustion	**5.56**	**3.50**	**5.76**	**3.74**	**6.20**	**5.76**	**5.70**	**3.67**	**5.70**	**3.67**
Energy Industries[b]	*4.56*	*2.45*	*4.62*	*2.53*	*5.10*	*4.60*	*4.60*	*2.51*	*4.60*	*2.51*
Residential	*0.06*	*0.07*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*
Commercial	*0.56*	*0.59*	*0.49*	*0.51*	*0.53*	*0.57*	*0.53*	*0.57*	*0.53*	*0.57*
Industrial	*0.52*	*0.55*	*0.46*	*0.48*	*0.50*	*0.53*	*0.50*	*0.53*	*0.50*	*0.53*
Transportation	**8.33**	**8.45**	**9.14**	**9.43**	**8.87**	**9.15**	**8.27**	**8.38**	**9.10**	**9.64**
Ground	*3.72*	*3.63*	*4.09*	*4.03*	*3.97*	*3.90*	*3.36*	*3.13*	*4.19*	*4.39*
Domestic Marine[c]	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*	*0.49*
Domestic Aviation	*3.28*	*3.49*	*3.72*	*4.07*	*3.58*	*3.93*	*3.58*	*3.93*	*3.58*	*3.93*
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]	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*	*0.20*
Incineration of Waste	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**
Oil and Natural Gas Systems[e]	**0.13**	**0.14**	**0.15**	**0.16**	**0.14**	**0.16**	**0.14**	**0.16**	**0.14**	**0.16**
Non-Energy Uses	**0.04**	**0.05**	**0.04**	**0.05**	**0.04**	**0.05**	**0.04**	**0.05**	**0.04**	**0.05**
Total	**14.37**	**12.44**	**15.39**	**13.68**	**15.56**	**15.41**	**14.45**	**12.55**	**15.28**	**13.82**

[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 2017 emission estimates.

[d] Because decisions about military operations are generally external to Hawaii's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2017 emission estimates.

Notes: Totals may not sum due to independent rounding.

7.3. Industrial Processes and Product Use (IPPU)

Baseline Scenario

Under the baseline scenario, emissions from the IPPU sector are projected to be 0.76 MMT CO_2 Eq. in 2020 and 2025, and 0.78 MMT CO_2 Eq. in 2030, accounting for 5 percent, 4 percent, and 4 percent of total projected statewide emissions under the baseline scenario, respectively. Projected emissions by source for 2020, 2025 and 2030 are summarized in Table 7-4.

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

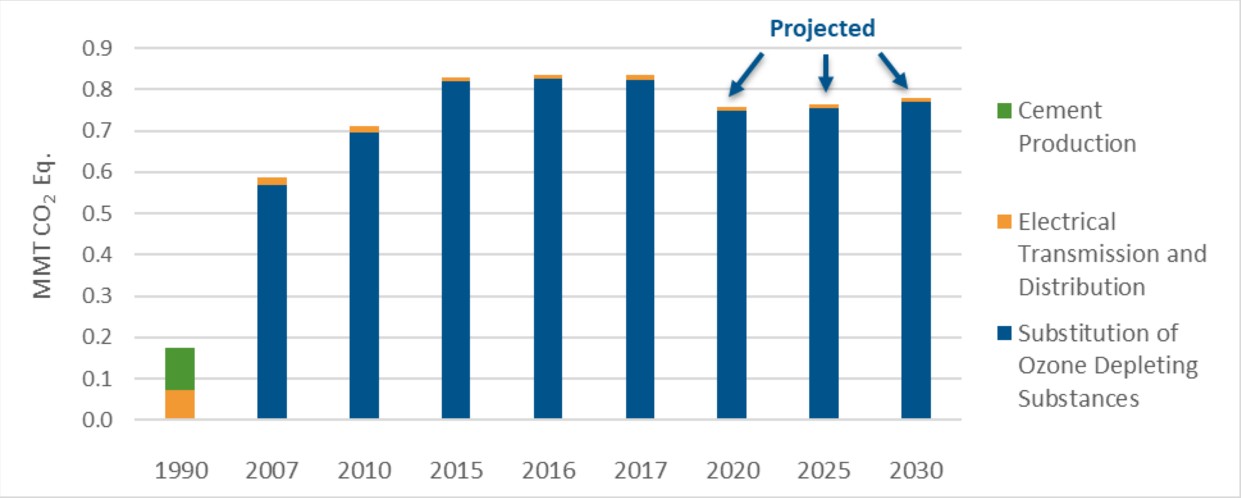
Source	2020	2025	2030
Cement Production	NO	NO	NO
Electrical Transmission and Distribution	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	0.75	0.75	0.77
Total	**0.76**	**0.76**	**0.78**

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 2030. Relative to 2017, electrical transmission and distribution emissions by 2030 are projected to decline slightly, while emissions from the substitution of ozone depleting substances are projected to increase slightly. The minimal growth in emissions from the substitution of ozone depleting substance is due to the anticipated adoption of Hawaii House Bill 2492, which would limit the use of HFCs in select end-uses, and thereby offset a more significant increase in emissions. Emissions from cement production, which were zero in 2017, are projected to remain at zero through 2030. Figure 7-5 shows historical and projected emissions from the IPPU sector by source category for select years under the baseline scenario.

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



Alternate Scenarios

Under alternate scenarios 1A and 1B, emissions from the IPPU sector are projected to range from 0.70 to 0.79 MMT CO_2 Eq. in 2025 and 0.71 to 0.81 MMT CO_2 Eq. in 2030. Emission projections from the IPPU sector are not projected to vary under alternate scenarios 2, 3A, or 3B. Projected emissions under each scenario by source for 2025 and 2030 are summarized in Table 7-5.

Table 7-5: Emission Projections from the IPPU Sector under the Alternate Scenarios by Source (MMT CO_2 Eq.)

Source	Alternate Scenario 1A		Alternate Scenario 1B	
	2025	2030	2025	2030
Cement Production	NO	NO	NO	NO
Electrical Transmission and Distribution	0.01	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	0.69	0.70	0.78	0.80
Total	**0.70**	**0.71**	**0.79**	**0.81**

NO (emissions are Not Occurring).

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

Total emissions (excluding sinks) from the AFOLU sector are projected to be 1.25 MMT CO_2 Eq. in 2020, 1.19 MMT CO_2 Eq. in 2025, and 1.12 MMT CO_2 Eq. in 2030, accounting for 8 percent, 7 percent, and 6 percent of total Hawaii emissions, respectively, under the baseline scenario. Carbon sinks are projected to be 2.68 MMT CO_2 Eq. in 2020, 2.63 MMT CO_2 Eq. in 2025, and 2.58 MMT CO_2 Eq. in 2030. Overall, the AFOLU sector is projected to result in a net increase in carbon sinks (i.e., net CO_2 removals) of 1.43 MMT CO_2 Eq. in 2020, 1.44 MMT CO_2 Eq. in 2025, and 1.46 MMT CO_2 Eq. in 2030. Projected emissions by source and sink category for 2020, 2025, and 2030 are summarized in Table 7-6.

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

Category	2020	2025	2030
Agriculture	**0.45**	**0.45**	**0.44**
Enteric Fermentation	0.25	0.24	0.24
Manure Management	0.03	0.02	0.02
Agricultural Soil Management	0.17	0.18	0.19
Field Burning of Agricultural Residues	NO	NO	NO
Urea Application	+	+	+
Land Use, Land-Use Change, and Forestry	**(1.88)**	**(1.89)**	**(1.90)**
Agricultural Soil Carbon	0.75	0.69	0.63
Forest Fires	0.05	0.05	0.05
Landfilled Yard Trimmings and Food Scraps	(0.04)	(0.04)	(0.03)
Urban Trees	(0.64)	(0.69)	(0.74)
Forest Carbon	(2.00)	(1.91)	(1.81)
Total (Sources)	**1.25**	**1.19**	**1.12**
Total (Sinks)	**(2.68)**	**(2.63)**	**(2.58)**
Net Emissions	**(1.43)**	**(1.44)**	**(1.46)**

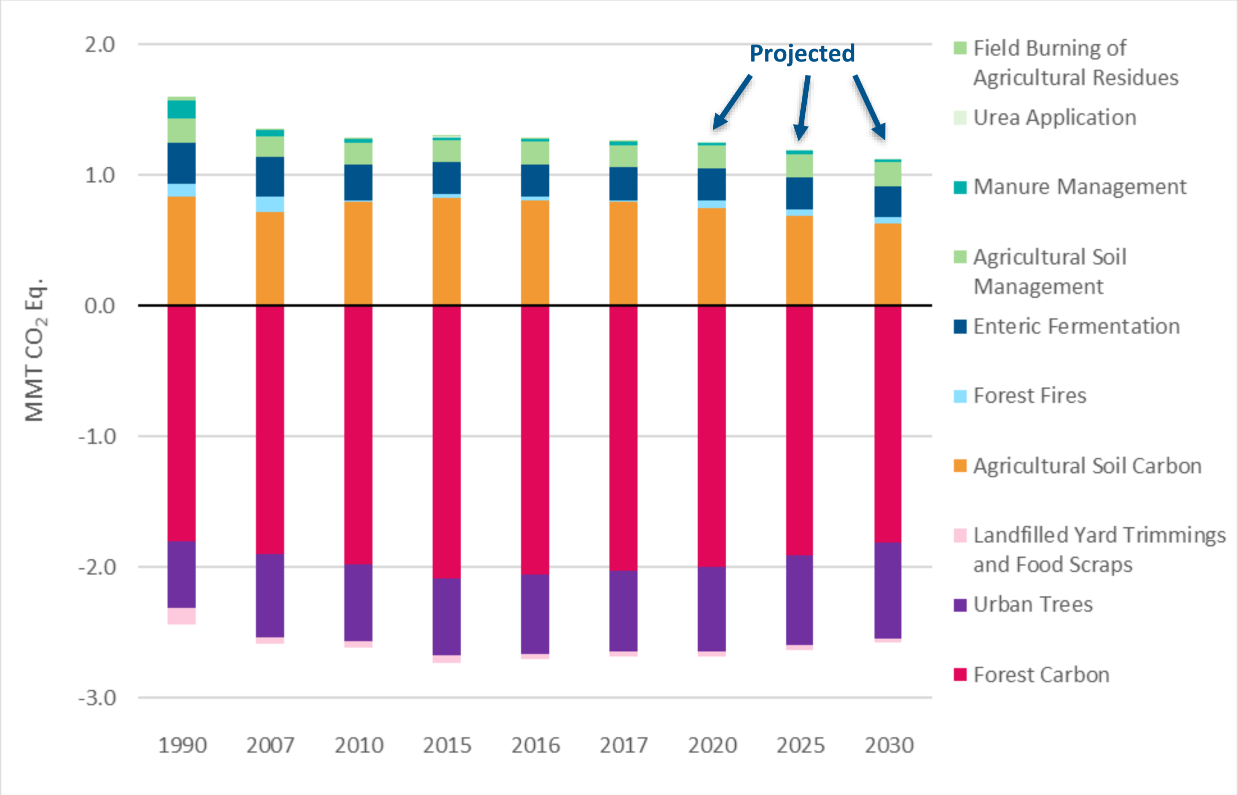
+ Does not exceed 0.005 MMT CO_2 Eq.; NO (emissions are Not Occurring).

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

Urban trees are projected to sequester more carbon (i.e., become a larger sink) over the projected time series due to expected increases in urban areas, while forest carbon is projected to sequester less carbon (i.e., become a smaller sink) over time based on projected changes in land cover and net carbon sequestration rates. Emissions from agricultural soil carbon are also projected to decrease based on projected changes in land cover. Landfilled yard trimmings and food scraps are projected to sequester less carbon over time, while emissions from enteric fermentation and manure management are projected to decrease and emissions from agricultural soil management are projected to increase based largely on the assumption that historical trends will continue. Zero emissions from field burning of agricultural residues are projected due the closing of the last sugar mill in Hawaii in 2018 while emissions from forest fires and urea application are projected to remain relatively flat.

Overall, in 2020, 2025, and 2030, both the carbon sequestered from AFOLU sink categories and emissions from AFOLU sources are projected to decrease. 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 0.81 MMT CO_2 Eq. in 2020, 0.80 MMT CO_2 Eq. in 2025, and 0.80 MMT CO_2 Eq. in 2030, accounting for 5 percent, 4 percent, and 4 percent of total projected statewide emissions under the baseline scenario, respectively. Projected emissions by source for 2020, 2025, and 2030 are summarized in Table 7-7.

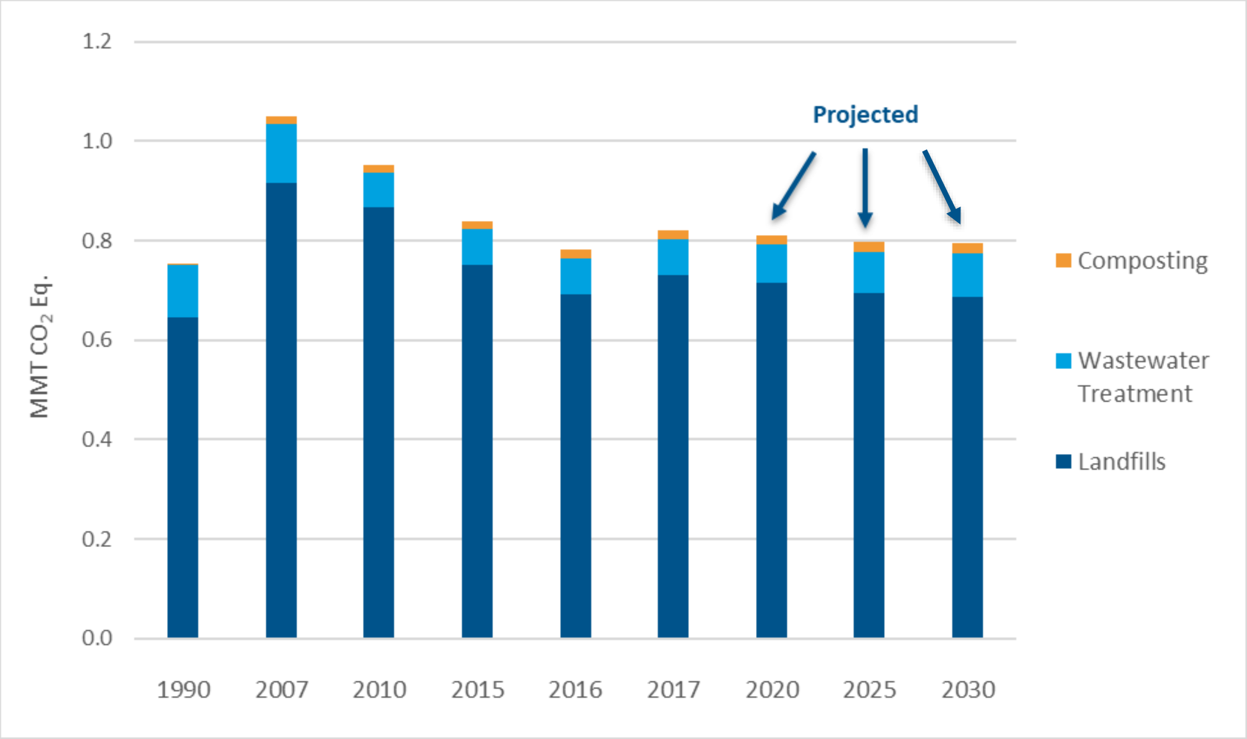
Table 7-7: GHG Emission Projections from the Waste Sector by Source (MMT CO_2 Eq.)

Source	2020	2025	2030
Landfills	0.71	0.70	0.69
Composting	0.02	0.02	0.02
Wastewater Treatment	0.08	0.08	0.09
Total	**0.81**	**0.80**	**0.80**

Note: Totals may not sum due to independent rounding.

Relative to 2017, emissions from landfills are expected to decline slightly due to a projected decrease in landfilled waste driven by greater diversion of waste to the H-POWER waste-to-energy facility. Emissions from composting and wastewater treatment are projected to increase slightly in proportion to projected population growth. Figure 7-7 shows historical and projected emissions from the waste sector by source category for select years.

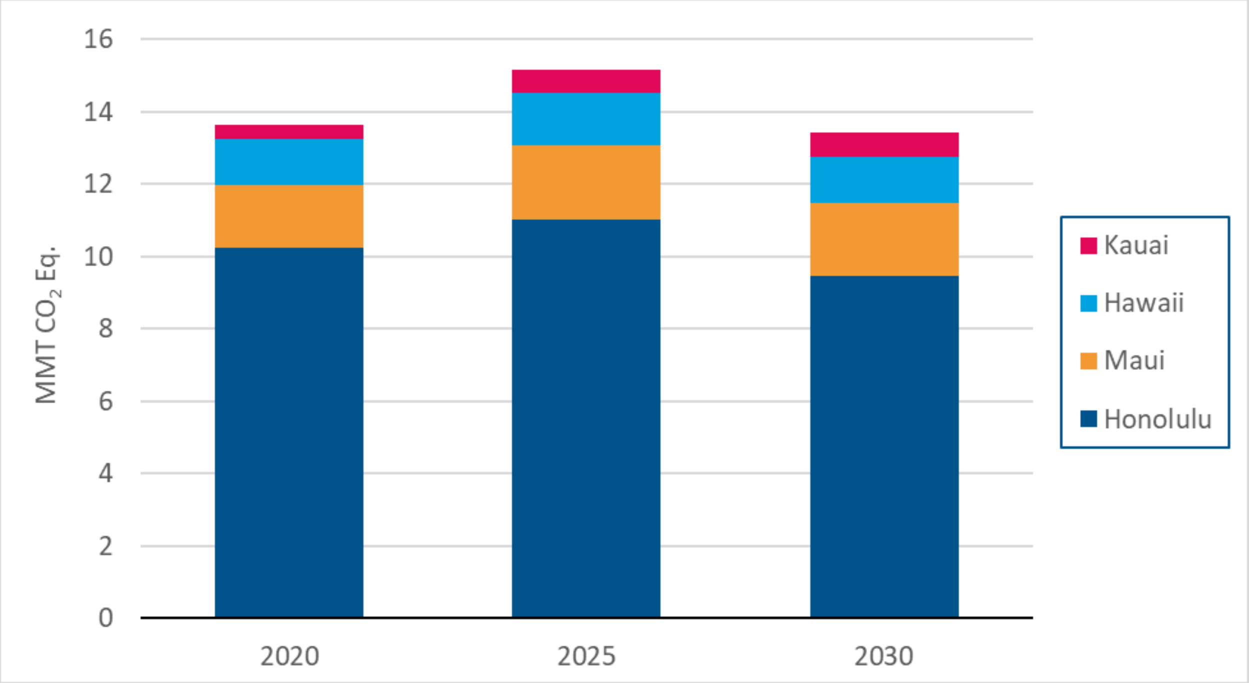
Figure 7-7: GHG Emissions and Projections from the Waste Sector



7.6. Emission Projections by County

Consistent with the historical trend, Honolulu County is projected to account for the largest share of net GHG emissions in 2020, 2025, and 2030, followed by Maui County, Hawaii County, and Kauai County. Figure 7-8 shows net emission projections by county and year.

Figure 7-8: Projected Net GHG Emissions by County (2020, 2025, and 2030)



Emissions from the Energy sector are projected to account for the largest portion of emissions from each county in 2020, 2025, and 2030. Emissions from AFOLU sources are projected to account for the second largest portion of emissions from all counties except Honolulu County, in which emissions from the IPPU and Waste sectors are projected to account for a larger share of emissions. Figure 7-9, Figure 7-10, Figure 7-11, and Figure 7-12 show 2020, 2025, and 2030 emission projections by sector for each county. Emission projections by sector and year for each county are summarized in Table 7-8.

The methodology used to develop these projections varies by emissions source. For some sources, projected county-level activity data were available to build bottom-up county level emission projections. Appendix J summarizes the methodology used to quantify Hawaii's projected GHG emissions by county. For other sources, only state-level activity data were available, requiring emissions to be allocated to each county using proxy information such as population projections or by assuming a breakout consistent with the 2017 county-level estimates.

Figure 7-9: Honolulu County Emission Projections by Sector (2020, 2025, and 2030)

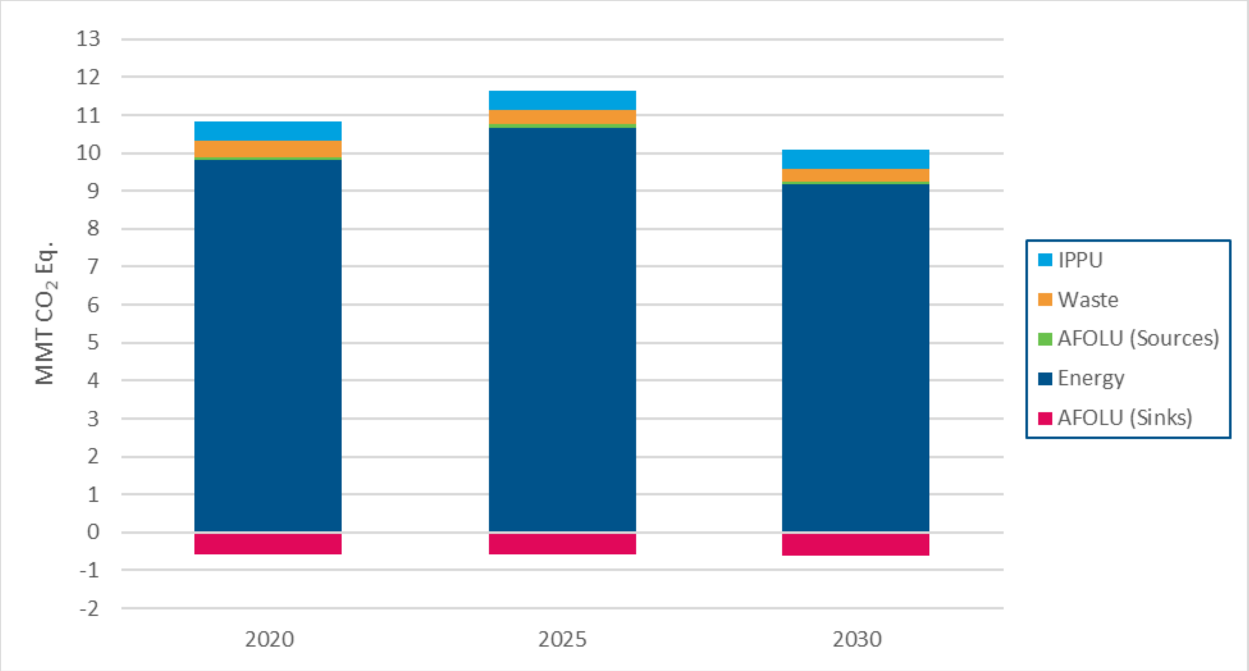


Figure 7-10: Hawaii County Emission Projections by Sector (2020, 2025, and 2030)

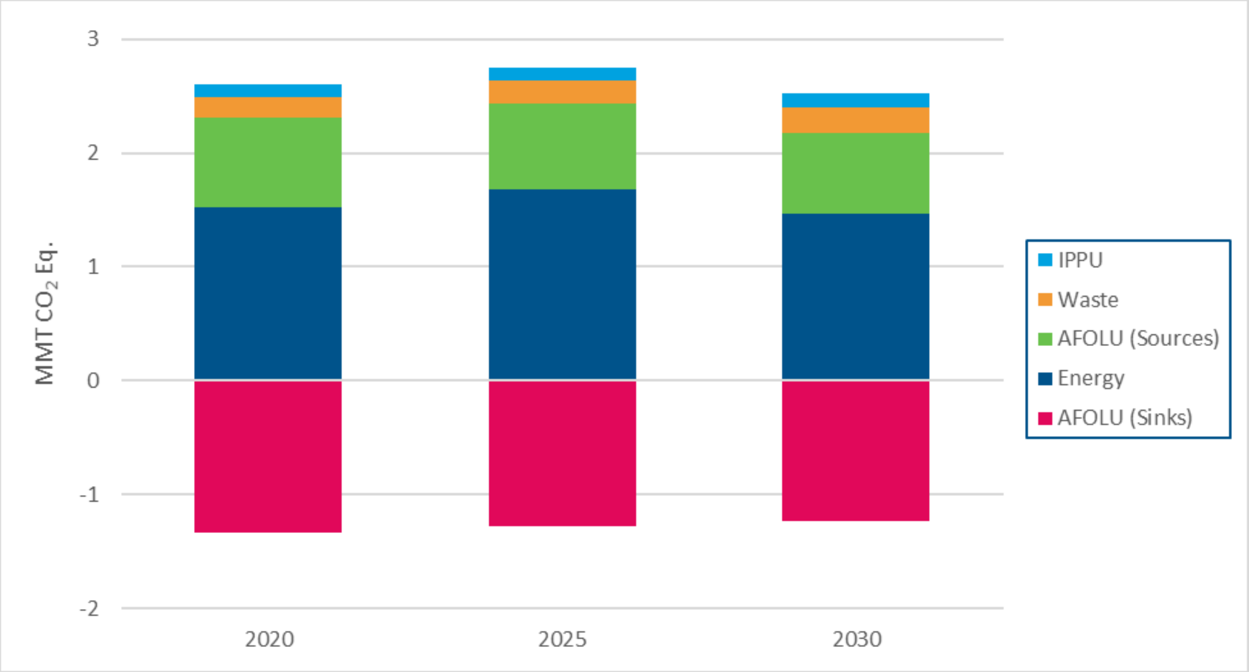


Figure 7-11: Maui County Emission Projections by Sector (2020, 2025, and 2030)

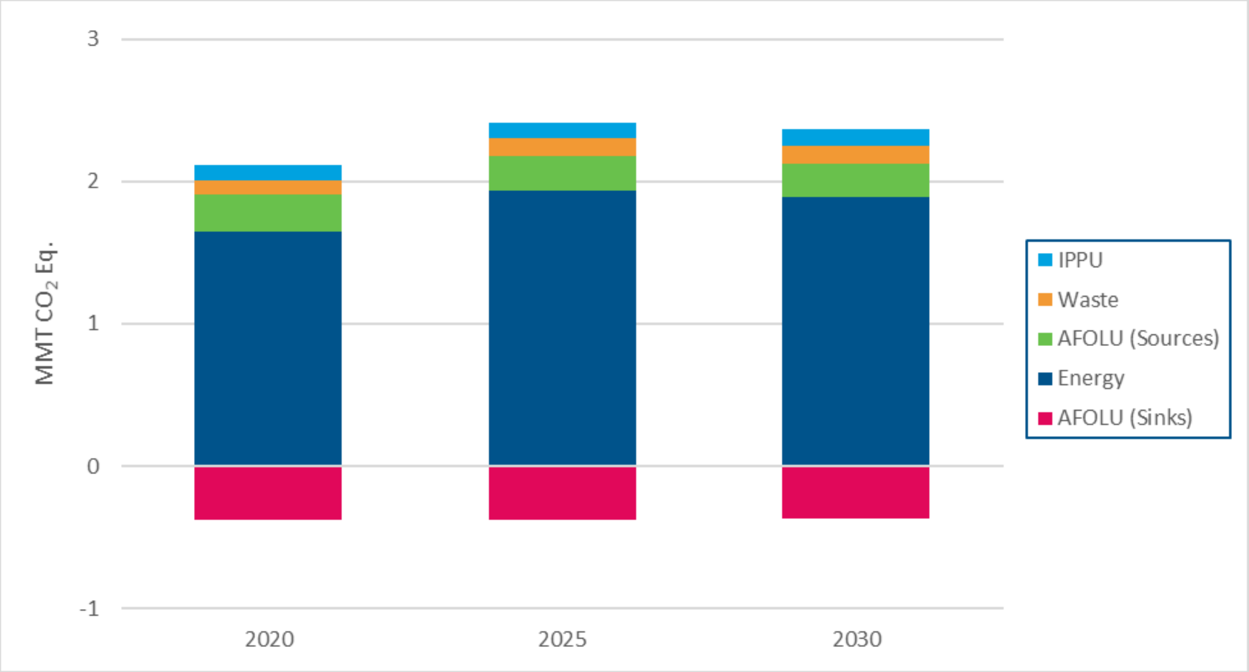


Figure 7-12: Kauai County Emission Projections by Sector (2020, 2025, and 2030)

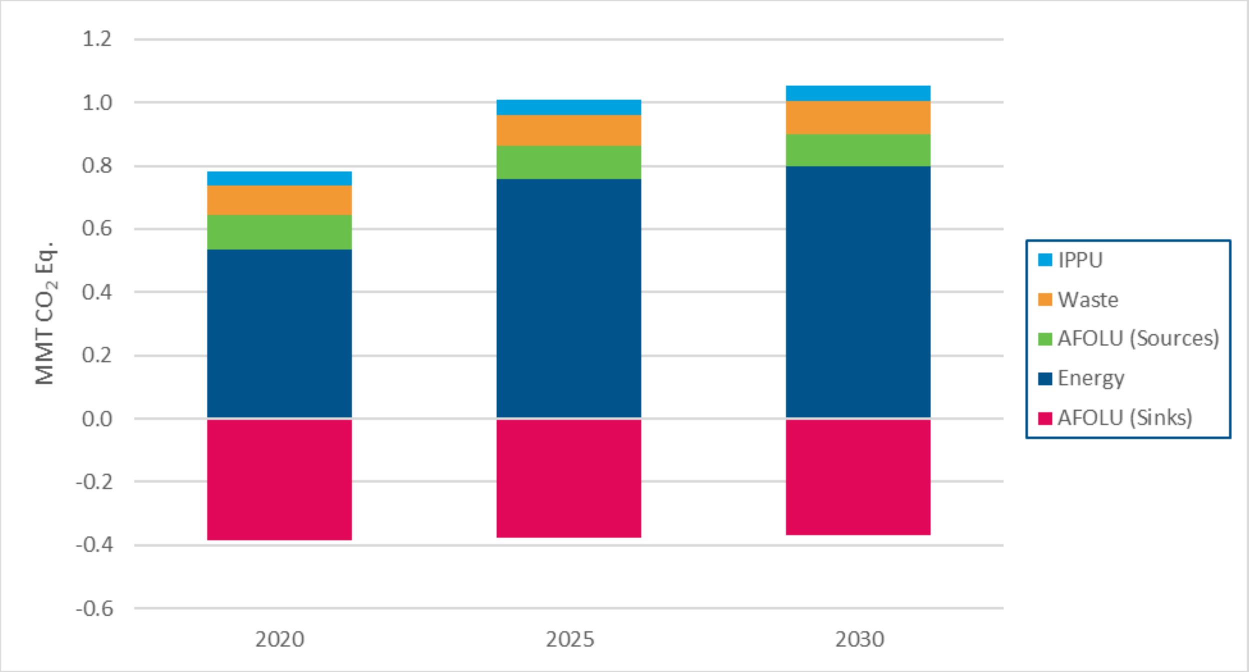


Table 7-8: GHG Emission Projections by Sector and County for 2020, 2025, and 2030 (MMT CO_2 Eq.)

Sector	2020	2025	2030
Honolulu County			
Energy	9.80	10.67	9.17
IPPU	0.49	0.49	0.50
AFOLU (Sources)	0.09	0.09	0.08
AFOLU (Sinks)	(0.59)	(0.60)	(0.61)
Waste	0.43	0.37	0.33
Total Emissions	**10.82**	**11.63**	**10.08**
Net Emissions	**10.23**	**11.03**	**9.47**
Hawaii County			
Energy	1.52	1.68	1.46
IPPU	0.11	0.11	0.12
AFOLU (Sources)	0.79	0.75	0.72
AFOLU (Sinks)	(1.33)	(1.28)	(1.23)
Waste	0.19	0.21	0.22
Total Emissions	**2.61**	**2.75**	**2.52**
Net Emissions	**1.28**	**1.47**	**1.29**
Maui County			
Energy	1.65	1.94	1.89
IPPU	0.11	0.11	0.11
AFOLU (Sources)	0.26	0.24	0.23
AFOLU (Sinks)	(0.38)	(0.38)	(0.37)
Waste	0.11	0.12	0.13
Total Emissions	**2.12**	**2.41**	**2.37**
Net Emissions	**1.74**	**2.03**	**2.00**
Kauai County			
Energy	0.53	0.76	0.80
IPPU	0.05	0.05	0.05
AFOLU (Sources)	0.11	0.11	0.10
AFOLU (Sinks)	(0.39)	(0.38)	(0.37)
Waste	0.09	0.10	0.11
Total Emissions	**0.78**	**1.01**	**1.05**
Net Emissions	**0.40**	**0.63**	**0.69**

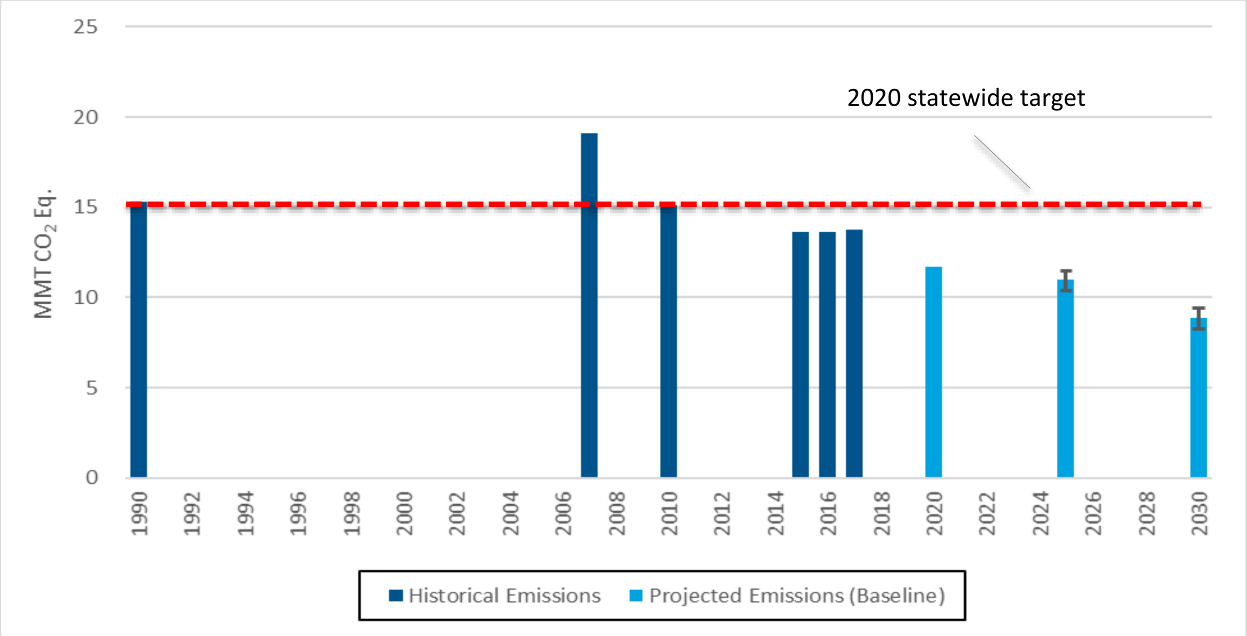
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

8. GHG Reduction Goal Progress

Act 234 (2007), Session Laws of Hawaii 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 (2007) specifies that emissions from airplanes (i.e., domestic aviation and military aviation) shall not be included in Hawaii's GHG target.**[64]

Excluding aviation, 1990 statewide emissions were estimated to be 15.28 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.[65] 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, 2025, and 2030 and the 2020 statewide target, which is equal to 1990 emission levels. As net emissions excluding aviation are projected to be 11.66 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)



Note: The uncertainty bars represent the range of emissions projected under the alternative scenarios. Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, the technology and policy variation modeled under the alternative scenarios is not applicable.

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[64] 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.

[65] 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. 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	✓	
1C	Carbon Dioxide Transport and Storage		NO: CO_2 is not transported or stored in Hawaii.
IPPU			
2A1	Cement Production	✓	NO after 1996 when clinker production ceased in Hawaii.
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	✓	IE: Included under the Energy sector.
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	✓	IE: Incineration of MSW has historically occurred at waste-to-energy facilities in Hawaii; thus emissions are accounted for under the Energy sector.
4D	Wastewater Treatment and Discharge	✓	

NO (emissions are Not Occurring); NE (emissions are Not Estimated); IE (emissions are Included Elsewhere).

Table A-2: Summary of Source and Sink Categories Included/Excluded in Totals

Sector/Category	Applicable IPCC Categories	Included in Net Emissions Inventory Total	Included in Act 234 Net Emissions Target
Energy			
Stationary Combustion	1A1, 1A2, 1A4, 1A5	✓	✓
Transportation	1A3	✓	✓
Ground	1A3	✓	✓
Domestic Marine	1A3	✓	✓
Domestic Aviation	1A3	✓	
Military Aviation	1A3	✓	
Military Non-Aviation	1A3	✓	✓
Incineration of Waste	1A1a	✓	✓
Oil and Natural Gas Systems	1B2	✓	✓
Non-Energy Uses	2D	✓	✓
International Bunker Fuels	1: Memo Items		
CO_2 from Wood Biomass and Biofuel Consumption	1A		
IPPU			
Cement Production	2A1	✓	✓
Electrical Transmission and Distribution	2G1	✓	✓
Substitution of Ozone Depleting Substances	2F	✓	✓
AFOLU (Sources)			
Enteric Fermentation	3A1	✓	✓
Manure Management	3A2 and 3C6	✓	✓
Agricultural Soil Management	3C4 and 3C5	✓	✓
Field Burning of Agricultural Residues	3C1b	✓	✓
Urea Application	3C3	✓	✓
Agricultural Soil Carbon	3B2, 3B3	✓	✓
Forest Fires	3C1a	✓	✓
AFOLU (Sinks)			
Landfilled Yard Trimmings and Food Scraps	3B5a	✓	✓
Urban Trees	3B5a	✓	✓
Forest Carbon	3B1a	✓	✓
Waste			
Landfills	5A1	✓	✓
Composting	5B1	✓	✓
Wastewater Treatment	5D	✓	✓

Appendix B. Updates to the Historical Emission Estimates Presented in the 2016 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, 2015, and 2016 relative to the estimates presented in the 2016 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 2016 inventory report by sector is presented in Table B-1.

Forest Carbon Sequestration Rates

Changes to estimates of carbon removals from AFOLU sinks across the entire time series accounted for almost 80 percent of the change in net emissions from the 2016 inventory report. The 2016 inventory report used carbon sequestration rates by forest type for Hawaii forests from USGS (Selmants et al. 2017). These sequestration rates, which were estimated based on Hawaii-specific biomass and soil organic carbon data, aboveground carbon density maps, and climate data, were identified as a key source of uncertainty in the preparation of the 2016 inventory report. Based on new information provided by USGS (Selmants 2020), new yearly carbon sequestration rates for forest and shrubland were calculated and incorporated into this inventory report. While the change in sequestration rates results in a reduction in estimated carbon sequestered in forests and shrubland by more than half, the impact is similar across all inventory years.

Figure B-1: Difference Between Emissions in this Report and Emissions Presented in the 2016 Inventory Report

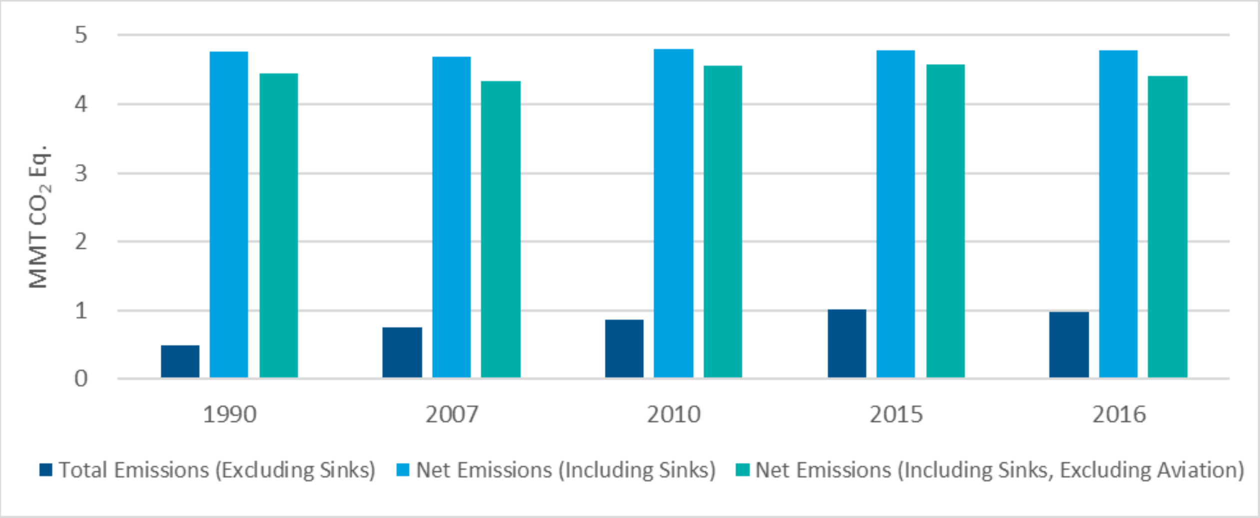


Table B-1: Change in Emissions Relative to the 2016 Inventory Report by Sector (MMT CO_2 Eq.)

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										
2016 Report	19.09	15.30	3.79	0.17	1.31	(6.70)	0.75	21.33	14.63	10.84
2017 Report	19.30	15.19	4.11	0.17	1.60	(2.44)	0.75	21.83	19.39	15.28
Difference	0.21	(0.11)	0.32	+	0.29	4.26	0	0.50	4.76	4.44
Percent Change	1.1%	-0.7%	8.5%	+	21.9%	-63.6%	0%	2.3%	32.5%	40.9%
2007										
2016 Report	22.65	18.53	4.11	0.55	1.12	(6.52)	1.05	25.37	18.85	14.73
2017 Report	23.12	18.66	4.46	0.59	1.35	(2.58)	1.05	26.11	23.53	19.07
Difference	0.48	0.13	0.34	0.03	0.24	3.94	0	0.75	4.68	4.34
Percent Change	2.1%	0.7%	8.4%	6.1%	21.1%	-60.4%	0%	2.9%	24.8%	29.4%
2010										
2016 Report	17.62	14.46	3.16	0.66	1.02	(6.55)	0.92	20.22	13.67	10.51
2017 Report	18.15	14.75	3.40	0.71	1.28	(2.62)	0.95	21.10	18.48	15.08
Difference	0.53	0.29	0.24	0.05	0.26	3.94	0.03	0.87	4.81	4.57
Percent Change	3.0%	2.0%	7.6%	7.3%	25.8%	-60.1%	3.6%	4.3%	35.1%	43.4%
2015										
2016 Report	16.97	12.98	3.99	0.77	1.03	(6.50)	0.77	19.54	13.04	9.04
2017 Report	17.58	13.38	4.20	0.83	1.30	(2.73)	0.84	20.55	17.82	13.61
Difference	0.60	0.40	0.21	0.06	0.27	3.77	0.07	1.01	4.78	4.57
Percent Change	3.6%	3.1%	5.2%	8.2%	26.6%	-58.0%	8.5%	5.1%	36.6%	50.5%
2016										
2016 Report	16.94	13.10	3.84	0.78	1.08	(6.51)	0.78	19.58	13.07	9.23
2017 Report	17.66	13.44	4.22	0.83	1.30	(2.71)	0.78	20.57	17.86	13.65
Difference	0.72	0.34	0.38	0.06	0.21	3.80	+	0.99	4.80	0.61
Percent Change	4.3%	2.6%	10.0%	7.4%	19.4%	-58.4%	+	5.1%	36.7%	47.8%

+ 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.

Appendix C. Inventory Improvements

This section summarizes the effort undertaken to investigate and implement areas for improvement to the Hawaii statewide greenhouse gas inventory, as identified in Appendix I of the 2016 inventory report. Improvements were prioritized based on the impact on statewide emission results, the availability of data, and the level of effort needed to implement the improvement. Based on additional research that was conducted to scope out and comprehensively assess the feasibility of implementing each area of improvement, new data and methodology updates were incorporated into the inventory calculations.

The remainder of this section summarizes each improvement area; an overview of the research and/or analysis conducted, including any new data sources that were identified; an overview of the updates that were made to the inventory methodology; and potential future improvements, if applicable. The detailed methodology changes and quantitative impact of these changes are further discussed in the corresponding source and sink category section within the body of this report.

Energy

Area for Improvement #1

Description of Improvement Area: Further review and verification of the SEDS fuel consumption data should be explored. Specifically, additional year by year trend analyses from 2010 onwards should be performed for fuel types and sectors to compare the Energy Industry Information Reporting Program (EIIRP) data against SEDS and other sources such as GHGRP.

Affected Source Categories: Stationary Combustion, Transportation, and International Bunker Fuels

Research/Analysis Conducted: To verify the emission estimates from stationary combustion, transportation, and international bunker fuels in Hawaii, ICF conducted a detailed review and crosswalk of the following datasets:

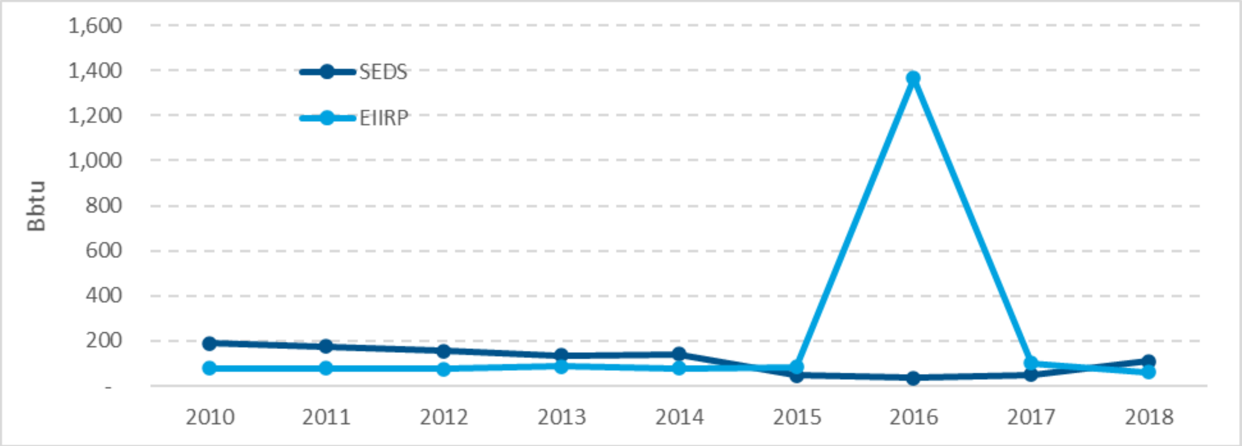
- **SEDS Data:** Fuel consumption data for the state of Hawaii obtained from the U.S. Energy Information Administration's (EIA) State Energy Data System (SEDS). The SEDS dataset was used to estimate stationary combustion, transportation, and international bunker fuel emissions for the 2016 inventory report.
- **EIIRP Data:** Retail and wholesale fuel transactions reported to the Department of Business, Economic Development, and Tourism (DBEDT) under the Energy Industry Information Reporting Program (EIIRP).
- **GHGRP Data:** Facility-level stationary combustion data by fuel type reported under the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP).

To perform this analysis, ICF compared data for ten fuel types for the 2010–2018 period.[66] The fuel types that were compared, which are estimated to account for more than 85 percent of total petroleum-based fuel consumption in Hawaii, include aviation gasoline, biodiesel, diesel, ethanol, jet fuel, motor gasoline, naphtha, natural gas, propane, and residual fuel. Data, in general, were not compared by end-use sector due to the inconsistency in the end-user categories used by the SEDS and EIIRP datasets. In select cases, data for "energy industries" from SEDS was compared to GHGRP data, since GHGRP data are only available for energy industries (i.e., power producers and refineries). The results from this analysis are summarized in the sections that follow.

Aviation Gasoline

Data on aviation gasoline consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP. The data sets match up closely throughout the time series with the exception of 2016, in which EIIRP reported a large spike in consumption. Consumption totals by year are graphically shown in Figure C-1.

Figure C-1: Aviation Gasoline Consumption by Source, 2010-2018



Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Biodiesel

Data on biodiesel consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP. While both data sets follow a similar increasing trend over time, the estimates differ by approximately 45 percent on average each year. The SEDS data set is consistent with and informed by data published in DBEDT's Data Warehouse on biodiesel consumed by utility companies in Hawaii (DEBEDT 2020a) as well as State Bill No. 348, which mandates that diesel fuel sold in Hawaii for use in on-highway diesel powered motor vehicles must contain no less than 5 percent biodiesel by volume by 2016, 10 percent biodiesel by volume by 2020, and 20 percent biodiesel by volume by 2025. Consumption totals by year are graphically shown below in Figure C-2.

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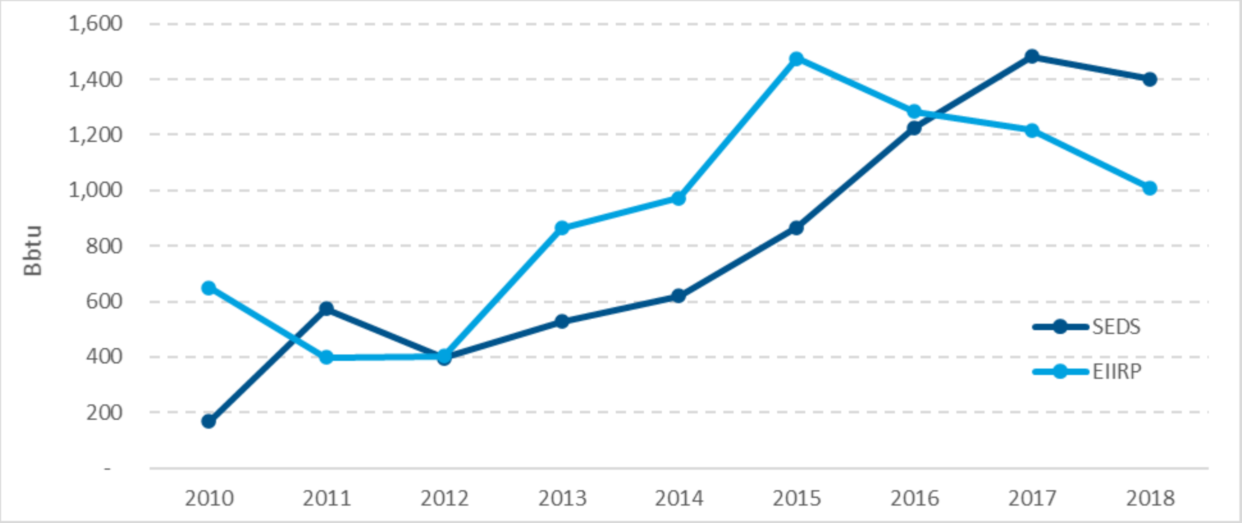
[66] EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Figure C-2: Biodiesel Consumption by Source, 2010-2018

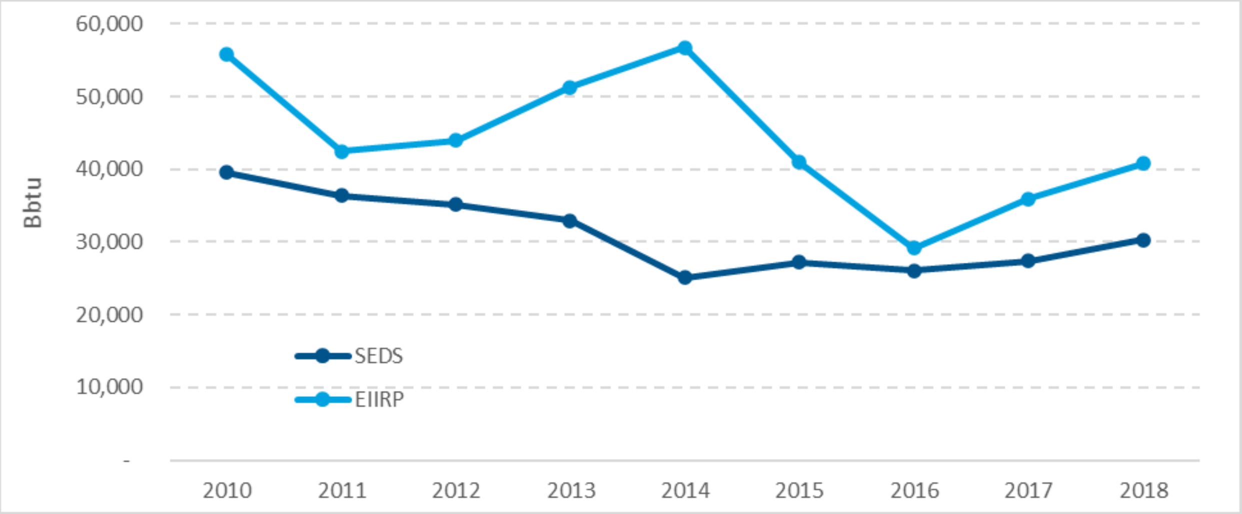


Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Diesel

Data on diesel consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP.[67] SEDS data follow a relatively stable trend over the time series. In contrast, EIIRP data fluctuate significantly. Consumption totals by year are graphically shown below in Figure C-3.

Figure C-3: Diesel Consumption by Source, 2010-2018



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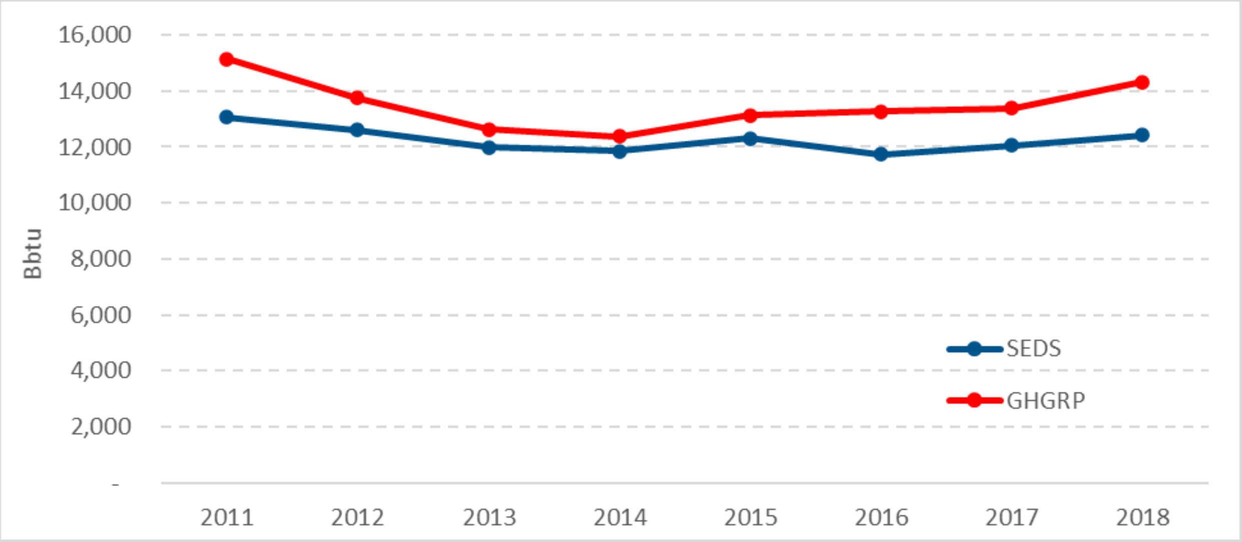
[67] The fuel types reported under the EIIRP that were included in this comparison include: Marine Gasoil, No. 2 Fuel Oil, No. 1 Distillate, No. 2 Diesel Sulfur <= 15 ppm, No. 2 Diesel 15 ppm < Sulfur <= 500 ppm, No. 2 Diesel Sulfur > 500 ppm, No. 2 Diesel Sulfur < 5000 ppm, and Kerosene.

Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Data on diesel consumption were available for power producers and refineries (i.e., "energy industries") from GHGRP for 2011-2018.[68] These data were compared against the SEDS energy industries diesel consumption data. EIIRP data were not included in this comparison because it was not possible to separate out consumption by energy industries from the totals. Since data are only available from GHGRP in metric tons carbon dioxide equivalent, these emissions were back-calculated to billion BTUs for the purposes of comparison.[69] While the totals do not match up exactly, both data sets follow a very similar trend. Consumption totals by energy industries by year are graphically shown in Figure C-4.

Figure C-4: Energy Industries Diesel Consumption by Source, 2011-2018



Ethanol

Data on ethanol consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP.[70] The EIIRP estimates are, on average, approximately 76 percent higher than the SEDS data each year. Consumption totals by year are graphically shown below in Figure C-5.

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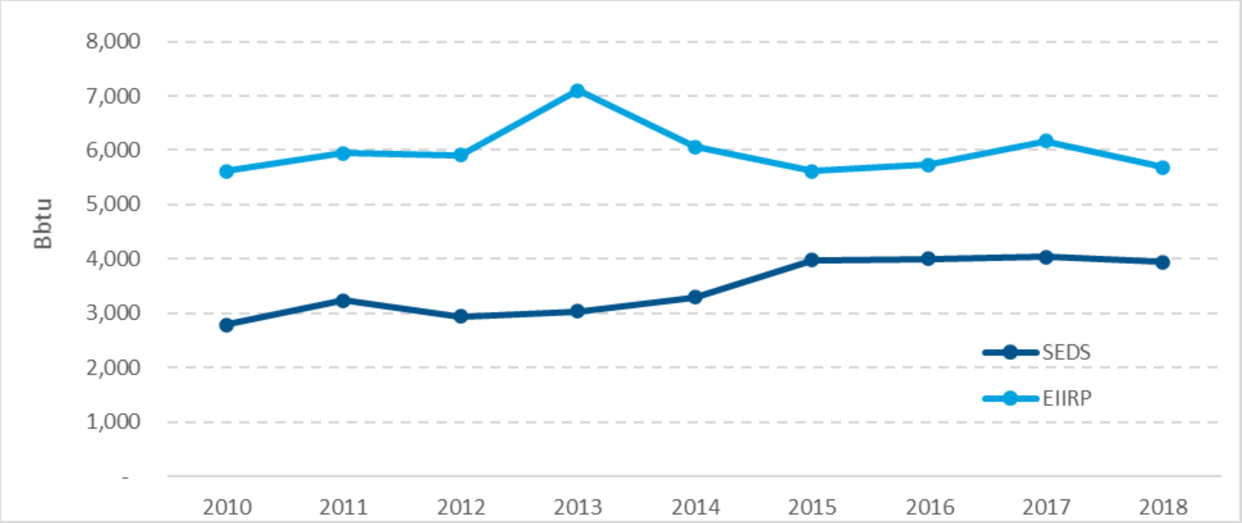
[68] GHGRP data were available for 2010 but are not included in this comparison because the data are not representative of all facilities. This is because 2010 was the first year that data were collected under GHGRP and not all facilities reported during that year.

[69] A conversion factor of 13,475 BTU/MT CO_2 Eq. was used to convert emissions estimates from GHGRP to BTUs. This factor was derived by dividing 2017 diesel fuel consumption estimates for Hawaii by 2017 diesel fuel emission estimates for Hawaii.

[70] The fuel types reported under the EIIRP that were included in this comparison include: Gasoline (E10) Regular (90% Gasoline/10% Ethanol), Gasoline (E10) Midgrade (90% Gasoline/10% Ethanol), Gasoline (E10) Premium (90% Gasoline/10% Ethanol), Gasoline (E85) Regular (15% Gasoline/85% Ethanol), and Ethanol. The totals were weighted to exclude pure gasoline.

Figure C-5: Ethanol Consumption by Source, 2010-2018

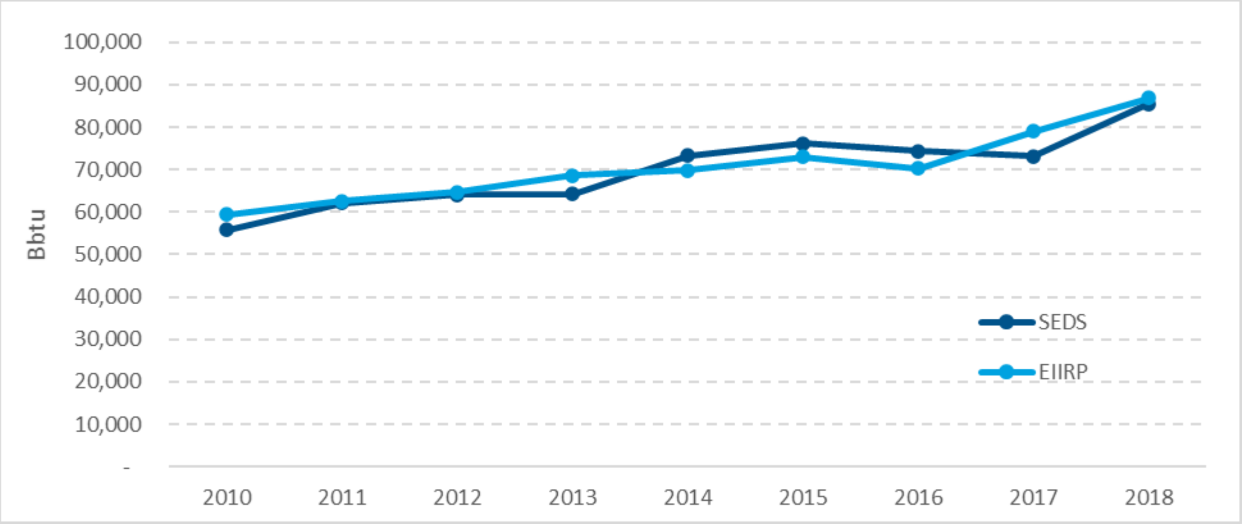


Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Jet Fuel

Data on jet fuel consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP.[71] Jet fuel consumption for both datasets closely align, differing on average by only approximately 1 percent each year. Consumption totals by year are graphically shown below in Figure C-6.

Figure C-6: Jet Fuel Consumption by Source, 2010-2018



Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

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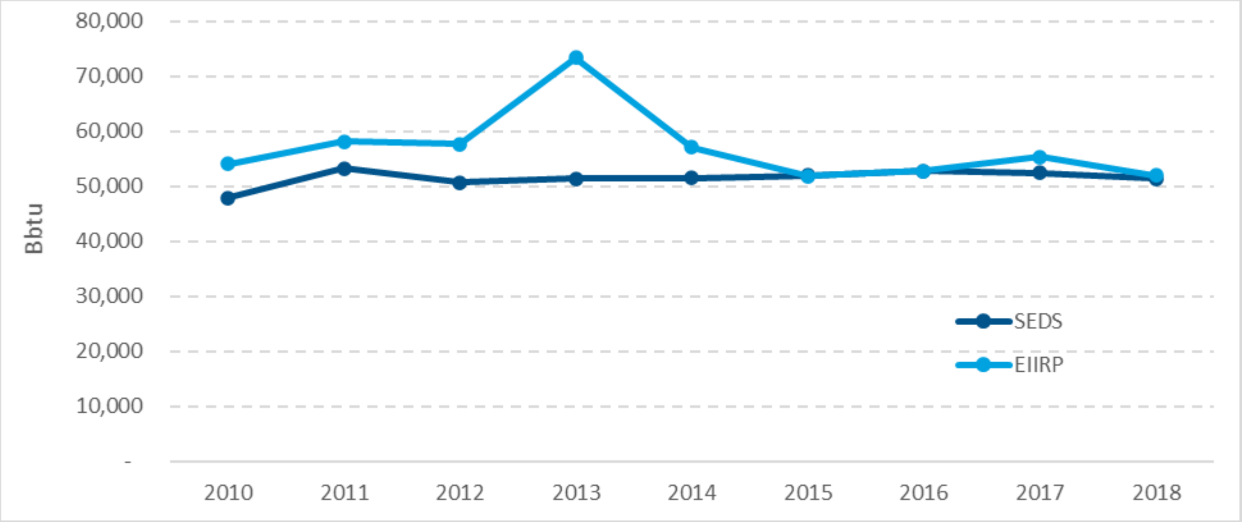
[71] The fuel types reported under the EIIRP that were included in this comparison include: Jet Kerosene, Non-bonded Jet Kerosene, Bonded, Jet A, and Jet Fuel.

Motor Gasoline

Data on motor gasoline consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP.[72] The data sets match up closely throughout the time series with the exception of 2013, in which EIIRP reported a spike in consumption. Consumption totals by year are graphically shown below in Figure C-7.

Figure C-7: Motor Gasoline Consumption by Source, 2010-2018



Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Naphtha

Data on naphtha consumption for 2010-2018 were available from GHGRP and EIIRP.[73] The SEDS dataset reports zero naphtha consumption for Hawaii. Based on direct correspondence with SEDS, ICF had previously assumed that the SEDS natural gas consumption estimates account for naphtha emissions because naphtha is used as a feedstock in synthetic natural gas (SNG) production. However, further analysis of the GHGRP and EIIRP data sets, which indicate naphtha consumption by utilities other than the SNG plant, and taking into account the natural gas comparison below, ICF has concluded that the SEDS dataset does not account for naphtha consumption in Hawaii. Consumption totals by year are graphically shown below in Figure C-8. Since data are only available from GHGRP in metric tons carbon

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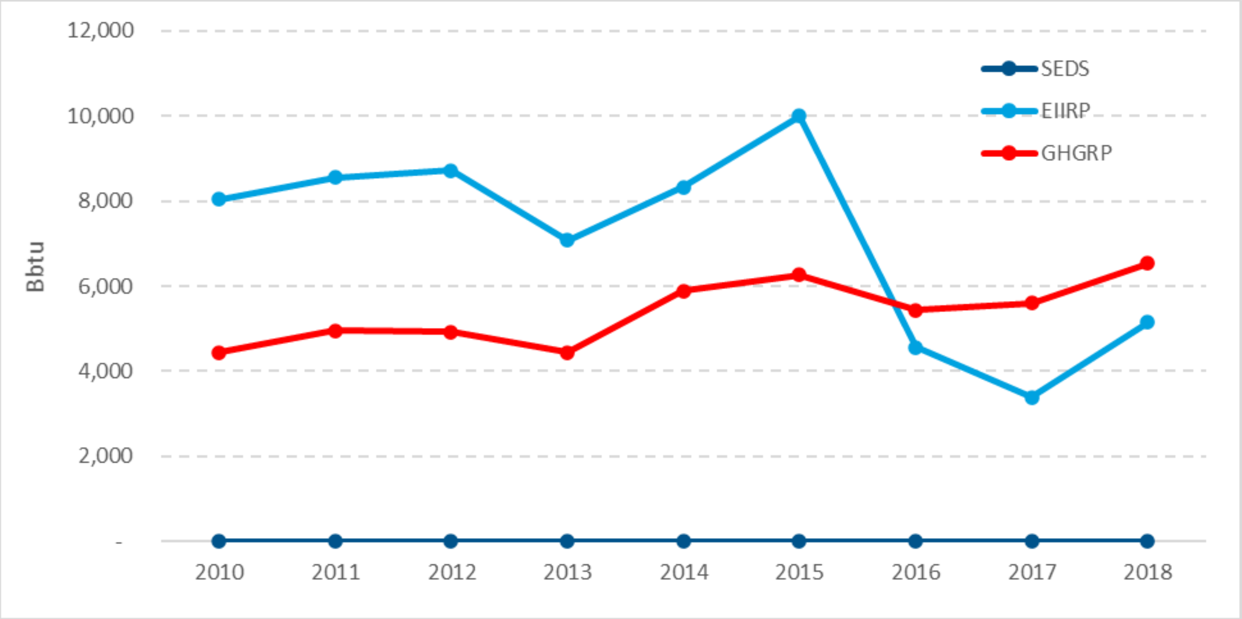
[72] The fuel types reported under the EIIRP that were included in this comparison include: Gasoline (E10) Regular (90% Gasoline/10% Ethanol), Gasoline (E10) Midgrade (90% Gasoline/10% Ethanol), Gasoline (E10) Premium (90% Gasoline/10% Ethanol), Unleaded Gasoline Regular, Unleaded Gasoline Midgrade, Unleaded Gasoline Premium, RON Gasoline, and Gasoline (E85) Regular (15% Gasoline/85% Ethanol). Totals were weighted to exclude Ethanol.

[73] The fuel types reported under the EIIRP that were included in this comparison include: Naphtha, Naphtha Utility, Synthetic Natural Gas Feedstock, SNG Feed, and SNG Naphtha.

dioxide equivalent, these emissions were back-calculated to billion BTUs for the purposes of comparison.[74]

Figure C-8: Naphtha Consumption by Source, 2010-2018



Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Natural Gas

Data on natural gas consumption for 2010-2018 were available from SEDS, EIIRP, and GHGRP.[75] Since data are only available from GHGRP in metric tons carbon dioxide equivalent, these emissions were back-calculated to billion BTUs for the purposes of comparison.[76] Data from all three datasets align closely between 2010 and 2017. The SEDS and EIIRP datasets also align closely in 2018 while implied consumption reported under GHGRP decline significantly. Investigation into this difference should be explored during the development of future inventories. Consumption totals by year are graphically shown in Figure C-9.

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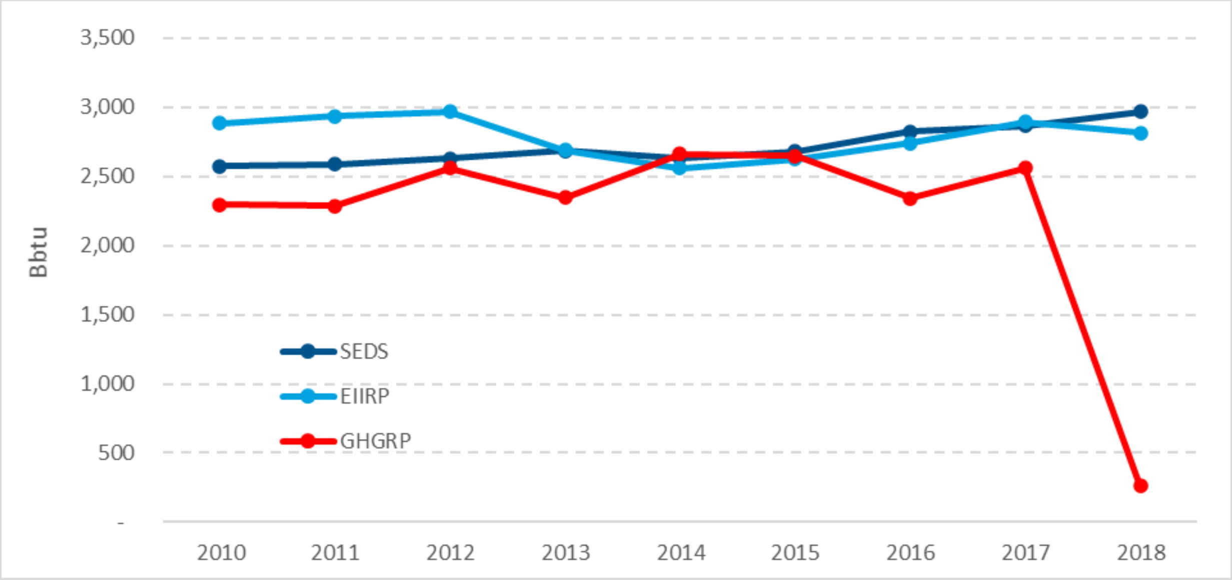
[74] A conversion factor of 14,702 BTU/MT CO_2 Eq. was used to convert emissions estimates from GHGRP to BTUs. This factor was derived by dividing 2017 naphtha consumption estimates for Hawaii by 2017 naphtha emission estimates for Hawaii.

[75] The fuel types reported under the EIIRP that were included in this comparison include: Synthetic Natural Gas.

[76] A conversion factor of 18.822 BTU/MT CO_2 Eq. was used to convert emissions estimates from GHGRP to BTUs This factor was derived by dividing 2017 natural gas consumption estimates for Hawaii by 2017 natural gas emission estimates for Hawaii.

Figure C-9: Natural Gas Consumption by Source, 2010-2018

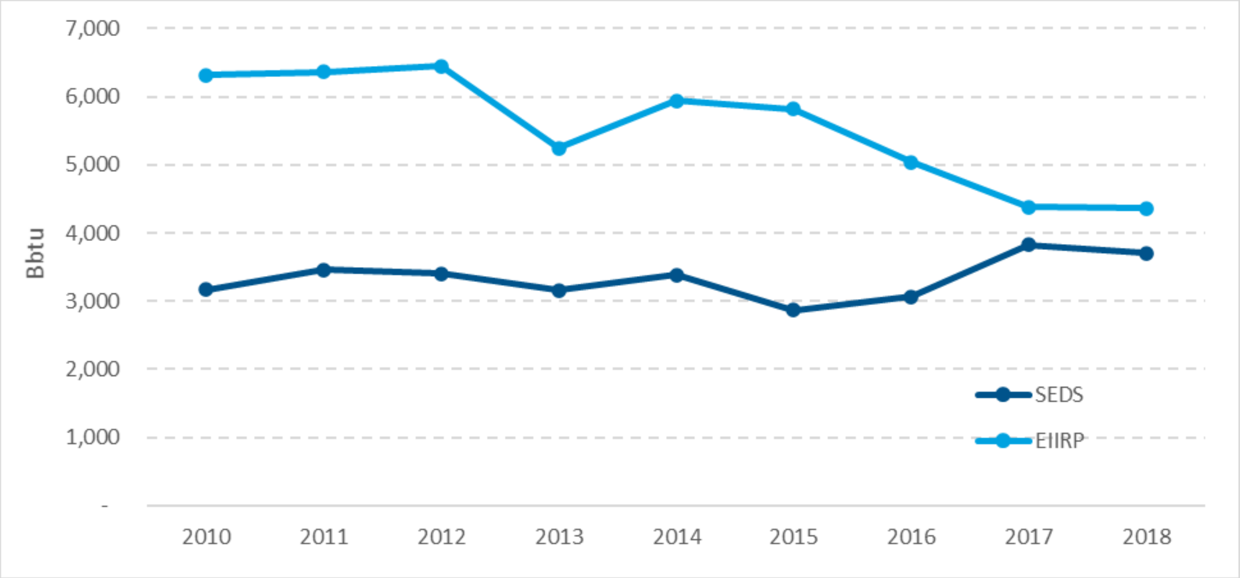


Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Propane

Data on propane consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP. Propane consumption reported by SEDS remains relatively flat across the timeseries, while the EIIRP dataset shows a gradual decline in consumption across the timeseries. Consumption totals by year are graphically shown below in Figure C-10.

Figure C-10: Propane Consumption by Source, 2010-2018

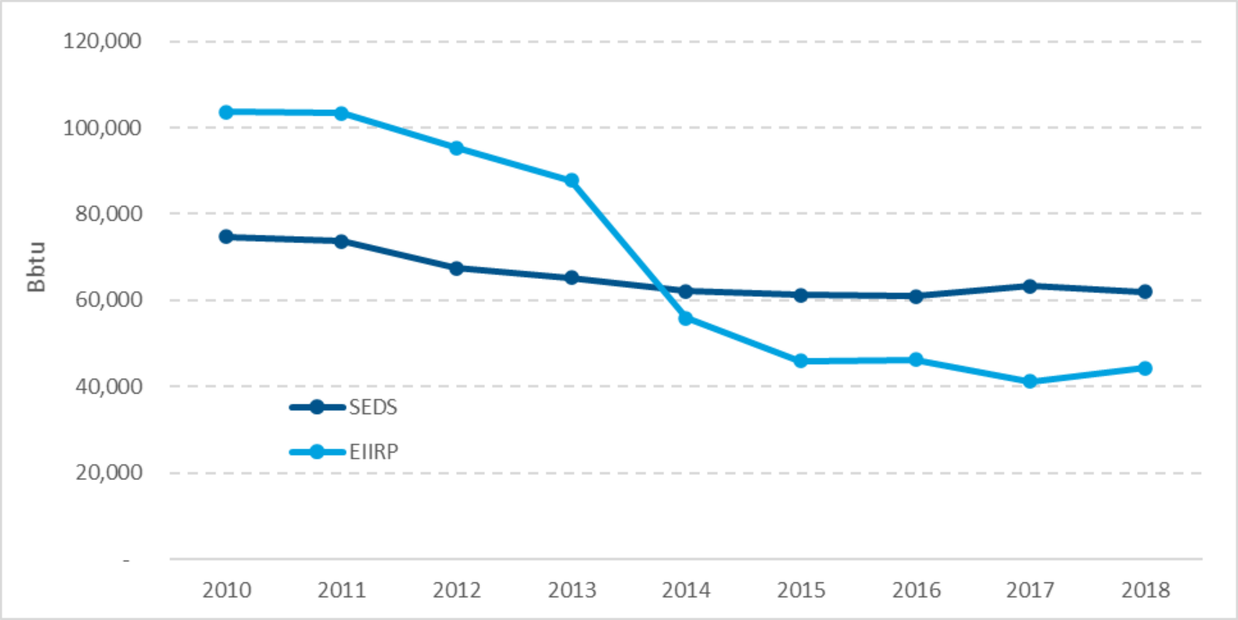


Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Residual Fuel

Data on residual fuel consumption in Bbtu for 2010-2018 were available from SEDS and EIIRP.[77] SEDS data follow a slightly decreasing trend over the time series. In contrast, EIIRP data shows a much greater decline in consumption. Consumption totals by year are graphically shown below in Figure C-11.

Figure C-11: Residual Fuel Consumption by Source, 2010-2018



Note: EIIRP data for 2010 are only available for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Data on residual fuel consumption for power producers and refineries (i.e., "energy industries") were also available from GHGRP for 2011-2018.[78] These data were compared against the SEDS energy industries residual fuel consumption data. EIIRP data were not included in this comparison because it was not possible to separate out consumption by energy industries from the totals. Since data are only available from GHGRP in metric tons carbon dioxide equivalent, these emissions were back-calculated to billion BTUs for the purposes of comparison.[79] As shown in Figure C-12, the consumption estimated from the two datasets align very closely across the entire timeseries.

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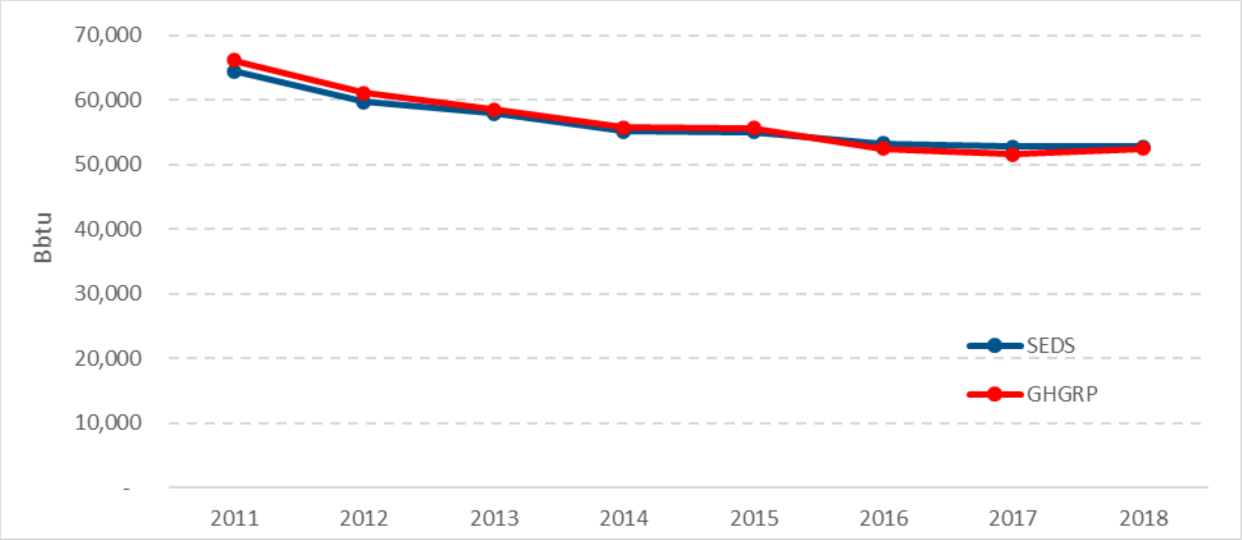
[77] The fuel types reported under the EIIRP that were included in this comparison include: Residual Fuel Oil Sulfur <= 1%, Residual Fuel Oil Sulfur > 1%, Intermediate Fuel Oil 180 CST, Intermediate Fuel Oil 380 CST, Intermediate Fuel Oil 480 CST, and Intermediate Fuel Oil 510 CST.

[78] 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.

[79] A conversion factor of 12,650 BTU/MT CO_2 Eq. was used to convert emissions estimates from GHGRP to BTUs. This factor was derived by dividing 2017 residual fuel consumption estimates for Hawaii by 2017 residual fuel emission estimates for Hawaii.

Figure C-12: Energy Industries Residual Fuel Consumption by Source, 2011-2018



Summary of Updates to the Inventory: The implementation of this improvement supports the use of the existing data source used to prepare Hawaii's statewide inventory. With the exception of naphtha consumption, which are not believed to be accounted for in the SEDS dataset, SEDS continued to be used as the main source of fuel consumption data in the development of Hawaii's statewide inventory. This source was supplemented with data from GHGRP in cases where fuel consumption data are not available in SEDS (e.g., naphtha, fuel gas), consistent with the approach used to develop the 2016 inventory report. Key reasons for continuing the use of SEDS data as the primary data source for Hawaii's statewide inventory for the 1990-2017 time period for the following reasons:

- **Time-Series Consistency:** SEDS data are available for all inventory years (i.e., 1990, 2007, 2010, 2015, 2016, and 2017). GHGRP data are only available beginning in 2010. EIIRP data are only available starting mid 2010; data for the full year are available starting in 2011. It is best practice to use a consistent data source across inventory years, particularly when evaluating trends and emission reduction targets. Switching datasets for later years can often result in data changes that are associated with data collection methods, not actual changes in consumption trends; therefore, it is strongly recommended that GHG inventories, whenever possible, use one consistent data source for the entire time series for each emissions source.
- **Alignment of SEDS with GHGRP Data:** SEDS energy industries diesel and residual fuel data closely align with GHGRP data across the timeseries (i.e., 2011-2018). This close alignment provides confidence in the accuracy in the SEDS data. EIIRP data are not broken out for energy industries, which makes it difficult to quality check the data, as well as difficult to use in the inventory.
- **Inconsistency in EIIRP Data Trends:** For a number of fuel types (e.g., aviation gasoline, diesel, motor gasoline, naphtha, and residual fuel), the EIIRP data indicate significant fluctuations or spikes in consumption across the timeseries (i.e., 2010-2018). For a number of years, these data do not align with SEDS or GHGRP, are at points not consistent with the economic trend, and do not provide confidence in the accuracy of the data series.

Potential Future Improvements: SEDS fuel consumption data should continue to be reviewed against other available datasets to verify its accuracy and completeness for use in the development of the Hawaii statewide inventory.

Area for Improvement #2

Description of Improvement Area: In the 2016 inventory report, consumption for coal, diesel fuel, propane, asphalt and road oil, lubricants, and waxes for non-energy uses (NEU) were excluded from the consumption totals used to estimate emissions from stationary combustion, and therefore were not accounted for in the inventory total. Future analyses should confirm this assumption, estimate emissions from the consumption of fossil fuel feedstocks for NEU, and include these emissions under the Energy sector.

Affected Source Category: Non-Energy Uses

Research/Analysis Conducted: 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. In the U.S. Inventory, emissions from the consumption of these fuels are included under a NEU source category (IPCC Source Category 1A5) within the Energy sector.

Summary of Updates to the Inventory: To improve the estimates, NEU consumption for coal, diesel fuel, propane, asphalt and road oil, lubricants, and waxes were calculated based on the percentage of NEU consumption for each fuel type from EPA's State Inventory Tool (SIT) CO2FFC module. Fuel-specific carbon contents obtained from the 2006 IPCC Guidelines and NEU storage factors obtained from the U.S. Inventory (EPA 2020a) were then applied to estimate CO_2, CH_4, and N_2O emissions for each fuel type. These emissions are accounted for in a new NEU source category (IPCC Source Category 1A5) within the Energy sector, consistent with the U.S. Inventory. The implementation of this improvement resulted in an increase in emissions of 0.04–0.05 MMT CO_2 Eq. from the Energy sector across all inventory years.

Potential Future Improvements: None.

Area for Improvement #3

Description of Improvement Area: For the 2016 inventory report, CH_4 and N_2O emissions from biodiesel consumption at the Hawaiian Electric Company (HECO) and the Maui Electric Company (MECO) were obtained directly from EPA's GHGRP for 2015 and 2016. For 2010, neither HECO nor MECO reported emissions from biodiesel consumption under GHGRP. Data on biodiesel consumption were not available for 1990 and 2007. If data becomes available, the following emissions should be calculated and incorporated into the stationary combustion totals: CH_4 and N_2O emissions from biodiesel consumption for 1990 and 2007; and CH_4 and N_2O emissions from biodiesel consumption at facilities in energy industries that fall below the reporting threshold for EPA's GHGRP for 2010, 2015, and 2016.

Affected Source Category: Stationary Combustion

Research/Analysis Conducted: In April 2020, EIA for the first-time incorporated biodiesel consumption at the state level for the years 2001-2018 into SEDS. DBEDT also reports barrels of biodiesel consumed by utility companies from 2011 to 2019 in their Economic Data Warehouse (DBEDT 2020a).

Summary of Updates to the Inventory: To improve the biodiesel consumption estimates, data on biodiesel consumption by electric utilities in barrels were obtained from the DBEDT Economic Data Warehouse for 2011-2016. These data are also used to inform EIA biodiesel consumption estimates for Hawaii. For 2007 and 2010, data on biodiesel consumption by utilities in gallons were provided by Hawaii DOH (2020a). These data were converted into Bbtu using emissions factors obtained from EIA (5.359 MMBtu/barrel and 0.02381 barrels/gallon). The implementation of this improvement resulted in a slight decrease in CH_4 and N_2O emissions from energy industries across all inventory years. This decrease is not visibly significant on the inventory results (i.e., the results are less than 0.005 MMT CO_2 Eq.).

Potential Future Improvements: Data obtained from the DBEDT Economic Data Warehouse should continue to be reviewed against other available datasets to verify its accuracy and completeness for use in the development of the Hawaii statewide inventory.

Area for Improvement #4

Description of Improvement Area: For the purposes of verifying the emission estimates [for all inventory years], 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 vehicle miles traveled (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 EIIRP.

Affected Source Category: Transportation

Research/Analysis Conducted: verify the emission estimates from ground transportation in Hawaii, ICF developed a bottom-up estimate of transportation sector gasoline consumption using the following approach:

- **Calculate the weighted average fuel economy for each vehicle class** by dividing national VMT estimates by vehicle class (Motorcycles, Passenger Cars, Light Trucks, Buses, Single-Unit Trucks, and Combination Trucks) and year by annual fuel consumption data reported in the FHWA Highway Statistics Series Tables VM-1 (FHWA 2010; 2015; 2016; 2017).
- **Calculate Hawaii VMT for each vehicle class** by multiplying annual VMT for rural and urban areas in Hawaii by the distribution of VMT by vehicle class for rural and urban areas, as provided in the FHWA Highway Statistics series Table VM-2 and Table VM-4, respectively.
- **Calculate total ground transportation fuel consumption** by dividing Hawaii VMT for each vehicle type by its average fuel economy.

- **Disaggregate total fuel consumption by fuel type** using the share of gasoline consumption obtained from the FHWA Highway Statistics Series Table MF-21, and assuming that, beginning in 2007, motor gasoline consists of 10% ethanol and 90% pure gasoline.

The results from this analysis are summarized below in Table C-1 for 2010, 2015, 2016, and 2017.[80] Estimates of transportation sector pure motor gasoline consumption in Hawaii from EIA's SEDS and DBEDT's EIIRP are also presented for comparison. As shown below, the bottom up gasoline consumption estimates are within -3 to 4 percent of the SEDS consumption estimates and -6 to 14 percent of the EIIRP consumption estimates.

Table C-1: Comparison of Hawaii Transportation Sector Pure Gasoline Consumption Estimates (MMBtu)

Gasoline Consumption	2010	2015	2016	2017
Bottom Up Estimate[a]	**45,496,317**	**50,467,053**	**51,572,854**	**51,313,499**
SEDS[b]	**47,102,000**	**49,126,000**	**49,925,000**	**49,540,000**
% Difference Relative to Bottom Up	-3%	3%	3%	4%
EIIRP[c]	**52,901,918**	**50,595,146**	**51,253,550**	**54,410,479**
% Difference Relative to Bottom Up	-14%	0%	1%	-6%

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

[a] Gasoline estimates in gallons were converted to MMBtu using the following conversion factors from EIA: 0.02381 gallons/barrel of gasoline and 5.053 MMBtu/barrel of gasoline.

[b] SEDS data are being used to estimate gasoline consumption for the inventory.

[c] The 2010 EIIRP dataset only includes data for July-December. To estimate a rough approximation for 2010, the data for July-December were doubled.

Summary of Updates to the Inventory: The implementation of this improvement supports the continued use of EIA SEDS for Hawaii's statewide inventory. Therefore, SEDS continued to be used as the source of fuel consumption data for the transportation sector in the development of this inventory.

Potential Future Improvements: None.

Area for Improvement #5

Description of Improvement Area: 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 Motor Vehicle Emission Simulator (MOVES) 2014 model. The use of these updated emission factors for off-road vehicles should be considered for future analyses.

Affected Source Category: Transportation

Research/Analysis Conducted: Annual emission factors for off-road vehicles that were developed based on the 2006 IPCC Guidelines Tier 3 guidance and from data obtained from EPA's MOVES2014 model, are readily available in Table A-114 and A-115 of Annex 3 of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018* (2020a).

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[80] The FHWA Highway Statistics Series does not provide Vehicle Mile Tables by state for 1990 or 2007. Therefore, this analysis was only possible for Inventory years 2010, 2015, 2016, and 2017.

Summary of Updates to the Inventory: To improve emission estimates from the transportation sector for Hawaii, updated non-road emission factors for CH_4 and N_2O emissions were incorporated into the inventory calculations. The implementation of this improvement resulted in a change in emissions that is not visibly significant across all inventory years (i.e., the change is less than 0.005 MMT CO_2 Eq.).

Potential Future Improvements: None.

Area for Improvement #6

Description of Improvement Area: For the 2016 inventory report, data on biodiesel consumption were not available for 1990 and 2007. Methane and N_2O emissions from biodiesel consumption for 1990 and 2007 should be incorporated into the transportation sector totals if data becomes available.

Affected Source Category: Transportation

Research/Analysis Conducted: In April 2020, EIA for the first-time incorporated biodiesel consumption at the state level for the years 2001-2018 into SEDS. Hawaii uses biodiesel in both the power generation and transportation sectors; however, the SEDS biodiesel consumption data does not report consumption by end-use sector.

Summary of Updates to the Inventory: To improve the biodiesel consumption estimates, data on biodiesel consumption was obtained from EIA. Biodiesel consumed by energy industries, as obtained from DBEDT’s Economic Data Warehouse (DBEDT 2020a) and Hawaii DOH (2020a), was subtracted from the SEDS biodiesel consumption total to estimate the amount of biodiesel consumed by the transportation sector. The implementation of this improvement results in a slight increase in CH_4 and N_2O emissions from transportation across all inventory years. This increase is not visibly significant on the inventory results (i.e., the results are less than 0.005 MMT CO_2 Eq.).

Potential Future Improvements: SEDS fuel consumption data should continue to be reviewed against other available datasets to verify its accuracy and completeness for use in the development of the Hawaii statewide inventory.

Area for Improvement #7

Description of Improvement Area: 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. These emissions were not previously captured in the 2016 inventory report. These emissions should be incorporated into future inventory analyses.

Affected Source Category: Oil and Natural Gas Systems

Research/Analysis Conducted: Emissions from hydrogen production at refineries are reported under EPA’s GHGRP, Subpart P. Data are available for 2010-2017.

Summary of Updates to the Inventory: To improve emission estimates for oil and natural gas systems for Hawaii, emissions from hydrogen production were incorporated into the inventory estimates. Estimates for 2010, 2015, 2016, and 2017 were obtained directly from EPA’s GHGRP, as reported under Subpart P. To estimate emissions from hydrogen production for 1990 and 2007, 2010 emissions data from EPA’s GHGRP were scaled based on the ratio of crude oil refined (i.e., throughput) each year for the two refineries relative to 2010. This is similar to the approach used to estimate 1990 and 2007 emissions from petroleum refining. Implementation of this improvement resulted in an increase in emissions of 0.08–0.13 MMT CO_2 Eq. from oil and natural gas systems across all inventory years.

Potential Future Improvements: None.

Area for Improvement #8

Description of Improvement Area: 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 the 2016 inventory report. Improvements to 1990 and 2007 emissions calculations should be made if additional data becomes available.

Affected Source Category: Oil and Natural Gas Systems

Research/Analysis Conducted: To improve emission estimates for 1990 and 2007**,** the methodology used to estimate emissions under the GHGRP, Subpart Y could be applied. The data requirements to implement this methodology are summarized in Table C-2 below. To implement this approach, additional data would need to be obtained from the refineries that operate in Hawaii.

Table C-2: Oil and Gas Emission Source Data Requirements

Emission Source	Data Required
Flares	Volume of flare gas combusted
Catalytic cracking units and traditional fluid coking units	Volumetric flow rate of exhaust gas; hourly average percent CO_2 concentration in the exhaust gas stream
Catalytic reforming units	Coke burn-off quantity; number of regeneration cycles or measurement periods
On-site sulfur recovery plants and sour gas sent off site for sulfur recovery	Volumetric flow rate of sour gas
Coke calcining units	Mass of green coke fed to the coke calcining unit; mass of marketable petroleum coke
Asphalt blowing operations	Quantity of asphalt blown
Delayed coking unit	Mass of steam generated and released per decoking cycle; number of decoking cycles
Process vents	Number of venting events per year; volumetric flow rate of process gas during the event; venting time for the event

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: Improvements to 1990 and 2007 emissions calculations should be made if additional data becomes available.

Area for Improvement #9

Description of Improvement Area: 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 U.S. Department of Transportation (DOT) 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.

Affected Source Categories: Transportation and International Bunker Fuels

Research/Analysis Conducted: Flight mileage and aircraft type data for the state of Hawaii are available from the DOT's Bureau of Transportation Statistics (BTS) by fuel type and sector for 1990-2017. Annual data on fuel consumption and plane miles traveled by aircraft type for U.S. domestic and international flights are available through Airline Data Inc.

Summary of Updates to the Inventory: To improve emission estimates from domestic aviation and international bunker fuels for Hawaii, the method used to allocate aviation fuel consumption into domestic and international consumption was revised. For the 2016 inventory report, flight mileage data from the U.S. Department of Transportation's Bureau of Transportation Statistics Transtats database (DOT 2020) was used to allocate jet fuel consumption. For the 2017 inventory, aircraft-specific fuel efficiency estimates (miles/gal) and mileage data are now used to calculate the ratio of domestic to international fuel consumption to allocate jet fuel consumption estimates from SEDS into domestic and international bunker fuel consumption.

For each inventory year, the annual fuel efficiency for each aircraft type for both domestic and international flights were calculated using ADI's Form 41 Fuel Statistics dataset (ADI 1990 through 2017). This dataset includes fuel consumed and plane miles traveled, by aircraft type, for domestic and international flights originating in Hawaii.

To calculate annual jet fuel consumption associated with all domestic and international flights originating in Hawaii, the calculated year-specific fuel efficiencies by aircraft type were then multiplied by the total distance traveled by year for domestic and international flights originating in Hawaii as obtained from the BTS flight dataset. The following assumptions were made to apply the fuel efficiency estimates from the ADI dataset to the specific aircraft types and mileage from the BTS dataset:

- This analysis only applied to flights originating in Hawaii.
- Where a BTS aircraft type aligned with an ADI aircraft type, the annual fuel efficiency for that aircraft type for the year in question was applied.
- Where a BTS aircraft type did not align with an ADI aircraft type, an annual average fuel efficiency for all aircrafts for the year in question was applied.
- Where a BTS aircraft type aligned with an ADI aircraft type but there was no recorded annual fuel efficiency for the year in question, an average annual fuel efficiency for that aircraft type was applied.

The implementation of this improvement resulted in an increase in emissions from domestic aviation of 0.24-0.34 MMT CO_2 Eq. and a decrease in emissions from international bunker fuels of 0.24-0.34 MMT CO_2 Eq. across all inventory years.

Potential Future Improvements: Additional analysis may be considered to further verify the approach for allocating fuel consumption estimates to domestic and international flights.

Area for Improvement #10

Description of Improvement Area: 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.

Affected Source Categories: Transportation and International Bunker Fuels

Research/Analysis Conducted: To improve emission estimates from domestic aviation and international bunker fuels for Hawaii, the viability of applying a revised methodology to calculate emissions from jet fuel consumption was assessed. For the 2016 inventory report, emissions were estimated by multiplying jet fuel consumption estimates and default emission factors from IPCC (2006), consistent with the IPCC Tier 1 methodology. To develop a separate estimate using an alternate approach, emissions using the IPCC Tier 2 methodology were calculated, which involved calculating emissions associated with landings and takeoff (LTO) separately from cruise emissions. Specifically, for 2017 emissions from jet fuel consumption for both international and domestic flights originating in Hawaii were calculated using the following approach:

1. Calculate the number of LTO cycles by aircraft type.
2. Calculate LTO emissions by applying the aircraft-specific LTO emissions factor.
3. Calculate LTO fuel consumption by applying the aircraft-specific LTO fuel consumption factor.

For steps 2 and 3, in particular, BTS Aircraft Types were compared with the available aircraft specific emission factors and fuel consumption estimates from IPCC 2006. Educated assumptions were made to map the emission factors based on aircraft types, as the aircraft types between BTS and the IPCC did not completely align. These assumptions introduce additional uncertainty into the calculations.

4. Calculate Cruise fuel consumption by subtracting LTO fuel consumption from total fuel consumption.
5. Calculate Cruise emissions by multiplying Cruise fuel consumption by the Tier 1 CO_2 emissions factor.
6. Calculate total aviation emissions by summing LTO emissions and Cruise emissions.

LTO data by aircraft type for the state of Hawaii were obtained from the U.S. Department of Transportation (DOT)'s Bureau of Transportation Statistics (BTS). LTO emission factors and an LTO fuel consumption factor were derived from IPCC (2006). In some cases, the aircraft identified in the BTS dataset did not align with the aircraft types for which IPCC provides LTO factors. In these instances, factors from IPCC were applied for aircraft types that are assumed to most closely align with the aircraft types identified in the BTS dataset. The results of this analysis are presented in Table C-3 below.

Table C-3: Estimated 2017 Hawaii Domestic and International Cruise and LTO Emissions (MMT CO_2 Eq.)

Emissions	Domestic	International
Estimated Cruise Emissions	3.01	1.12
Estimated LTO Emissions	0.44	0.11
Total Aviation Emissions	**3.45**	**1.23**

Summary of Updates to the Inventory: The implementation of this improvement supports the continued use of the IPCC Tier 1 methodology to estimate emissions from jet fuel consumption. Use of the Tier 2 methodology results in very similar emission estimates as compared to the Tier 1 methodology. Relative to using the IPCC Tier 1 methodology, application of the Tier 2 methodology results in a 0.3 percent decrease in domestic aviation emissions and a 1.8 percent increase in 2017 international bunker fuel emissions. Given the significant effort required to apply the IPCC Tier 2 methodology, the additional uncertainty introduced by the Tier 2 methodology, and the relatively small impact the Tier 2 methodology has on emission results, the IPCC Tier 1 methodology continues to be used to estimate emissions from aviation fuel consumption in this inventory report.

Potential Future Improvements: None.

Area for Improvement #11

Description of Improvement Area: 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. If data becomes available, marine bunker fuel consumption data for 1990 should be incorporated into emissions calculations.

Affected Source Category: International Bunker Fuels

Research/Analysis Conducted: For the 2016 inventory report, marine bunker fuel consumption for Hawaii for 2007, 2010, 2015, 2016 was obtained from the U.S. Census Bureau. 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). Additional research was conducted but another source containing estimates of marine bunker fuel consumption data for Hawaii was not identified.

Summary of Updates to the Inventory: Since marine bunker fuel consumption for Hawaii varies year-to-year, to improve the Hawaii marine bunker fuel consumption estimate in 1990, ICF applied the average of 2006 and 2007 Hawaii marine bunker fuel consumption to apportion U.S. consumption in 1990. Due to year-to-year variations, an average across multiple years is likely to be a better proxy than data for a single year. Implementation of this improvement results in a small (0.027 MMT CO_2 Eq.) decrease in 1990 marine bunker fuel emissions.

Potential Future Improvements: If data becomes available, marine bunker fuel consumption data for 1990 should be incorporated into emissions calculations.

Area for Improvement #12

Description of Improvement Area: 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. If and when this project is completed, future inventories should account for renewable natural gas combusted in Hawaii.

Affected Source Category: CO_2 Emissions from Wood Biomass and Biofuel

Research/Analysis Conducted: The Honouliuli Wastewater Treatment Plant produces about 80 million cubic feet of renewable natural gas (RNG) each year.[81] Hawaii Gas captures the RNG and uses it for injection into their synthetic natural gas (SNG) distribution system. Therefore, RNG consumption in Hawaii is expected to be included in the SNG consumption totals reported by EIA's Natural Gas Annual beginning in 2019.

Summary of Updates to the Inventory: The Honouliuli Wastewater Treatment Plant began capturing biogas in December 2018; therefore, emissions from RNG consumption are not relevant for the 2017 inventory.

Potential Future Improvements: Future inventory reports should account for renewable natural gas that is combusted in Hawaii.

Area for Improvement #13

Description of Improvement Area: 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.

Affected Source Category: CO_2 Emissions from Wood Biomass and Biofuel

Research/Analysis Conducted: In April 2020, EIA for the first-time incorporated biodiesel consumption at the state level for the years 2001-2018 into SEDS.

Summary of Updates to the Inventory: To improve the biodiesel consumption estimates, data on biodiesel consumption was obtained from EIA. This information was then used to update CO_2 emissions from biodiesel. The implementation of this improvement slightly decreased CO_2 emissions from wood biomass and biofuels across all inventory years.

Potential Future Improvements: SEDS fuel consumption data should continue to be reviewed against other available datasets to verify its accuracy and completeness for use in the development of the Hawaii statewide inventory.

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[81] https://www.hawaiigas.com/clean-energy/renewable-natural-gas/

IPPU

Area for Improvement #14

Description of Improvement Area: 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.

Affected Source Category: Substitutes of ODS

Research/Analysis Conducted: EIA's Residential Energy Consumption Survey (RECs) provides data on the number of air conditioning units in the United States by both region and climate zone. Hawaii falls within the Pacific region and the Hot and Humid climate zone. This information is provided for 1993, 1997, 2001, 2005, 2009, and 2015.

Summary of Updates to the Inventory: To improve emission estimates from substitutes of ODS for Hawaii, the method used to disaggregate national emissions from 'other air conditioners' (i.e., all residential and commercial air conditioners other than mobile air conditioners) was revised. For the 2016 inventory report, national emissions from 'other air conditioners' were apportioned to Hawaii based on population. To improve the estimates, national emissions were instead apportioned based on number of houses with air conditioners, using the following methodology:

1. Allocate national ODS substitute emissions from refrigeration and air conditioning end-uses from the U.S. Inventory (EPA 2020a) to 'other air conditioning' end-uses by subtracting out emissions from mobile air conditioners, and assuming that 50% of remaining emissions are associated with refrigeration end-uses while the remaining 50% are associated with other air conditioning end-uses (based on expert judgement on the typical proportion).
2. Estimate the number of houses with air conditioners in Hawaii by apportioning the total number of houses with air conditioners in hot and humid climate regions in the United States, as obtained from EIA's Residential Energy Consumption Survey (RECs), based on population.
3. Calculate the ratio of houses with air conditioning units in Hawaii relative to the United States by dividing the estimated number of houses with air conditioners in Hawaii by the total number of houses with air conditioning units in the United States, as obtained from RECs.
4. Calculate Hawaii emissions from other air conditioners by multiplying national emissions from other air conditioning end-uses by the ratio of houses with air conditioning units in Hawaii relative to the United States.

The implementation of this improvement resulted in a slight increase in ODS substitute emissions (0.003-0.017 MMT CO_2 Eq.) for Hawaii for all inventory years except 1990; for 1990, the implementation of this improvement results in a negligible change in ODS substitute emissions.

Potential Future Improvements: None.

Area for Improvement #15

Description of Improvement Area: 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.

Affected Source Category: Electrical Transmission and Distribution

Research/Analysis Conducted: Data are available for SF_6 purchases and emissions for HECO from GHGRP, subpart DD for 2011 through 2018. These data are not inclusive of HECO's subsidiaries, HELCO and MECO, or emissions from Kauai Island Utility Cooperative (KIUC).[82]

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: 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.

AFOLU

Area for Improvement #16

Description of Improvement Area: 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 those used in the U.S. Inventory may be considered in future analyses.

Affected Source Categories: Enteric Fermentation and Manure Management

Research/Analysis Conducted: The U.S. Inventory (EPA 2020a) obtains population data from USDA's National Agricultural Statistics Service (NASS) and maps the cattle categories to the U.S. EPA Cattle Enteric Fermentation Model (CEFM) cattle categories. Specifically, cattle populations in the U.S. Inventory are estimated using the cattle transition matrix in the CEFM, which uses USDA population estimates and weight data to simulate the population of cattle from birth to slaughter, and results in an estimate of the number of animals in a particular cattle grouping while taking into account the monthly rate of weight gain, the average weight of the animals, and the death and calving rates (EPA 2020a).

For the 2016 inventory report, population data were also obtained from USDA's NASS but were not characterized into the CEFM cattle categories. A mapping of the cattle categories from USDA-NASS, the categories used in the Hawaii 2016 inventory report, and the CEFM cattle categories used in the U.S. Inventory is shown in Table C-4.

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[82] Hawaii State Energy Office: Utility Landscape in Hawaii. Available online at: https://energy.hawaii.gov/developer-investor/utility-resources

Table C-4: USDA-NASS Quickstats, Hawaii 2016 Inventory Report, and CEFM Cattle Category Mapping

USDA-NASS Quickstats	Hawaii 2016 Inventory Report	CEFM
Cattle, Calves	Calves	Dairy Calves
		Beef Calves
Cattle, Cows, Milk	Dairy Cows	Dairy Cows
Cattle, Heifers, GE 500 lbs, Milk Replacement	Dairy Replacement Heifers	Dairy Replacements 7-11 months
		Dairy Replacements 12-23 months
Cattle, Bulls, GE 500 lbs	Bulls	Bulls
Cattle, Cows, Beef	Beef Cows	Beef Cows
Cattle, Heifers, GE 500 lbs, Beef Replacement	Beef Replacement Heifers	Beef Replacements 7-11 months
		Beef Replacements 12-23 months
Cattle, Steers, GE 500 lbs	Steers	Steer Stockers
Cattle, Heifers, GE 500 lbs, (Excl. Replacement)	Other Dairy and Beef Heifers	Heifer Stockers
Cattle, On Feed	IE (Steers & Other Dairy and Beef Heifers)	Steer Feedlot
		Heifer Feedlot

IE – Included Elsewhere

Summary of Updates to the Inventory: To improve emission estimates from enteric fermentation, manure management, and agricultural soil management for Hawaii, cattle population data for all inventory years was further disaggregated to allow for the application of more granular emission factors. Based on Hawaii-specific cattle population data obtained from the U.S. EPA for 1990 through 2018 (Steller 2020) population data was disaggregated for the following animal groupings:

- **Calves** into Beef and Dairy Calves;
- **Beef Replacement Heifers** into the 7-11 months and 12-23 months age ranges;
- **Dairy Replacement Heifers** into 7-11 months and 12-23 month age ranges;
- **Steer** into Steer Feedlot and Steer Stockers; and
- **Other Beef Heifers** into Heifer Feedlot and Heifer Stockers.

More granular annual emission factors for the new cattle groups from the U.S. Inventory (EPA 2020a) were then applied to estimate emissions. Specifically, the following factors were updated:

- Volatile solid rates
- Nitrogen excretion rates
- Typical animal mass
- Fraction volatile solids distribution
- Maximum potential emissions (B_O)
- Weighted methane conversion factors (MCFs)

The implementation of this improvement resulted in a change in emissions that is not visibly significant across all inventory years (i.e., the change is less than 0.005 MMT CO_2 Eq.).

Potential Future Improvements: None.

Area for Improvement #17

Description of Improvement Area: Updated and/or Hawaii-specific enteric emission factors should be incorporated into future analyses if data becomes available.

Affected Source Category: Enteric Fermentation

Research/Analysis Conducted: Additional research was conducted to identify updated and/or Hawaii-specific enteric emission factors but no new information was identified that could be used to inform emission estimates from enteric fermentation.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: Updated and/or Hawaii-specific enteric emission factors should be incorporated into future analyses if data becomes available.

Area for Improvement #18

Description of Improvement Area: If updated data becomes available, updated and/or Hawaii-specific emission factors should be incorporated into future analyses.

Affected Source Category: Manure Management

Research/Analysis Conducted: Additional research was conducted to identify updated and/or Hawaii-specific emission factors but no new information was identified that could be used to inform emission estimates from manure management.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: If updated data becomes available, updated and/or Hawaii-specific emission factors should be incorporated into future analyses.

Area for Improvement #19

Description of Improvement Area: Further research into the accuracy of interpolated and extrapolated animal population, crop production, and synthetic fertilizer application data may be considered in future analyses.

Affected Source Category: Agricultural Soil Management

Research/Analysis Conducted: For the 2016 inventory report, crop area, crop production and animal population data for 1987, 1992, 2007 and 2012 were obtained from the USDA Census of Agriculture, which is compiled every five years. In 2019, data for 2017 was published by the USDA Census of Agriculture. Additional research was conducted to identify updated synthetic fertilizer application data but no new information was identified that could be used to inform emission estimates from agricultural soil management.

Summary of Updates to the Inventory: The USDA Census of Agriculture continues to be used as the main source of information for crop area, crop production, and animal population data. The most recently published data for 2017 was incorporated into the inventory and interpolated to identify estimates for other inventory years.

Potential Future Improvements: Further research into the accuracy of extrapolated synthetic fertilizer application data may be considered in future analyses.

Area for Improvement #20

Description of Improvement Area: Further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses.

Affected Source Category: Agricultural Soil Management, Urea Application

Research/Analysis Conducted: Additional research was conducted on fertilizer consumption in Hawaii but no new information was identified that could be used to verify the accuracy of calendar year fertilizer consumption patterns.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: Further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses.

Area for Improvement #21

Description of Improvement Area: If crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly.

Affected Source Category: Agricultural Soil Management

Research/Analysis Conducted: Additional research was conducted to identify updated crop residue factors but no new information was identified that could be used to inform emission estimates from agricultural soil management.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: If crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly.

Area for Improvement #22

Description of Improvement Area: Conducting further research to identify seed production activity data may be considered to estimate emissions from seed production in future analyses.

Affected Source Category: Agricultural Soil Management

Research/Analysis Conducted: Data on Hawaii seed crop acreage and production of seed (i.e., out-shipments) are available for 1990 and for 2007 to 2018 from the U.S. Department of Agriculture (USDA 1998 and 2018). According to these sources, seed corn accounts for over 95 percent of the value of Hawaii's seed industry.

Summary of Updates to the Inventory: Because seed corn accounts for over 95 percent of the value of Hawaii's seed industry, crop residue factors for corn for grain from IPCC (2006) were applied to seed production data to estimate emissions from nitrogen applied from crop residues. The USDA provides seed production data only for out-shipments of seed. Data on out-shipments of seed are not representative of total seed production in Hawaii because the majority of the seeds produced are not sold but instead are used for ongoing research or for further propagation before sale (USDA 1999b). Therefore, seed crop acreage data were used to estimate total seed production by using the average production per acre of corn for grain as a proxy. The implementation of this improvement resulted in a slight increase in emissions from agricultural soil management that is not visibly significant across all inventory years (i.e., the change is less than 0.005 MMT CO_2 Eq.).

Potential Future Improvements: None.

Area for Improvement #23

Description of Improvement Area: 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.

Affected Source Category: Field Burning of Agricultural Residues

Research/Analysis Conducted: Additional research was conducted to identify whether the residuals of other crops are burned in Hawaii but no new information was identified that that could be used to inform emission estimates from field burning of agricultural residues in Hawaii.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: 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.

Area for Improvement #24

Description of Improvement Area: As [field burning of agricultural] residue factors are updated and/or better data become available, future analyses should update the factors accordingly.

Affected Source Category: Field Burning of Agricultural Residues

Research/Analysis Conducted: Additional research was conducted to identify updated field burning of agricultural residue factors but no new information was identified that could be used to inform emission estimates from field burning of agricultural residues.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: As field burning of agricultural residue factors are updated and/or better data become available, future analyses should update the factors accordingly.

Area for Improvement #25

Description of Improvement Area: If more recent urea fertilizer application data become available, it should be incorporated into future inventory analyses.

Affected Source Category: Urea Application

Research/Analysis Conducted: Additional research was conducted to identify updated urea fertilizer application data but no new information was identified that could be used to inform emission estimates from urea consumption.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: If more recent urea fertilizer application data become available, it should be incorporated into future inventory analyses.

Area for Improvement #26

Description of Improvement Area: 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.

Affected Source Category: Forest Carbon

Research/Analysis Conducted: The 2016 inventory report used carbon sequestration rates and land cover data by forest type for Hawaii forests from the United States Geological Survey (USGS) paper titled "Baseline and Projected Future Carbon Storage and Carbon Fluxes in Ecosystems of Hawaiʻi" (Selmants et al. 2017). Paul Selmants (USGS) was contacted to confirm that the 2017 study contains the latest available information on Hawaii land-cover and sequestration rates. Paul indicated that his team recently finished a new set of model runs that incorporate two new land use/land cover change scenarios and two new climate change scenarios.

Summary of Updates to the Inventory: Based on the new information provided by Paul Selmants (USGS), new yearly carbon sequestration rates for forest and shrubland were calculated and incorporated into this inventory report.

Potential Future Improvements: Incorporate additional data on forest land cover if they become available.

Area for Improvement #27

Description of Improvement Area: 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.

Affected Source Category: Agricultural Soil Carbon

Research/Analysis Conducted: For the 2016 inventory report, emissions from agricultural soil carbon in Hawaii were based on state-level estimates for 1990 through 2015, as obtained from the 1990-2015 U.S. Inventory (EPA 2017). The 1990-2018 U.S. Inventory (EPA 2020a) contains updated national emission estimates for 1990 through 2018 but only includes state-level estimates for 2015. The updated estimates reflect several improvements to the methodology used to calculate emissions from agricultural soils for the U.S. Inventory. These improvements include development of a more detailed time series of management activity data from various USDA surveys, incorporating new land-use and crop histories from a National Resource Inventory survey, and incorporating new land-use data from the National Land Cover Database (EPA 2020a).

Summary of Updates to the Inventory: To estimate emissions from agricultural soil carbon for all inventory years for Hawaii, the change in emission estimates between the 1990-2015 U.S. Inventory (EPA 2017) and the 1990-2018 U.S. Inventory (EPA 2020a) for 2015 were used to scale state-level emission estimates from the 1990-2015 U.S. Inventory (EPA 2017) for all other inventory years. Estimates for 2016 and 2017 cropland soils were then projected using the same methodology previously used to estimate 2016 emissions in the 2016 inventory report (i.e., based on projected changes in land cover by USGS (Selmants et al. 2017). Estimates for 2016 and 2017 grassland soils were projected using an updated estimate of annual grassland carbon stock changes from 2011 through 2025 (Selmants 2020). The implementation of this improvement results in an increase in emissions of 0.24-0.27 MMT CO_2 Eq. from agricultural soil carbon across all inventory years.

Potential Future Improvements: None.

Area for Improvement #28

Description of Improvement Area: 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.

Affected Source Category: Agricultural Soil Carbon

Research/Analysis Conducted: Outreach was conducted to better understand the potential impact of efforts being implemented by Hawaii Greenhouse Gas Sequestration Task Force on emissions. Specifically, Susan Crow, a member of the Task Force, was contacted to inquire about the status of her research on soil carbon. Susan clarified that research efforts are currently underway to develop a soil carbon map for Hawaii and that new models are being explored to model GHG flux and soil carbon in Hawaii. While Susan also noted that there are currently limitations with modeling emissions from agricultural soil carbon in Hawaii using the DAYCENT model, which is used to estimate emissions from agricultural soil carbon for the U.S. Inventory (EPA 2020a), it was determined that state-level emission estimates from the U.S. Inventory (EPA 2020a) continue to reflect the best available estimates of emissions from agricultural soil carbon in Hawaii.

Summary of Updates to the Inventory: None. While Susan also noted that there are currently limitations with modeling emissions from agricultural soil carbon in Hawaii using the DAYCENT model, which is used to estimate emissions from agricultural soil carbon for the U.S. Inventory (EPA 2020a), it was determined that state-level emission estimates from the U.S. Inventory (EPA 2020a) continue to reflect the best available estimates of emissions from agricultural soil carbon in Hawaii.

Potential Future Improvements: Further research into emissions reductions from improved agricultural soil management practices may be considered in future analyses.

Area for Improvement #29

Description of Improvement Area: Further research into urban tree sequestration rates by county or island may be considered in future analyses.

Affected Source Category: Urban Trees

Research/Analysis Conducted: Additional research was conducted on the availability of county- or island-specific tree sequestration rates but was unable to identify new information on tree sequestration rates. As part of this research, a recent study published by the U.S. Forest Service was identified that presents estimates for Hawaii of the net carbon flux from settlement trees in Settlements Remaining Settlements, which includes urban trees (Domke et al., 2020). The methodology used in the Forest Service's estimates are described in detail in the U.S. Inventory (EPA 2020a). Specifically, carbon sequestration from trees in the Settlements Remaining Settlements category is estimated by multiplying the percent tree cover in settlement areas by the carbon sequestration rate per unit of tree cover. This methodology is similar to the methodology used to estimate carbon sequestration from urban trees in Hawaii in the 2016 inventory report. However, the results differ due to different assumptions regarding tree coverage and carbon sequestration rates. In the 2016 inventory report, carbon sequestration values were based on the City and County of Honolulu's Municipal Forest Resource Analysis performed in 2007, while the U.S. Inventory estimates are based on published literature by Nowak et al. and data from the U.S. Forest Service's i-Tree Eco mode.

Summary of Updates to the Inventory: Based on the more recent and comprehensive methodology used in the U.S. Inventory, the rates for gross and net carbon sequestration per unit of tree cover in settlement areas within Hawaii were updated (EPA 2020a). These values replaced the previous estimates, which were based on the 2007 Honolulu Municipal Forest Resource Analysis. The implementation of this improvement results in an increase in net sequestration of 0.23-0.29 MMT CO_2 Eq. from urban trees across all inventory years.

Potential Future Improvements: None.

Area for Improvement #30

Description of Improvement Area: 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.

Affected Source Category: Urban Trees

Research/Analysis Conducted: Publications and materials from recent Task Force meetings, as available on the Task Force’s website, were reviewed and Michael Madsen (DOH) was consulted on recent efforts.

Summary of Updates to the Inventory: None. It was determined that there is no information available from the Task Force that can be used at this time to improve the current methodology and assumptions used to estimate urban tree sequestration in Hawaii.

Potential Future Improvements: None.

Area for Improvement #31

Description of Improvement Area: Further investigation into alternative sources for historical wildfire acres burned and prescribed fire acres burned may be considered in future analyses.

Affected Source Category: Forest Fires

Research/Analysis Conducted: To improve emission estimates from forest fires for Hawaii, Michael Walker (DLNR) was contacted to ask about the availability of historical data on acres burned from wildland and prescribed fires. Michael confirmed that 1990 wildfire data are available, but he was unable to access the data while working remotely (due to Covid-19). He also confirmed that DLNR does not maintain a record of prescribed burns in Hawaii.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: Incorporate 1990 wildfire data from DLNR into the 1990 inventory for Hawaii once it becomes available.

Area for Improvement #32

Description of Improvement Area: 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.

Affected Source Category: Forest Fires

Research/Analysis Conducted: Tesh Rao (EPA), the point of contact for data on agricultural fires and events (wildfires and prescribed burning) published in EPA's National Emissions Inventory (NEI), was contacted to inquire about the emission estimates from prescribed burning in Hawaii. In the 2016 inventory report, It was assumed there were no emissions from prescribed fires based on input from Christian Giardina from the Institute of Pacific Islands Forestry that prescribed burning is not a common practice in Hawaii; therefore emissions from prescribed fires is likely very small. However, the NEI indicates that emissions from prescribed fires in Hawaii were 0.13 MMT CO_2 Eq. in 2011, 2.07 MMT CO_2 Eq. in 2014, and 0.09 MMT CO_2 Eq. in 2017. According to Tesh, different models (e.g., the FINN model, NOAA's Hazard Mapping System) were used to identify acres-burned from prescribed fires for the NEI, which are the reason for the large variation in reported emissions from prescribed fires for Hawaii.

Summary of Updates to the Inventory: None. Due to the inconsistency in methodology used to identify emissions for the NEI, a lack of data available for the all inventory years, and expert guidance from Christian Giardina, this inventory continues to assume that emissions from prescribed fires in Hawaii are negligible.

Potential Future Improvements: Incorporate emissions from prescribed fires into the statewide inventory for Hawaii if data becomes available.

Area for Improvement #33

Description of Improvement Area: 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.

Affected Source Category: Forest Fires

Research/Analysis Conducted: Additional research was conducted to identify new information on the percent of area burned by forest type. New estimates from USGS were provided by Paul Selmants, which break down area burned by forest type for 1999 to 2019 (Selmants 2020). These estimates included one new vegetation class, wet shrubland, in addition to the existing vegetation classes from the 2016 Inventory (with the exception of alien tree plantations).

Summary of Updates to the Inventory: New data on the percent area burned by forest type were incorporated into this Inventory report. The implementation of this improvement results in a change in emissions of -0.05 to 0.02 MMT CO_2 Eq. from forest fires across all inventory years.

Potential Future Improvements: None.

Area for Improvement #34

Description of Improvement Area: 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.

Affected Source Category: Landfilled Yard Trimmings and Food Scraps

Research/Analysis Conducted: Additional research was conducted to identify Hawaii-specific waste composition data and sequestration rates but no new information was identified that could be used to inform emission estimates from landfilled yard trimmings and food scraps.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: 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.

Area for Improvement #35

Description of Improvement Area: Identify data and estimate emissions for source and sink categories that are currently not estimated due to a lack of data.

Affected Source Category: Land Converted to Forest Land, Wetlands, Land Converted to Settlements, Other Land, Biomass Burning in Grassland, Liming, Harvested Wood Products

Research/Analysis Conducted: Research was conducted to identify additional data from sources and sinks that are not currently included in the Hawaii Inventory but no new information was identified that could be used to estimate emissions from these categories. It is assumed that emissions from these categories, if estimated, would have an insignificant impact on the statewide total.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: Identify data and estimate emissions for source and sink categories that are currently not estimated due to a lack of data.

Waste

Area for Improvement #36

Description of Improvement Area: 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.

Affected Source Category: Landfills

Research/Analysis Conducted: Data obtained from EPA's Landfill Methane Outreach Program (LMOP) and EPA's GHGRP were obtained and reviewed. LMOP data was obtained from EPA for 2007, 2010, 2015, 2016, and 2017. Specifically, data on landfill gas recovered from flaring and energy projects in Hawaii were obtained from LMOP for all years. MSW disposal data from EPA's GHGRP for 2010, 2015, 2016, and 2017 for all landfills in Hawaii were also obtained. These data were cross-walked against the data received from the DOH Solid & Hazardous Waste Branch to identify any potential gaps in the data.

Based on this analysis, the landfill data from the DOH Solid & Hazardous Waste Branch was confirmed to be complete and accurate.

Summary of Updates to the Inventory: None. Based on this analysis, it was confirmed that the landfill data from the DOH Solid & Hazardous Waste Branch is complete and accurate. It was also confirmed that additional data on historical waste disposal, historical landfill gas management practices, and the composition of landfilled waste is not available at this time to improve the inventory methodology.

Potential Future Improvements: 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.

Area for Improvement #37

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

Affected Source Category: Composting

Research/Analysis Conducted: Additional research was conducted to identify Hawaii-specific data on composting volumes but no new information was identified that could be used to inform emission estimates from composting.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

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

Area for Improvement #38

Description of Improvement Area: 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.

Affected Source Category: Wastewater Treatment

Research/Analysis Conducted: Additional research was conducted to identify more recent data on the share of households in Hawaii on septic systems, and Hawaii-specific data on the share of wastewater solids anaerobically digested at wastewater treatment plants (WWTP) and the percentage of biosolids used as fertilizer at WWTPs. Based on previous communications with the Hawaii DOH, Wastewater Branch, this information is not available from DOH. Through this research, no new information was identified that could be used to inform emission estimates from wastewater treatment.

Summary of Updates to the Inventory: None. It was determined that there is not sufficient information available at this time to improve the inventory methodology.

Potential Future Improvements: More recent and Hawaii-specific data should be incorporated into future inventory analyses, if it becomes available.

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., 2017).

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)[83] 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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[83] 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., 2017). 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 2017. 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, 2016, and 2017 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 2020b). The emission breakdowns also include revised emissions from the AES facility, using SEDS energy consumption by state data. GHGRP facility level emissions data were unavailable for the years 1990 and 2007. Emissions for the energy industries and industrial sectors for 1990 and 2007 were calculated using the methodology described in Section 3.1 and allocated to each county by applying the 2010 county allocations derived from GHGRP facility level emissions data (EPA 2020b).

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 (2019).

Transportation

Ground transportation emissions for 2007, 2010, 2015, 2016, and 2017 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 2019). 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 data obtained from DBEDT (2008a) 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 (which ceased operations in the early 1990s) 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.

Non-Energy Uses

Emissions for non-energy uses for 2010, 2015, 2016, and 2017 were calculated using the methodology described in Section 3.5 and allocated to each county based on county-level emission breakdowns for the energy industries and industrial sector calculated from GHGRP data (EPA 2020b).

GHGRP facility level emissions data were unavailable for the years 1990 and 2007. Emissions for non-energy uses for 1990 and 2007 were calculated using the methodology described in Section 3.5 and allocated to each county by applying the 2010 county allocation for the energy industries and industrial sector derived from GHGRP facility level emissions data (EPA 2020b).

IPPU

Cement Production

All process emissions from cement production in 1990 occurred within Honolulu County. Clinker production in Hawaii ceased in 1996; as a result, there are no emissions from cement production in Hawaii for all other inventory years.

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 2020a). National electricity sales data come from the EIA

(2019b). Hawaii electricity sales data by island come from the State of Hawaii Data Book (DBEDT 2019). 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 2020a) to each county based on the ratio of the county's vehicle registrations from the State of Hawaii Data Book (DBEDT 2019) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2017). County emissions from other air-conditioning systems (i.e., air conditioning systems excluding mobile air conditioners) were estimated by apportioning national emissions from the U.S. Inventory (EPA 2020a) to each county based on the ratio of the number of houses with air conditioners in each county to the number of houses with air conditioners in the U.S. The number of houses in each county with air conditioners was estimated by apportioning the total number of houses with air conditioners in hot and humid climate regions in the United States using EIA's 2009 and 2015 Residential Energy Consumption Survey (RECS) to each county based on population (EIA 2013; EIA 2018). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2020a) were apportioned to each county based on the ratio of the county's population from DBEDT (2019) to U.S. population from the U.S. Census Bureau (2019).

AFOLU

Enteric Fermentation

County-level population data for total cattle, beef cattle, swine, and chickens were obtained from USDA NASS. County-level cattle population data were further disaggregated based on Hawaii-specific, state-level cattle population data from Steller (2020), using the methodology described in Section 5.1. 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. County-level cattle population data were further disaggregated based on Hawaii-specific, state-level cattle population data from Steller (2020), using the methodology described in Section 5.1. 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 the Hawaii State Office of Planning (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 years 2016 and 2017 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. County-level cattle population data were further disaggregated based on Hawaii-specific, state-level cattle population data from Steller (2020), using the methodology described in Section 5.1. 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 and for year 2017 from the USDA Census of Agriculture. 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 the Hawaii State Office of Planning (2015) for 1992 and the University of Hawaii (2016) for 2015. Agricultural land use by county for years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and years 2016 and 2017 were 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 the Hawaii State Office of Planning (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 2019, 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 2019).

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 (2019). 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 2020a) and MSW composting volumes for each county were calculated using population data from the State of Hawaii Data Book (DBEDT 2019).

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 of CO_2 Eq.[84] 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 2020b), Table F-1 summarizes annual GHG emissions from HAR affected facilities for 2010 to 2017. Table F-2 summarizes projected GHG emissions for the HAR affected facilities for 2020, 2025, and 2030. 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 are not presented, as these emissions are excluded from the annual facility-wide GHG emission cap.

HAR Facility Projections

Methodology: For the Hawaiian Electric power plants, data were taken directly from the Power Supply Improvement Plan (PSIP) E3 with Grid Modernization Plan (PUC 2016; DCCA 2017), and adjusted based on the Integrated Grid Plan (IGP) demand forecast (consistent with the methodology described in Appendix J). Because the PSIP does not provide unit level data for Molokai, emissions for Palaau Generating Station were projected based on the IGP electricity demand forecast (GWh). According to the PSIP, Molokai will generate electricity entirely from renewable energy by 2025 (PUC 2016), as such Palaau is projected to have no emissions in 2025 and 2030. 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 petroleum refinery that remains in operation were projected based on the methodology and assumptions described in Appendix J.

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 6.37 MMT CO_2 Eq. This combined emissions cap would allow each HAR facility to exceed the individual cap of 16 percent below baseline 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 Appendix J, which are estimated to lead to additional emissions of 0.87 MMT CO_2 Eq. in 2020 and 1.58 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 additional emissions while still meeting the requirements of the rule. How these emissions will be absorbed remains unknown.

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[84] Hawaii Administrative Rules, Chapter 11-60.1, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.

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	2017
AES Hawaii, Inc.	Energy Industries (1A1ai)	1.50	1.41	1.48	1.33	1.52	1.39	1.55	1.43
Hamakua Energy Partners	Energy Industries (1A1ai)	0.17	0.13	0.14	0.10	0.11	0.13	0.09	0.09
Hawaiian Commercial & Sugar Company[a]	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	0.18
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.17	0.18	0.15	0.19	0.21	0.21	0.21	0.22
HELCO Shipman Generating Station[b]	Energy Industries (1A1ai)	NE	NE	NE	NO	NO	NO	NO	NO
HELCO Puna Generating Station	Energy Industries (1A1ai)	0.09	0.09	0.08	0.09	0.05	0.02	0.02	0.02
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.97	0.88	0.86	0.86	0.88	1.01	0.80	0.81
HECO Kahe Generating Station	Energy Industries (1A1ai)	2.52	2.63	2.41	2.22	2.13	2.02	2.03	2.01
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	NO	+	+	+	+	+	+	+
HECO Honolulu Generating Station[c]	Energy Industries (1A1ai)	0.12	0.10	0.05	0.06	+	NO	NO	NO
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[d]	Energy Industries (1A1ai)	NO	NO	NO	NO	NO	NO	NO	NO
Kalaeloa Cogeneration Plant	Energy Industries (1A1ai)	0.95	0.99	0.91	0.96	0.92	0.95	0.85	0.86
Kauai Island Utility Co. Kapaia Power Station	Energy Industries (1A1ai)	0.13	0.12	0.13	0.12	0.13	0.12	0.11	0.11
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	0.08
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.21	0.19	0.18	0.13	0.14	0.11	0.14	0.18
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.56	0.55	0.52	0.49	0.46	0.49	0.48	0.48
MECO Palaau Generating Station	Energy Industries (1A1ai)	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Island Energy Services Refinery[e]	Energy Industries (1A1b)	0.34	0.35	0.34	0.30	0.32	0.33	0.31	0.31
	Oil and Natural Gas (1B2)	0.19	0.21	0.23	0.16	0.21	0.19	0.19	0.17
Par Hawaii Refinery[e]	Energy Industries (1A1b)	0.44	0.45	0.41	0.26	0.43	0.44	0.43	0.47
	Oil and Natural Gas (1B2)	0.12	0.13	0.12	0.07	0.13	0.11	0.09	0.13
Energy Industries Subtotal[f]		**8.55**	**8.45**	**8.00**	**7.46**	**7.62**	**7.56**	**7.35**	**7.28**
Industrial Subtotal[f]		**0.14**	**0.13**	**0.12**	**0.15**	**0.14**	**0.12**	**0.04**	**+**
Oil and Natural Gas Subtotal		**0.32**	**0.34**	**0.34**	**0.24**	**0.34**	**0.30**	**0.29**	**0.30**
Total		**9.01**	**8.92**	**8.47**	**7.84**	**8.11**	**7.98**	**7.68**	**7.58**

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

[b] 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.

[d] The Hu Honua Bioenergy, LLC Pepeekeo Power Plant is currently under development.

[e] 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.

[f] 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	2030	2020 Cap	2020 Difference
AES Hawaii, Inc.	Energy Industries (1A1ai)	1.32	NO	NO	1.28	(0.04)
Hamakua Energy Partners	Energy Industries (1A1ai)	0.15	0.11	0.08	0.14	(0.02)
Hawaiian Commercial & Sugar Co.	Industrial (1A2)	NO	NO	NO	NA	NA
HELCO Kanoelehua Hill Generating Station	Energy Industries (1A1ai)	+	+	+	0.16	0.15
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.13	0.07	0.02	0.22	0.09
HELCO Shipman Generating Station	Energy Industries (1A1ai)	NO	NO	NO	NA	NA
HELCO Puna Generating Station	Energy Industries (1A1ai)	0.02	0.02	0.01	0.03	0.01
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.58	0.22	0.01	0.80	0.21
HECO Kahe Generating Station	Energy Industries (1A1ai)	1.04	0.33	NO	2.00	0.96
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	0.01	0.01	NO	0.11	0.10
HECO Honolulu Generating Station[c]	Energy Industries (1A1ai)	NO	NO	NO	NA	NA
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[d]	Energy Industries (1A1ai)	NO	NO	NO	NA	NA
Kalaeloa Cogeneration Plant	Energy Industries (1A1ai)	0.83	1.11	1.05	1.06	0.23
KIUC Kapaia Power Station	Energy Industries (1A1ai)	0.11	0.08	0.07	0.09	(0.02)
KIUC Port Allen Generating Station	Energy Industries (1A1ai)	0.04	0.03	0.04	0.14	0.10
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.07	NO	NO	0.14	0.07
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.28	0.16	0.12	0.42	0.13
MECO Palaau Generating Station	Energy Industries (1A1ai)	0.02	NO	NO	0.02	0.00
Island Energy Services Refinery[f]	Energy Industries (1A1b)	NO	NO	NO	0.19	0.19
	Oil and Natural Gas (1B2)	NO	NO	NO	NA	NA
Par Hawaii Refinery[f]	Energy Industries (1A1b)	0.18	0.49	0.54	0.91	0.73
	Oil and Natural Gas (1B2)	0.05	0.14	0.15	NA	NA
TBD[g]	*Energy Industries (1A1b)*	*0.87*	*1.58*	*NA*	*NA*	*NA*
Energy Industries Subtotal[h]		**5.68**	**4.22**	**1.93**	**7.70**	**2.90**
Industrial Subtotal[h]		**NO**	**NO**	**NO**	**NA**	**NA**
Oil and Natural Gas Subtotal		**0.05**	**0.14**	**0.15**	**NA**	**NA**
Total		**5.73**	**4.35**	**2.08**	**7.70**	**2.90**

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

[b] The HELCO Shipman Generating Station was deactivated in 2012 and closed at the end of 2015.

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

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

[f] 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 2018, the Island Energy Services refinery ceased its refinery operations and converted to an import terminal (Mai 2018).

[g] 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.

[h] Sector subtotals presented in this table, 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 in this table only represent emissions from HAR facilities, not 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	2017
Residential						
Diesel Fuel	2	19	1	2	0	1
Propane	217	480	918	505	690	580
Natural Gas	605	528	529	562	560	558
Wood and Waste	0	172	367	14	10	32
Commercial						
Diesel Fuel	2,636	1,629	1,528	1,298	904	1,181
Motor Gasoline[a]	310	60	58	1,452	1,473	1,495
Propane	359	857	2,041	2,319	2,327	3,025
Residual Fuel	5,189	3	0	0	0	0
Natural Gas	2,379	1,904	1,848	1,874	2,339	2,385
Ethanol	0	2	3	111	112	115
Wood and Waste	0	2,350	2,945	3,185	3,734	3,553
Other Fuels[b]	1	0	0	0	0	0
Industrial[c]						
Coal	695	1,795	1,415	1,136	271	0
Diesel Fuel	4,222	2,606	1,882	1,851	939	1,789
Motor Gasoline[a]	701	1,216	684	1,335	1,320	1,329
Propane	53	198	191	33	39	217
Residual Fuel	10,942	2,690	2,834	1,876	2,565	3,233
Natural Gas	0	521	353	434	81	83
Ethanol	0	37	40	102	100	103
Wood and Waste	18,159	5,447	4,392	3,169	3,360	24
Other Fuels[b]	2,653	169	5,350	4,410	2,923	2,692
Energy Industries						
Coal	26	15,313	15,702	14,495	16,160	14,948
Diesel Fuel	9,747	13,377	12,971	12,297	11,726	12,053
Residual Fuel	77,780	71,832	65,157	54,987	53,197	52,777
Fuel Gas[d]	0	1,763	2,503	3,794	3,992	3,992
Biodiesel[e]	0	0	130	867	643	907

Wood and Waste	7,765	0	40	853	1,076	1,762
Other Fuels[b]	(2905)	573	241	(148)	67	605
Naphtha[f]	0	4,065	4,419	6,240	5,413	5,578

[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, 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 2020b) 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 2020a).
[e] Biodiesel data were obtained from EPA's GHGRP (EPA 2020b) 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 2020a).
[f] Naphtha data were obtained from EPA's GHGRP (EPA 2020b) for 2010, 2015, and 2016 and were only available in MMT CO2 Eq. Fuel consumption in Bbtu was estimated by back-calculating emissions using the corresponding naphtha emissions factor from the U.S. Inventory (EPA 2020a). Naphtha data were obtained from DBEDT (2008a) for 1990 and 2007 in Bbtu.
Note: Totals may not sum due to independent rounding.
Sources: EIA (2020a); EPA (2020a); EPA (2020b); DBEDT (2008a).

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

Mode/Fuel Type	1990	2007	2010	2015	2016	2017
Aviation[a]						
Aviation Gasoline	1,375	206	188	47	35	50
Jet Fuel Kerosene[b]	51,816	63,670	49,098	65,076	65,406	64,394
Ground[a]						
Diesel Fuel[c]	9,674	16,096	10,412	10,511	8,785	8,384
Motor Gasoline[d]	39,916	55,301	47,059	49,072	49,902	49,515
Propane	49	48	21	11	10	0
Natural Gas	0	3	2	2	2	2
Ethanol	0	1,699	2,742	3,765	3,787	3,821
Biodiesel[e]	0	204	38	0	584	576
Marine[a]						
Diesel Fuel[c]	5,771	9,601	6,061	627	973	787
Motor Gasoline[d]	18	35	43	54	23	25
Residual Fuel[f]	15,897	28,069	6,756	4,394	5,091	7,215
Ethanol	0	0	3	4	1	1
Military Aviation						
Aviation Gasoline	0	0	+	+	+	+
Jet Fuel Kerosene[b]	1,449	8,659	6,677	9,109	8,895	8,757
Naphtha[g]	17,786	0	0	0	0	0
Military Non-Aviation						
Diesel Fuel[c]	4,929	10,428	6,738	669	2,202	2,632

Motor Gasoline	4,597	0	0	0	0	0
Residual Fuel[f]	806	0	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 direct communication with EIA (2019a).

[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 (2020) 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 (2020).

[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 2019b).

[g] Military aviation naphtha consumption was obtained from direct communication with EIA (2019a).

Note: Totals may not sum due to independent rounding.

Sources: EIA (2020a); EIA (2019a); EIA (2019b); DBEDT (2020).

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

Fuel Type	1990	2007	2010	2015	2016	2017
Industrial						
Coal	0%	1%	1%	1%	2%	0%
Asphalt and Road Oil	100%	100%	100%	100%	100%	100%
Propane	71%	79%	86%	84%	82%	82%
Lubricants	100%	100%	100%	100%	100%	100%
Diesel Fuel	1%	1%	1%	1%	1%	0%
Transportation						
Lubricants	100%	100%	100%	100%	100%	100%

Source: EPA (2019h).

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

Fuel Type	1990	2007	2010	2015	2016	2017
Industrial						
Coal	3	19	15	17	4	0
Diesel Fuel	27	38	10	10	6	0
Propane	38	156	165	28	32	179
Other Fuels[a]	2,652	169	5,350	4,410	2,923	2,692
Aviation						
Other Fuels[a]	214	185	17	49	59	49
Ground Transportation						
Other Fuels[a]	187	162	368	375	336	318

Marine Transportation						
Other Fuels[a]	61	53	79	30	25	25

[a] Other fuels include asphalt and road oil, lubricants, and waxes.

Sources: EIA (2020a), EPA (2019h).

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

Aviation Miles	1990	2007	2010	2015	2016	2017
International Gallons	7,517,488	9,960,882	9,557,257	16,322,531	17,115,139	18,070,399
Domestic Gallons	18,205,192	45,911,647	40,933,992	48,092,538	51,015,410	50,703,798
International Share	29%	18%	19%	25%	25%	26%
Domestic Share	71%	82%	81%	75%	75%	74%

Note: Consumption 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 (2020).

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

Mode/Fuel Type	1990	2007	2010	2015	2016	2017
Aviation[a]						
Jet Fuel Kerosene	15,143	11,351	9,294	16,490	16,431	16,919
Marine[b]						
Diesel Fuel	783	251	2,398	1,084	442	1,190
Residual Fuel	466	425	2,769	247	304	384

[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 2020a).

Note: Totals may not sum due to independent rounding.

Source: EIA (2020a), DOT (2018), DOC (2008), DOC (2018), EPA (2020a).

IPPU

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

	1990	2007	2010	2015	2016	2017
Clinker Production	195,044	0	0	0	0	0

Source: Wurlitzer (2008).

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

	1990	2007	2010	2015	2016	2017
Hawaii	8.3	10.6	10.0	9.4	9.3	9.1
U.S.	2,712.6	3,764.6	3,754.8	3,759.0	3,762.5	3,723.4

Sources: EIA (2019b) (U.S.); DBEDT (2019) (Hawaii).

Table G-9: Registered Vehicles by Year

	1990	2007	2010	2015	2016	2017
Hawaii	870,657	1,103,782	1,086,185	1,193,863	1,194,727	1,213,093
U.S.	188,170,927	246,430,169	241,214,494	254,120,376	259,143,542	262,782,464

Sources: FHWA (2010; 2015; 2016; 2017) (U.S.); DBEDT (2019) (Hawaii).

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

Source	1990	2007	2010	2015	2016	2017
Cars and Trucks A/C ODS Substitutes	0	71.2	68.1	46.3	43.3	40.1
Other A/C ODS Substitutes	0	15.0	25.2	39.2	41.6	43.3
Other ODS Substitutes	0.2	36.9	55.9	80.3	82.4	83.4
Electrical Transmission and Distribution	23.2	6.3	5.7	3.8	4.1	4.1

Source: EPA (2020a).

AFOLU

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

Animal Type	1990	2007	2010	2015	2016	2017
Cattle	**205,000**	**158,000**	**151,000**	**133,000**	**140,000**	**142,000**
Dairy Cattle	25,599	6,520	3,714	4,348	4,514	**4,601**
Dairy Cows	11,000	3,800	1,800	2,200	2,400	2,400
Dairy Replacement Heifers	6,000	1,000	1,000	1,000	1,000	1,000
7-11 months	1,765	299	297	299	296	298
12-23 months	4,235	701	703	701	704	702
Other Dairy Heifers	2,174	213	130	155	126	126
Dairy Calves	6,425	1,507	784	993	988	1,074
Beef Cattle	**179,401**	**151,480**	**147,286**	**128,652**	**137,486**	**137,399**
Beef Cows	75,000	85,200	81,200	68,800	73,600	73,600
Beef Replacement Heifers	16,000	15,000	12,000	11,000	13,000	13,000
7-11 months	4,792	4,376	3,465	3,319	3,867	3,795
12-23 months	11,208	10,624	8,535	7,681	9,133	9,205
Other Beef Heifers	14,826	4,787	5,870	4,845	3,874	3,874
Heifer Stockers	10,902	4,368	5,175	4,388	3,509	3,359

Animal Type	1990	2007	2010	2015	2016	2017
Heifer Feedlot	3,924	419	694	457	365	514
Steers	26,000	8,000	8,000	9,000	10,000	10,000
Steer Stockers	17,001	7,182	6,725	8,001	8,909	8,822
Steer Feedlot	8,999	818	1,275	999	1,091	1,178
Beef Calves	42,575	33,493	35,216	31,007	33,012	32,926
Bulls	5,000	5,000	5,000	4,000	4,000	4,000
Sheep and Lambs	**22,526**	**22,376**	**22,103**	**25,077**	**26,129**	**27,181**
Goats	**3,348**	**9,169**	**11,465**	**14,933**	**15,579**	**16,225**
Swine	**36,000**	**15,000**	**12,500**	**9,000**	**8,000**	**8,000**
Horses and ponies	**3,770**	**6,547**	**5,687**	**4,774**	**4,661**	**4,548**
Chickens	**1,487,918**	**424,628**	**368,876**	**256,244**	**242,578**	**228,912**
Chickens (excluding broilers)	1,183,000	422,500	366,000	247,242	231,700	216,159
Broilers	304,918	2,128	2,876	9,002	10,877	12,753

Sources: USDA (2018a, 2018b, 2018c) [cattle, swine, and chickens (for years 1990-2010)]; USDA (1989, 1994, 2009, 2014, and 2019) [sheep, goats, horses, broilers, and chickens (for years 2015 – 2017].

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

Crop Type	1990	2007	2010	2015	2016	2017
Sugarcane for sugar	72,000	20,400	15,500	12,900	15,500	30
Pineapples	18,205	7,314	5,986	4,288	4,011	3,752
Sweet potatoes	193	297	648	878	877	876
Ginger root	300	80	64	115	136	157
Taro	462	535	503	489	492	495
Corn for grain	0	3,115	4,365	5,019	4,959	4,899
Seed production	900	4260	6,500	4,260	3,980	4,090

Sources: USDA (2018d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain); USDA (2004b, 2015, 2016, 2018e) (seed production).

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

Crop Type	1990	2007	2010	2015	2016	2017
Sugarcane for sugar	6,538,000	1,493,000	1,195,000	1,139,000	1,336,000	435
Pineapples	607,322	225,952	185,246	133,037	124,513	116,536
Sweet potatoes	1,024	1,430	3,120	4,229	4,224	4,218
Ginger root	4,503	1,266	908	1,614	1,928	2,243
Taro	3,511	2,554	2,060	2,331	2,530	2,730
Corn for grain	0	3,497	7,567	12,880	13,747	14,614
Seed production	1,169	4,782	11,268	10,933	11,034	12,201

Sources: USDA (2018d) (sugarcane); USDA (1989, 1994, 2009, 2014) (pineapples, sweet potatoes, ginger root, taro, and corn for grain); USDA (2004b, 2015, 2016, 2018e) (seed production).

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

Fertilizer Type	1990	2007	2010	2015	2016	2017
Urea Fertilizer Consumption (short tons)	2,638	2,038	2,002	2,262	2,305	2,349
Synthetic Fertilizer Consumption (kg N)	16,218,014	12,550,066	12,324,312	13,953,712	14,227,325	14,500,939

Sources: TVA (1991); AAPFCO (2008, 2011, 2013, 2014, 2017).

Note: 2015 through 2017 consumption totals were estimated based on 2010-2014 data.

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

Area Burned	1990	2007	2010	2015	2016	2017
Area Burned (Hectares)	8,172	11,975	3,856	2,264	7,335	3,115

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

Table G-16: Forest and Shrubland Area (Hectares)

Forest and Shrubland Area	1990	2007	2010	2015	2016	2017
Forest and Shrubland Area (Hectares)	497,430	486,100	491,039	487,449	488,159	490,217

Source: DBEDT (2019).

Table G-17: Forest and Shrubland Area (Percent)

Forest and Shrubland Area	1990	2007	2010	2015	2016	2017
Forest	52.0%	60.9%	64.5%	68.4%	68.4%	68.4%
Shrubland	48.0%	39.1%	35.5%	31.6%	31.6%	31.6%

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

Table G-18: Hawaii Landfilled Yard Trimmings and Food Scraps (thousand short tons, wet weight)

Material	1990	2007	2010	2015	2016	2017
Landfilled Yard Trimmings	**126**	**45**	**55**	**53**	**47**	**42**
Grass	38	14	17	16	14	13
Leaves	51	18	22	21	19	17
Branches	37	13	16	16	14	13
Food Scraps	**85**	**119**	**136**	**149**	**150**	**150**

Source: EPA (2020c).

Table G-19: Hawaii Urban Area (km^2)

Hawaii Urban Area	1990	2007	2010	2015	2016	2017
Urban Area (km^2)	757.0	988.9	1,018.2	1,089.4	1,105.3	1,121.4

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

Waste

Table G-20: 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**	513,907
1978	772,606	**1997**	851,153	**2016**	536,847
				2017	609,923

Sources: Hawaii DOH (2017); Otsu (2008); EPA (2018c).

Table G-21: Volume of Composted MSW (MT)

MSW Composted	1990	2007	2010	2015	2016	2017
Hawaii	18,934	92,564	85,861	102,207	102,154	103,842
U.S.	3,810,000	19,695,000	18,298,000	21,052,000	21,163,000	21,503,000

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

Table G-22: Per Capita Biological Oxygen Demand for Wastewater treatment (kg/person/day)

Island	1990	2007	2010	2015	2016	2017
Hawaii	0.0615	0.0615	0.0004	0.0002	0.0002	0.0001
Kauai	0.0615	0.0615	0.0001	0.0002	0.0002	0.0001
Lanai	0.0615	0.0615	0.0615	0.0615	0.0615	0.0168
Maui	0.0615	0.0615	0.0003	0.0003	0.0006	0.0006
Molokai	0.0615	0.0615	0.0615	0.0615	0.0009	0.0009
Niihau	0.0615	0.0615	0.0615	0.0615	0.0615	0.0615
Oahu	0.0615	0.0615	0.0001	0.0273	0.0273	0.0298

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

Table G-23: Fraction of Population not on Septic (Percent)

Island	1990	2007	2010	2015	2016	2017
Hawaii	99.976%	87.885%	87.885%	87.885%	87.885%	87.885%
Kauai	99.773%	84.753%	84.753%	84.753%	84.753%	84.753%
Lanai/Maui/Molokai	99.973%	93.745%	93.745%	93.745%	93.745%	93.745%
Niihau	99.999%	99.967%	99.967%	99.967%	99.967%	99.967%
Oahu	99.960%	99.353%	99.353%	99.353%	99.353%	99.353%

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

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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	2017
Residential						
Diesel Fuel	44.47	44.47	44.47	44.47	44.47	44.47
Propane	37.17	37.93	37.93	37.93	37.93	39.93
Natural Gas	31.87	31.88	31.91	31.81	31.81	31.82
Commercial						
Diesel Fuel	44.47	44.47	44.47	44.47	44.47	44.47
Motor Gasoline	42.82	43.12	42.89	42.89	42.89	42.89
Propane	37.17	37.93	37.93	37.93	37.93	37.93
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.87	31.87	31.87	31.87	31.87	31.87
Other Fuels						
Kerosene	44.01	44.01	44.01	44.01	44.01	44.01
Industrial						
Coal	57.18	57.38	57.38	57.38	57.38	57.38
Diesel Fuel	44.47	44.47	44.47	44.47	44.47	44.47
Motor Gasoline	42.82	42.89	42.89	42.89	42.89	42.89
Propane	37.17	37.93	37.93	37.93	37.93	37.93
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.87	31.87	31.87	31.87	31.87	31.87
Other Fuels						
Asphalt and Road Oil	45.31	45.31	45.31	45.31	45.31	45.31
Kerosene	44.01	44.01	44.01	44.01	44.01	44.01
Lubricants	44.53	44.53	44.53	44.53	44.53	44.53
Waxes	43.64	43.64	43.64	43.64	43.64	43.64
Energy Industries						
Coal	57.18	57.39	57.42	57.47	57.46	57.50
Diesel Fuel	44.47	44.47	44.47	44.47	44.47	44.47
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15
Fuel Gas	40.11	40.11	40.11	40.11	40.11	40.11

Other Fuels						
Aviation Gasoline Blending Components	41.60	41.60	41.60	41.60	41.60	41.60
Motor Gasoline Blending Components	42.82	43.12	42.89	42.89	42.89	42.89
Unfinished Oils	44.41	44.71	44.77	44.77	44.77	44.77

Source: EPA (2020a).

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/Gigajoules (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 (2020a).

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	2017
Aviation Gasoline	41.57	41.57	41.57	41.57	41.57	41.57
Diesel Fuel	44.47	44.47	44.47	44.47	44.47	44.47
Jet Fuel Kerosene	42.77	43.42	43.42	43.42	43.42	43.42
Motor Gasoline	42.82	42.89	42.89	42.89	42.89	42.89
Propane	37.17	37.93	37.93	37.93	37.93	37.93
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.87	31.87	31.87	31.87	31.87	31.87
Ethanol	41.16	41.16	41.16	41.16	41.16	41.16
Biodiesel	33.49	33.49	33.49	33.49	33.49	33.49
Lubricants	44.53	44.53	44.53	44.53	44.53	44.53

Source: EPA (2020a).

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

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 (2020a).

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

Vehicle/Fuel Type	1990	2007	2010	2015	2016	2017
Ships and Boats						
Residual Fuel	0.16	0.16	0.16	0.16	0.16	0.16
Aircraft						
Aviation Gasoline	0.04	0.04	0.04	0.04	0.04	0.04
Industrial and Commercial Equipment						
Motor Gasoline	0.05	0.07	0.07	0.07	0.07	0.07
Diesel Fuel	0.15	0.15	0.15	0.15	0.15	0.15

Source: EPA (2020a).

Table H-7: CH_4 Emission Factors Used to Estimate Emissions from Off-Road Vehicles by Vehicle Type and Fuel Type (g/kg fuel)

Vehicle/Fuel Type	1990	2007	2010	2015	2016	2017
Ships and Boats						
Residual Fuel	0.03	0.16	0.16	0.16	0.16	0.16
Aircraft						
Aviation Gasoline	2.64	2.64	2.64	2.64	2.64	2.64
Industrial and Commercial Equipment						
Motor Gasoline	11.66	5.80	3.74	2.14	2.05	2.00
Diesel Fuel	0.04	0.11	0.12	0.09	0.09	0.08

Source: EPA (2020a).

Table H-8: 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-9: 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 (2006).

IPPU

Table H-10: Clinker Production Emission Factors and Correction Factor by Year (Ton CO_2/Ton clinker produced)

	1990	2007	2010	2015	2016	2017
Clinker Production Emission Factor	0.51	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	1.02

Source: IPCC (2006).

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Table H-11: 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	2017
Dairy Cows	117.93	107.74	110.59	120.12	123.83	123.83
Dairy Replacements 7-11 months	72.54	69.78	69.31	68.91	68.75	68.75
Dairy Replacements 12-23 months	60.24	58.01	57.62	57.27	57.16	57.38
Other Dairy Heifers	11.54	12.23	12.16	12.20	12.17	12.18
Dairy Calves	94.40	100.47	100.47	100.47	100.47	100.47
Beef Cows	57.91	64.52	64.56	64.38	64.53	64.53
Beef Replacements 7-11 months	36.36	36.63	31.20	36.45	36.16	36.16
Beef Replacements 12-23 months	33.15	34.49	29.01	35.87	34.56	34.99
Heifer Stockers	33.15	34.49	29.01	35.87	34.56	34.99
Heifer Feedlot	11.57	11.29	11.27	11.31	11.29	11.29
Steer Stockers	117.93	107.74	110.59	120.12	123.83	123.83
Steer Feedlot	47.94	46.24	45.92	45.64	45.58	45.58
Beef Calves	72.54	69.78	69.31	68.91	68.75	68.75
Bulls	60.24	58.01	57.62	57.27	57.16	57.38

Source: EPA (2020a).

Table H-12: Typical Animal Mass (TAM) by Cattle Type and Year (kg)

Cattle Type	1990	2007	2010	2015	2016	2017
Dairy Cows	679.77	679.77	679.77	679.77	679.77	679.77
Dairy Replacement Heifers	407.72	406.35	406.87	406.38	407.23	406.51
Other Dairy Heifers	407.72	406.35	406.87	406.38	407.23	406.51
Dairy Calves	122.10	122.54	122.48	122.54	122.50	122.53
Beef Cows	553.34	610.89	610.89	610.89	610.89	610.89
Beef Replacement Heifers	371.54	405.73	406.33	403.81	404.53	405.54
Heifer Stockers	295.34	320.27	323.45	323.85	325.55	321.82
Heifer Feedlot	383.38	420.76	424.92	445.35	449.37	443.57
Steer Stockers	313.61	326.80	329.27	325.35	327.32	324.34
Steer Feedlot	418.46	449.66	451.89	470.22	474.89	470.55
Beef Calves	122.10	122.54	122.48	122.54	122.50	122.53
Bulls	830.00	916.34	916.34	916.34	916.34	916.34

Source: EPA (2020a).

Table H-13: Volatile Solids (VS) by Animal Type and Year (kg VS/1000 kg animal mass/day)

Cattle Type	1990	2007	2010	2015	2016	2017
Dairy Cows	7.99	8.21	8.44	9.22	8.81	9.52
Dairy Replacement Heifers	7.86	8.48	8.44	8.44	8.43	8.44
Other Dairy Heifers	7.86	8.48	8.44	8.44	8.43	8.44
Dairy Calves	6.41	7.59	7.70	7.70	7.70	7.70
Beef Cows	8.80	8.48	8.48	8.48	8.48	8.48
Beef Replacement Heifers	7.96	8.52	8.44	8.51	8.50	8.54
Heifer Stockers	10.01	10.79	10.60	10.61	10.56	10.76
Heifer Feedlot	5.72	4.37	4.36	4.25	4.25	4.27
Steer Stockers	9.20	9.35	9.28	9.40	9.37	9.46
Steer Feedlot	5.18	3.99	4.00	3.89	3.89	3.90
Beef Calves	6.41	7.59	7.70	7.70	7.70	7.70
Bulls	5.99	5.85	5.85	5.85	5.85	5.85
Sheep	9.20	8.40	8.30	8.30	8.30	8.30
Goats	9.50	9.50	9.50	9.50	9.50	9.50
Horses	10.00	6.50	6.10	6.10	6.10	6.10
Chickens	10.80	11.00	11.00	11.00	11.00	11.00
Broilers	15.00	16.80	17.00	17.00	17.00	17.00
Swine - Breeding	2.60	2.70	2.70	2.70	2.70	2.70
Swine < 50 lbs.	8.80	8.80	8.80	8.80	8.80	8.80
Swine 50 - 119 lbs.	5.40	5.40	5.40	5.40	5.40	5.40
Swine 120 - 179 lbs.	5.40	5.40	5.40	5.40	5.40	5.40
Swine > 180 lbs.	5.40	5.40	5.40	5.40	5.40	5.40

Source: EPA (2020a).

Table H-14: Nitrogen Excreted (Nex) Produced by Animal Type and Year (kg Nex per head per year)

Cattle Type	1990	2007	2010	2015	2016	2017
Dairy Cows	146.32	127.82	126.51	134.83	130.44	138.05
Dairy Replacement Heifers	79.10	71.27	68.93	68.85	68.99	68.87
Other Dairy Heifers	79.10	71.27	68.93	68.85	68.99	68.87
Dairy Calves	13.37	19.57	20.12	20.13	20.12	20.13
Beef Cows	52.71	59.14	59.14	59.14	59.14	59.14
Beef Replacement Heifers	33.60	41.18	40.75	40.80	40.85	41.27
Heifer Stockers	33.60	41.18	40.75	40.80	40.85	41.27
Heifer Feedlot	57.36	53.07	54.64	55.81	56.53	55.72
Steer Stockers	30.78	33.44	33.55	33.41	33.58	33.46
Steer Feedlot	59.86	54.57	56.13	56.81	57.64	56.97
Beef Calves	13.37	19.57	20.12	20.13	20.12	20.13
Bulls	61.14	68.53	68.53	68.53	68.24	68.24

Sheep	0.42	0.45	0.45	0.45	0.45	0.45
Goats	0.45	0.45	0.45	0.45	0.45	0.45
Horses	0.30	0.25	0.25	0.25	0.25	0.25
Chickens	0.83	1.08	1.10	1.10	1.10	1.10
Broilers	1.10	0.97	0.96	0.96	0.96	0.96
Swine_Breeding	0.24	0.21	0.20	0.20	0.20	0.20
Swine < 50 lbs	0.60	0.89	0.92	0.92	0.92	0.92
Swine 50 - 119 lbs	0.42	0.53	0.54	0.54	0.54	0.54
Swine 120 - 179 lbs	0.42	0.53	0.54	0.54	0.54	0.54
Swine > 180 lbs	0.42	0.53	0.54	0.54	0.54	0.54

Source: EPA (2020a).

Table H-15: Weighted Methane Conversion Factor (MCF) by Animal Type and Year

Animal Type	1990	2007	2010	2015	2016	2017
Dairy Cows	62%	53%	51%	50%	49%	50%
Dairy Replacement Heifers	2%	2%	2%	2%	2%	2%
Other Dairy Heifers	2%	2%	2%	2%	2%	2%
Dairy Calves	2%	2%	2%	2%	2%	2%
Beef Cows	2%	2%	2%	2%	2%	2%
Beef Replacement Heifers	2%	2%	2%	2%	2%	2%
Heifer Stockers	2%	2%	2%	2%	2%	2%
Heifer Feedlot	2%	2%	2%	2%	2%	2%
Steer Stockers	2%	2%	2%	2%	2%	2%
Steer Feedlot	2%	2%	2%	2%	2%	2%
Beef Calves	2%	2%	2%	2%	2%	2%
Bulls	2%	2%	2%	2%	2%	2%
Sheep	2%	2%	2%	2%	2%	2%
Goats	2%	2%	2%	2%	2%	2%
Swine	35%	45%	42%	39%	38%	38%
Horses	2%	2%	2%	2%	2%	2%
Chickens & Broilers	60%	20%	20%	21%	20%	20%

Sources: EPA (2020a).

Table H-16: Non-Cattle Emission Factors for Enteric CH_4 and Typical Animal Mass by Animal Types

Animal Type	Enteric CH_4 (kg CH_4 per head per year)	Typical Animal Mass (kg)
Sheep	8.00	68.60
Goats	5.00	64.00
Swine	1.50	60.59
Swine_Breeding	1.50	198.00

Swine < 50 lbs	1.50	15.88
Swine 50-119 lbs	1.50	40.60
Swine 120-179 lbs	1.50	67.82
Swine > 180 lbs	1.50	90.75
Horse	18.00	450.00
Chickens	NA	1.80
Broilers	NA	0.90

Sources: EPA (2020a).

NA (Not Applicable).

Table H-17: 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
Dairy Calves	0.17
Beef Cows	0.17
Beef Replacement Heifers	0.33
Heifer Stockers	0.17
Heifer Feedlot	0.33
Steer Stockers	0.17
Steer Feedlot	0.33
Beef Calves	0.17
Bulls	0.17
Sheep	0.34
Goats	0.17
Swine	0.48
Horses	0.33
Chickens	0.39
Broilers	0.36

Source: EPA (2020a)

Table H-18: Fraction Volatile Solids Distribution by Animal Type, Waste Management System (WMS), and Year

Animal Type	WMS	1990	2007	2010	2015	2016	2017
Dairy Cows	Pasture	0%	7%	6%	4%	4%	4%
Dairy Cows	Anaerobic Lagoon	68%	55%	55%	54%	54%	54%
Dairy Cows	Liquid/Slurry	21%	11%	8%	3%	2%	2%
Dairy Cows	Solid Storage	11%	20%	22%	26%	27%	27%
Dairy Cows	Deep Pit	0%	6%	7%	9%	9%	9%
Dairy Replacement Heifers	Liquid/Slurry	1%	1%	1%	1%	1%	1%

Animal Type	WMS	1990	2007	2010	2015	2016	2017
Dairy Replacement Heifers	Dry Lot	100%	100%	100%	100%	100%	100%
Other Dairy Heifers	Liquid/Slurry	1%	1%	1%	1%	1%	1%
Other Dairy Heifers	Dry Lot	100%	100%	100%	100%	100%	100%
Dairy Calves	Pasture	100%	100%	100%	100%	100%	100%
Beef Cows	Pasture	100%	100%	100%	100%	100%	100%
Beef Replacement Heifers	Pasture	100%	100%	100%	100%	100%	100%
Heifer Feedlot	Liquid/Slurry	1%	1%	1%	1%	1%	1%
Heifer Feedlot	Dry Lot	100%	100%	100%	100%	100%	100%
Heifer Stockers	Pasture	100%	100%	100%	100%	100%	100%
Steer Feedlot	Liquid/Slurry	1%	1%	1%	1%	1%	1%
Steer Feedlot	Dry Lot	100%	100%	100%	100%	100%	100%
Steer Stockers	Pasture	100%	100%	100%	100%	100%	100%
Beef Calves	Pasture	100%	100%	100%	100%	100%	100%
Bull	Pasture	100%	100%	100%	100%	100%	100%
Sheep	Pasture	55%	69%	69%	69%	69%	69%
Sheep	Dry Lot	45%	31%	31%	31%	31%	31%
Goats	Pasture	92%	92%	92%	92%	92%	92%
Goats	Dry Lot	8%	8%	8%	8%	8%	8%
Swine	Pasture	36%	30%	34%	41%	41%	42%
Swine	Anaerobic Lagoon	13%	21%	21%	18%	18%	18%
Swine	Liquid/Slurry	18%	24%	24%	22%	22%	22%
Swine	Deep Pit	30%	16%	13%	11%	11%	11%
Swine	Solid Storage	3%	0%	0%	0%	0%	0%
Horses	Pasture	92%	92%	92%	92%	92%	92%
Horses	Dry Lot	8%	8%	8%	8%	8%	8%
Chickens	Anaerobic Lagoon	80%	25%	25%	25%	25%	25%
Chickens	Poultry without bedding	10%	75%	75%	75%	75%	75%
Chickens	Solid Storage	10%	0%	0%	0%	0%	0%

Source: EPA (2020a).

Table H-19: Urea Emission Factor

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

Source: IPCC (2006).

Table H-20: 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-21: 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 $AG_{DM(T)}$ (MT/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 ($R_{BG\text{-}BIO}$)	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-22: 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-23: 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 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-24: 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-25: Fire Emission Factors, Forest and Shrubland (MT Carbon/ha)

Emission Factor	Value
Dry Forest	1.44
Mesic Forest	34.97
Wet Forest	15.05
Dry Shrubland	2.12
Mesic Shrubland	10.29

Source: Selmants et al. (2017).

Table H-26: Ratio of Hawaii Forest Land to Wildland (Dimensionless)

Factor	1990	2007	2010	2015	2016	2017
Ratio of Hawaii forestland to wildland	0.37	0.36	0.36	0.36	0.36	0.37

Source: NASF (1998, 2002); DLNR (2011, 2016, 2017).

Table H-27: 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-28: Carbon Storage Factors for Landfilled Yard Trimmings and Food Scraps

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

Source: EPA (2020c).

NA (Not Applicable).

Table H-29: 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)	-464.0

Source: EPA (2020a).

Table H-30: Forest Carbon Net Sequestration Factors

Year	Annual Net Forest C Sequestration Rate (MT C/ha/year)	Annual Net Shrubland C Sequestration Rate (MT C/ha/year)
2011	1.29	0.71
2012	1.36	0.70
2013	1.36	0.69
2014	1.37	0.67
2015	1.40	0.64
2016	1.38	0.61
2017	1.36	0.60
2018	1.39	0.57
2019	1.40	0.54
2020	1.37	0.52
2021	1.37	0.50
2022	1.38	0.49
2023	1.37	0.46
2024	1.39	0.44
2025	1.34	0.42

Source: Selmants (2020).

Waste

Table H-31: 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/MT of refuse)	100
Methane Oxidation Rate (%)	10%

Source: EPA (2020a).

Table H-32: 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-33: 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
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 (2020c).

Appendix I. 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 I-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 2020a). National population numbers were obtained from the U.S. Census Bureau (2019) while Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2019). Table I-2 summarizes ODS emissions in Hawaii by gas for 1990, 2007, 2010, 2015, 2016, and 2017.[85]

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

Gas	1990	2007	2010	2015	2016	2017
CFC-11	0.15	0.05	0.11	0.12	0.12	0.12
CFC-12	0.68	0.06	0.03	0.02	0.02	0.01
CFC-113	0.30	0.06	0.03	+	+	+

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[85] 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 that are discussed in Section 4.3 are also applicable to the estimates of ODS emissions in Hawaii presented in this appendix.

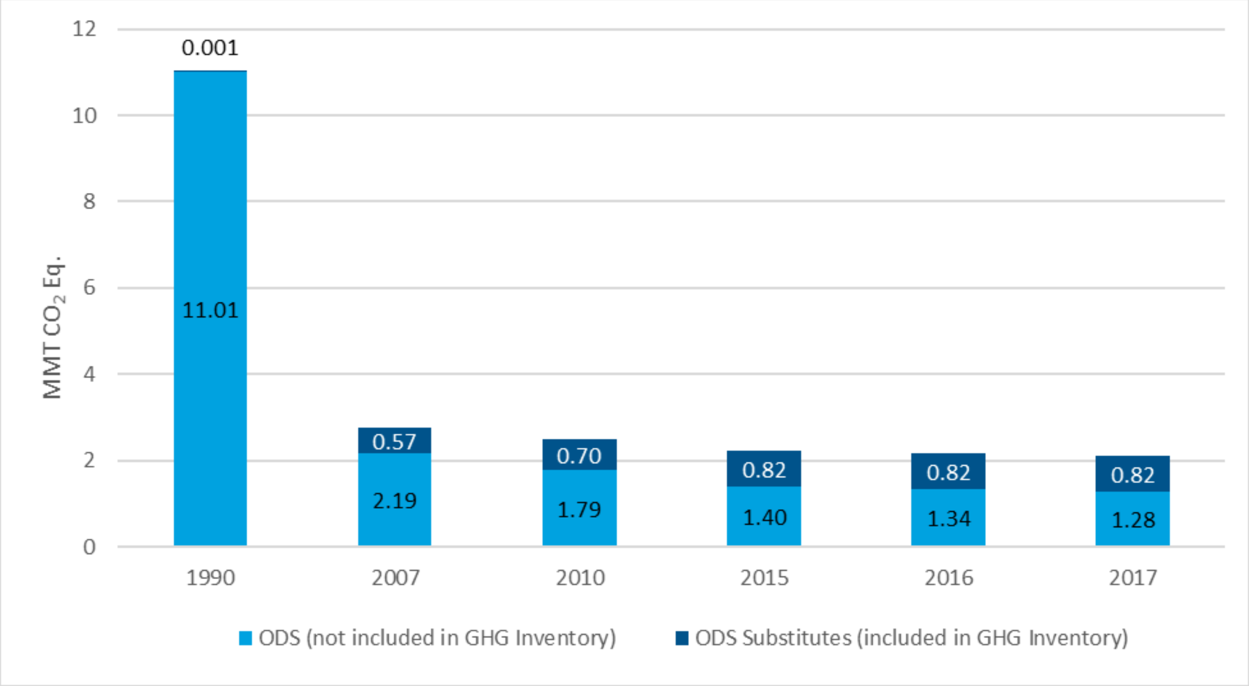
Gas	1990	2007	2010	2015	2016	2017
CFC-114	0.02	+	+	+	+	+
CFC-115	0.04	0.01	+	+	+	+
Carbon Tetrachloride	0.02	NO	NO	NO	NO	NO
Methyl Chloroform	1.12	NO	NO	NO	NO	NO
Halon 1211	0.01	0.01	0.01	0.01	0.01	0.01
Halon 1301	0.01	+	+	+	+	+
HCFC-22	0.15	0.36	0.34	0.28	0.26	0.25
HCFC-123	NO	+	+	+	+	+
HCFC-124	NO	0.01	+	+	+	+
HCFC-141b	0.01	0.03	0.04	0.05	0.04	0.04
HCFC-142b	0.01	0.02	0.01	0.01	0.01	0.02
HCFC-225ca/cb	+	0.02	0.03	0.06	0.07	0.07
Total	**2.51**	**0.64**	**0.62**	**0.55**	**0.54**	**0.52**

+ Does not exceed 0.005 kt; NO (emissions are <u>N</u>ot <u>O</u>ccurring).

Source: EPA (2020a).

Emissions from ODS in Hawaii have decreased significantly since 1990, following the implementation of the *Montreal Protocol*. Figure I-1 below presents combined emissions from ODS and ODS substitutes in Hawaii. Combined emissions have similarly decreased between 1990 and 2017, even though emissions from ODS substitutes increased during the same period.

Figure I-1: Emissions from ODS and ODS Substitutes



Appendix J. Emission Projections Methodology

This section summarizes the methodology used to project statewide emissions for 2020, 2025, and 2030 by source and sink category under both the baseline and alternate scenarios, as applicable. In addition, this section summarizes the methodology used to quantify Hawaii's GHG emission projections by county. A discussion of key uncertainties and areas for improvement associated with the statewide emission projections is also provided.

Energy

Stationary Combustion

Baseline Scenario Methodology

Emissions from stationary combustion were projected based on the constructed macroeconomic forecast as well as utility-specific emission projections. For the residential, commercial, and industrial sectors, statewide emissions are assumed to grow at the rate of forecasted gross state product. Emissions from the residential, commercial, and industrial sectors were then adjusted to account for the use of RNG produced from the biogas project at Honouliuli Wastewater Treatment Plant.[86] For the energy industries sector, emissions were projected for the petroleum refinery[87] and each of the two electric utilities in Hawaii: Hawaiian Electric, which serves Oahu, Hawaii Island, and Maui County; and the Kauai Island Utility Cooperative (KIUC), which serves the island of Kauai. An adjustment factor was then applied to the energy industries estimates to account for differences in how EIA SEDS, which was used as the primary source of fuel consumption data to prepare the 2017 statewide inventory, allocates its data by end-use sector relative to the facility-specific data. This adjustment avoids double-counting with commercial and industrial sector emissions.

For the petroleum refinery, emissions were projected out from 2017 based on the projected growth in aviation emissions, as jet fuel currently represents a majority of the fuel output from the refinery (see the transportation section below for details on the method used to project aviation emissions). For KIUC, emission projections for 2020 and 2025 are based on the utility's GHG estimates (KIUC 2019). The 2020 electricity demand for KIUC was adjusted by a factor of 0.9 to account for the expected near-term

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[86] The City and County of Honolulu in 2018 implemented a biogas project at the Honouliuli Wastewater Treatment Plant. Each year the project is projected to produce 800,000 therms (80 Bbtu) of RNG, which will offset the use of SNG (County & City of Honolulu 2018b). Carbon dioxide emissions from RNG are considered biogenic and therefore are not included in the inventory totals. For this analysis it is assumed that the project continues through 2030 and GHG reductions are allocated to Residential, Commercial and Industrial sectors based on their relative share of SNG consumption in 2017. In total, 0.0042 MMT CO_2 Eq. are offset annually.

[87] In 2018, Par Hawaii Inc. acquired Island Energy Services, LLC., which had recently ceased its refinery operations and converted to an import terminal (Mai 2018).

decline in sales due to COVID-19 (Rockwell 2020). Emission projections for 2030 were estimated by growing KIUC‘s 2025 emissions by DBEDT‘s county population forecast (DBEDT 2018).

For the service area under Hawaiian Electric, emissions projections for 2020, 2025, and 2030 were developed based on the utility’s preliminary Integrated Grid Plan (IGP) and Power Supply Improvement Plan (PSIP) (PUC 2016; Hawaiian Electric 2020a). The PSIP provides utility generation scenarios out to 2045. For the purposes of this analysis, projections were based on the PSIP “preferred plan” to achieve 100 percent of generation from renewable sources by 2045 (i.e., the E3 Plan with Grid Modernization), with modifications to assumptions regarding distributed solar PV and the overall electricity demand forecast based on the more recent IGP (Hawaiian Electric 2020a). In addition, the renewable energy capacity estimates in the PSIP were adjusted to account for current renewable energy capacity on the grid (Hawaiian Electric 2020b; HSEO 2020) and updated estimates of additional renewable energy capacity that will be added to the grid by 2025 (Hawaiian Electric 2020b). These updates result in a lower than planned buildout of renewable energy capacity by 2025. Table J-1 summarizes the difference in projected renewable energy capacity by 2020 and 2025 under the original PSIP and the updated plan.

Table J-1: Hawaiian Electric 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	721	1,152	(291)	(360)
Maui County	146	192	117	232	(29)	40
Hawaii County	125	184	107	201	(18)	17
Solar Total	**1,283**	**1,888**	**945**	**1830**	**(338)**	**(344)**
Wind						
Oahu County	133	333	99	123	(34)	(163)
Maui County	134	134	72	72	(62)	(62)
Hawaii County	57	107	34	34	(22)	(73)
Wind Total	**324**	**574**	**229**	**276**	**(118)**	**(344)**
Hydro						
Oahu County	-	-	-	-	-	-
Maui County	1	1	1	1	-	-
Hawaii County	18	18	16	16	(2)	(2)
Hydro Total	**19**	**19**	**17**	**17**	**(2)**	**(2)**

Sources: PUC (2016), Hawaiian Electric (2020b), HSEO (2020)

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 PSIP (PUC 2016). This output was converted to emissions using the following equation:

$$E\_Initial_t = \big(D(solar)_{t,c} \times CF(solar)_{t,c} + D(wind)_{t,c} \times CF(wind)_{t,c} + D(hydro)_{t,c} \times CF(hydro)_{t,c}\big) \times HR_t \times EF_g \times GWP_g$$

where,

$E\_Initial_t$ = Initial estimate of 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/Kilowatt hours (kWh))
EF_g = GHG emissions factor for gas *g* (g per btu)
GWP_g = GWP of gas *g*

An adjustment factor was additionally applied to the GHG emissions estimate for each county to reflect the more recent demand forecast presented in the IGP (Hawaiian Electric 2020a). The adjustment was made using the following equation:

$$E\_Adjusted_{t,c} = \frac{(GWh\_IGP_{t,c} + \Delta EV_{t,c})}{GWh\_PSIP_{t,c}} \times E\_Initial_{t,c}$$

where,

$E\_Adjusted_{t,c}$ = Electricity GHG emissions (MMT CO_2 Eq.) after adjusting for updated demand forecast, for year *t* and county *c*
$GWh\_IGP_{t,c}$ = IGP electricity demand forecast (GWh) for year t and county c
$\Delta EV_{t,c}$ = Difference in Heavy Duty Vehicles (HDV) EV electricity demand (difference between IGP EV demand and transportation forecast) (GWh) for year t and county c
$GWh\_PSIP_{t,c}$ = PSIP electricity demand forecast (GWh) for year t and county c

The Hawaiian Electric demand forecast from the IGP was further adjusted to account for the difference in EV demand, from what is embedded in the IGP and what was estimated for the purposes of this analysis (see the transportation sector below).[88] The IGP demand forecast was released during the COVID-19 period (August 2020) and accounts for changing demand patterns. Overall, the Hawaiian Electric utility expects a one percent increase in net sales from 2017-2030.

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[88] The EV demand forecast estimated in this report is 2 percent higher than that in the IGP in 2030.

A final adjustment was made for emissions on Hawaii Island to incorporate emissions caused by the closure of Puna Geothermal Venture. Based on the PSIP, lost generation is assumed to be replaced by distillate fuel oil in 2020. Puna Geothermal is assumed to be operational by 2021 (Thursday 2020).

Alternate Scenario 1A and 1B

Alternate scenarios 1A and 1B assess statewide impacts to Residential, Commercial, and Industrial energy sector, as well as refinery emissions within energy industries based on *low* and *high* gross state product pathways. Whereas the baseline assumes that Hawaii's gross state product will return to 2019 levels by 2025, the *low* scenario (Alternate Scenario 1A) assumes that Hawaii's gross state product does not return to 2019 levels until 2030 and the *high* scenario (Alternate Scenario 1B) assumes that it is achieved by 2023.

Alternate Scenario 2

Although the baseline scenario accounts for recent updates to Hawaiian Electric's planned renewable energy infrastructure and updates to the electricity demand forecast following the preliminary IGP, there is considerable uncertainty associated with the energy technologies that will ultimately be used to meet future electricity demand. The State's RPS requires 30 percent of net sales of electricity be met through renewable sources in 2020, 35 percent in 2025, and 40 percent in 2030 (HRS§269-92).[89] The PSIP (which is used as the basis for the baseline scenario) goes far beyond the RPS target, meeting an estimated 40 percent in 2020, 63 percent in 2025, and 65 percent in 2030, adjusted for net sales. This alternate scenario assesses the GHG implications of only meeting the minimum RPS target in 2025 and 2030. Because projects already under way will allow KIUC to achieve 70 percent renewable energy generation, as assumed in the baseline, emissions for KIUC were not adjusted under this scenario.

Estimating GHG emissions under a scenario in which the minimum RPS target is met requires first estimating the percentage of renewable energy generation presented in the PSIP relative to total electricity generation, excluding behind-the-meter renewable energy, calculated as follows:

$$RPS\_PSIP_t = \frac{GSR_t + DGPV_t}{TotGen_t - DGPV_t}$$

where,

RPS_PSIP_t = Percentage of renewable energy generation presented in the PSIP calculated per RPS law, excluding distributed generation

GSR_t = Grid scale renewable generation in the PSIP in GWh in year t

$DGPV_t$ = Behind the meter distributed generation in the IGP in GWh in year t

$TotGen_t$ = Total electricity generation in the PSIP in GWh in year t

Actual generation from renewables is similarly calculated using the following equation:

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[89] The State's calculation of "net sales" allows for the double-counting of behind-the-meter renewable energy, mainly distributed solar PV.

$$PR_t = \frac{GSR_t + DGPV_t}{TotGen_t}$$

where,

PR_t = Percentage renewable generation in the PSIP in year t
GSR_t = Grid scale renewable generation in the PSIP in GWh in year t
$DGPV_t$ = Behind the meter distributed generation in the IGP in GWh in year t
$TotGen_t$ = Total electricity generation in the PSIP in GWh in year t

The ratio of the actual proportion of renewable energy generation relative to the amount implied by the legal intepretation of renwable energy generation, multiplied by the legal RPS targets per year give the new percentage of renewable energy.

$$RE_t = \frac{PR_t}{\text{RPS\_PSIP}_t} \times \text{RPS\_Legal}_t$$

where,

RE_t = Percentage of renewable energy generation under the RPS constraint
PR_t = Percentage renewable generation in the PSIP in year t
RPS_PSIP_t = Percentage of renewable energy generation presented in the PSIP calculated per RPS law, excluding distributed generation
RPS_Legal_t = Legal RPS target in year t

The legal RPS target for 2020 and 2030 is 30 percent and 40 percent, respectively. Based on this and assuming 35 percent is achieved by 2025, the effective amount of renewable energy generation implied under Scenario 2 is 31 percent in 2025 and 36 percent in 2030. To calculate emissions, the renewable energy generation percentages were multiplied by the total generation (GWh) in the PSIP and subtracted from the total to estimate the amount of fossil fuel generation. Emissions were then calculated by multiplying fossil fuel generation by the PSIP‘s implied emissions per GWh by fuel type.

County-level Projections

For the residential, commercial, and industrial economic sectors, projected statewide emissions were allocated to each county by assuming that the ratio of county-level emissions in 2017 remains constant through 2030. Emissions from Honolulu County were then adjusted to account for the use of RNG produced from the biogas project at Honouliuli Wastewater Treatment Plant. Emissions for energy industries were calculated using the bottom-up methodology described above.

Uncertainties and Areas for Improvement

As highlighted by the alternate scenario described above, there is uncertainty associated with the future build out of renewable energy capacity as well as the impact of the current recession. 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. In addition, it assumes that the last refinery will remain in operation through 2030.

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 their related fuel sources, 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 2017 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

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

Light Duty Vehicles

For LDVs, statewide on-road gasoline consumption was estimated based on the future fleet vehicle fuel efficiency and future LDV VMT by non-electric vehicles. It is assumed that all gasoline in Hawaii is used by LDVs. 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 corporate average fuel economy (CAFE) standards for cars and light trucks (EPA and NHTSA 2020). Current CAFE standards require light duty cars and trucks to have an EPA rated efficiency of 204 g CO_2 Eq./mile and 284 g CO_2 Eq./mile, respectively, by 2026, or 43.7 mpg and 31.3 mpg (EPA and NHTSA 2020). These standards are assumed to gain the same annual rate of improvement through 2030.

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 statewide 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 2019 was obtained from Hawaii Automobile Dealers Association sales records as reported by DBEDT (2020b). There were a total of 57,323 new car and light truck registrations in Hawaii in 2019. Of those, 31 percent were cars.

The average fuel efficiency (in miles per gallon, or mpg) of all new LDVs accounting for adjustment for true on-road efficiency (compared to CAFE) was then calculated using the following equation:

$$FE\_New_t \; = 1 \Big/ \left(\frac{S\_Cars_t}{(1-A) \times CAFE\_Cars_t} + \frac{(1-S\_Cars_t)}{(1-A) \times CAFE\_Trucks_t} \right)$$

where,

FE_New_t = Fleet fuel efficiency for new LDV in year *t* (mpg)
S_Cars_t = Share of sales for cars in year *t* (%)
$CAFE\_Cars_t$ = CAFE standards for cars in year *t* (mpg)
$CAFE\_Trucks_t$ = 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 LDVs on the road in 2017 was calculated by dividing total miles traveled by LDV gasoline consumption, as derived from the ground transportation gasoline consumption estimate used to prepare the 2017 statewide inventory (ICF 2020).

$$FE\_Fleet_{2017} \; = {}^{VMT_{2017}} \big/ {}_{Gasoline_{2017}}$$

where,

FE_Fleet_{2017} = Fleet fuel efficiency for all LDVs in 2017 (mpg)
$Gasoline_{2017}$ = E10 gasoline consumed by LDVs in 2017 (gal)
VMT_{2017} = LDV VMT in 2017 (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 2020a).[90] Taking the average fuel efficiency of vehicles in 2017 and the share of miles driven by new vehicles on the road each year, the statewide fleet fuel efficiency for future years was calculated using the following equation:

$$FE\_Fleet_t \; = 1 \Big/ \left(\frac{1 - VMT\_LDVnew}{FE\_Fleet_{t-1}} + \frac{VMT\_LDVnew}{FE\_New_t} \right)$$

where,

VMT_LDVnew = Share of miles driven by new vehicles on the road annually (%)
FE_Fleet_t = Fleet fuel efficiency for all LDVs in year *t* (mpg)
FE_Fleet_{t-1} = Fleet fuel efficiency for all vehicles in year *t-1* (mpg)
FE_New_t = Fuel efficiency for new vehicles in year *t* (mpg)

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[90] 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.

Future LDV VMT. To estimate future LDV VMT, the team estimated an Ordinary Least Squares regression between historical gross state product (UHERO 2018), population (DBEDT 2020d) and LDV VMT (DBEDT 2020d) from 1997 to 2018.[91] Using the DBEDT (2018) gross state product and population and forecast for state population, LDV VMT was then calculated using the following equation:

$$VMT_t = 100 + 0.104\ \times GSP_t + 0.00191 \times Pop_t$$

where,

VMT_t = LDV VMT in year *t*
100 = Intercept term in the least squares fit
0.104 = Estimated coefficient (slope term) for Gross State Product (GSP) in the least squares fit
GSP_t = Gross state product in year *t*
0.00191 = Estimated coefficient (slope term) for population in the least squares fit
Pop_t = Population in year *t*

Future LDV Electric Vehicle (EV) VMT. Statewide vehicle 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 share of EVs on the road is based on Hawaiian Electric's EV assumptions in the IGP (Hawaiian Electric 2020a).[92] Whereas 1.1 percent of statewide VMT is from EVs in 2020, it was assumed that this share will increase to 3.2 percent by 2025 and 8.6 percent by 2030.

$$VMT\_EV_t = VMT\_AVG_t \ \times Q\_EV_t$$

where,

VMT_EV_t = EV VMT in year *t* (Billions of miles)
VMT_AVG_t = Average VMT per vehicle in year *t* (Billions of miles)
Q_EV_t = Share of VMT from EVs 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. The fuel efficiency of EVs was estimated based on Hawaiian Electric's IGP forecast, matching EV adoption with electricity demand (Hawaiian Electric 2020a). The equation used to estimate LDV gasoline consumption is shown below.

$$GasolineBlend_t = \frac{VMT_t - VMT\_EV_t}{FE\_Fleet_t}$$

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[91] This time frame is chosen because there is a break in the VMT data in 1983.

[92] For Kauai, which is not included in the IGP, it is assumed that Kauai has the same relative rate of EV adoption as Maui County, adjusted for population.

where,

$GasolineBlend_t$ = Total LDV gasoline (E10) consumption in year *t* (Billions of gallons)
VMT_t = LDV VMT in year *t*
VMT_EV_t = EV VMT in year *t* (Billions of miles)
FE_Fleet_t = Fleet fuel efficiency for all LDVs 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 2020a).

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:

$$EF\_Fleet_{t,g} = 1 \Big/ \left(\frac{1 - VMT\_LDVnew}{EF\_Fleet_{t-1,g}} + \frac{VMT\_LDVnew}{EF\_Fleetnew_{t,g}} \right)$$

where,

VMT_{LDVnew} = Share of miles driven by new vehicles on the road annually (%)
$\mathrm{EF\_Fleet}_{t,g}$ = Fleet average emissions factor for all LDVs in year *t* for gas *g* (g/mile)
$\mathrm{EF\_Fleet}_{t-1,g}$ = Fleet average emissions factor for all LDVs in year *t-1* for gas *g* (g/mile)
$\mathrm{EF\_Fleetnew}_{t,g}$ = Average emissions factor for new LDVs in year *t* for gas *g* (g/mile)

Heavy Duty Vehicles

For heavy duty vehicles (HDV),[93] diesel consumption was estimated based on future VMT by diesel powered HDVs and their average fuel efficiency. It is assumed that all transportation diesel in Hawaii is used by HDVs. Heavy duty VMT is assumed to grow at the rate of gross state product.

$$HDV\_VMTtotal_t = HDV\_VMTtotal_{2017} \times GSP_t / GSP_{2017}$$

where,

$HDV\_VMTtotal_t$ = Total HDV VMT in year t (millions of miles)
$HDV\_VMTtotal_{2017}$ = HDV VMT in 2017 (millions of miles)
GSP_t = Projected gross state product in year t
GSP_{2017} = Gross state product in 2017

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[93] 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 heavy duty trucks.

Total HDV VMT is divided into travel by diesel powered and electric powered HDVs. The projected number of HDV EVs on the road is based on Hawaiian Electric‘s EV assumptions in the IGP, which forecasts the number of electric buses on the road for its service territory (Hawaiian Electric 2020).[94] Miles traveled by EV HDVs is the product of the number of electrified HDVs and average distance travelled by HDVs (DBEDT 2020d).[95]

$$HDV\_VMTEV_t = HDV\_VMTaverage_t \times HDV\_Q\_EV_t$$

where,

HDV_VMTEV_t = HDV EV VMT in year *t* (millions of miles)
$HDV\_VMTaverage_t$ = Average VMT per HDV in year *t* (millions of miles)
$HDV\_Q\_EV_t$ = Number of electrified HDVs in year *t*

It is estimated that 2.1 and 3.9 percent of vehicle miles traveled by HDVs are from EVs by 2025 and 2030, respectively. The amount of electricity demand was estimated with a starting HDV vehicle efficiency of 2.2 kWh/mile in 2020 and reaching 1.4 kWh/mile in 2030 (KITV 2018). Subtracting HDV travel by EVs from total HDV travel yields HDV travel by diesel fuel alone. The fuel efficiency of the 2016 diesel HDV fleet was estimated to be 7.4 mpg, based on the average fuel consumption per vehicle of all HDVs over 10,000 pounds (FHWA 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 2016a). Specifically, vehicle efficiency standards for new HDVs increase by about 10 percent from 2010 to 2017. Vehicle efficiency for HDVs using diesel in 2010 was 7.3 mpg; therefore, the vehicle efficiency of new HDVs in 2017 is taken to be 8.0 mpg (EPA 2016a). From 2017 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 HDVs over this period. It is assumed to remain at 8.9 mpg through 2030.

For this analysis, approximately 9 percent of vehicle miles are assumed to be driven by new HDVs each year, which is derived from estimates of HDV VMT by model year as obtained from the U.S. Inventory (EPA 2020a).[96] Using this information, the fleet average fuel efficiency for HDVs consuming diesel was calculated using the following equation:

$$FE\_HDVfleet_t = {}^{1}\Big/\left(\frac{1 - ShrVMT\_HDVnew}{FE\_HDVfleet_{t-1}} + \frac{ShrVMT\_HDVnew}{FE\_HDVnew_t}\right)$$

where,

$FE\_HDVfleet_t$ = Fleet average fuel efficiency (mpg)
$FE\_HDVfleet_{t-1}$ = Fleet average fuel efficiency in year t-1 (mpg)
$ShrVMT\_HDVnew$ = Share of miles driven by new vehicles on the road annually (%)

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[94] Electric buses on Kauai are assumed to equal half the number of buses in operation on Hawaii Island.

[95] Calculated for Oahu, which has the largest bus fleet, as an average between 2010 and 2019.

[96] 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.

FE_HDVnew_t = Average fuel efficiency for new HDVs in year *t* (mpg)

Diesel fuel consumption by HDVs was then calculated using the following equation:

$$Diesel_t = {}^{HDV\_VMTdiesel_t}\!/_{FE\_HDVfleet_t}$$

where,

$Diesel_t$ = Total HDV diesel and biodiesel consumption in year *t* (gallons)
$HDV\_VMTdiesel_t$ = HDV VMT for diesel powered vehicles in year *t* (miles)
$FE\_HDVfleet_t$ = Average fuel efficiency for all diesel powered HDVs in year *t* (mpg)

Assuming biodiesel consumption grows at the same rate as gross state product, fossil fuel diesel consumption was calculated by subtracting projected biodiesel consumption from total diesel consumption. Carbon dioxide emissions from HDVs were then calculated by multiplying fossil fuel diesel consumption by emission factors obtained from the U.S. Inventory (EPA 2020a).

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:

$$EF\_Fleet_{t,g} = {}^{1}\!\Big/\!\left(\frac{1 - ShrVMT\_HDVnew}{EF\_Fleet_{t-1,g}} + \frac{ShrVMT\_HDVnew}{EFnew_{t,g}}\right)$$

where,

$ShrVMT\_HDVnew$ = Share of miles driven by new vehicles on the road annually (%)
$\mathrm{EF\_Fleet}_{t,g}$ = Fleet average emissions factor for all HDVs in year *t* for gas *g* (g/mile)
$\mathrm{EF\_Fleet}_{t-1,g}$ = Fleet average emissions factor for all HDVs in year *t-1* for gas *g* (g/mile)
$\mathrm{EFnew}_{t,g}$ = 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 and assumed to remain constant for 2017 (EPA 2020a). Total VMT for motorcycles was assumed to grow at the rate of gross state product. The average fuel efficiency of motorcycles was assumed to be 44 mpg (FHWA 2017). Motorcycle gasoline consumption was then calculated using the following equation:

$$Mot\_Gasoline_t = Mot\_FE_t \times VMT\_Mot_t$$

where,

$Mot\_Gasoline_t$ = Total motorcycle gasoline consumption in year *t* (gallons)
Mot_FE_t = Fuel efficiency for motorcycles (mpg)
VMT_Mot_t = 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 2020a). Methane and N_2O emissions were calculated by multiplying motorcycle VMT by emissions factors obtained from the U.S. Inventory (EPA 2020a).

Domestic Aviation

The impact of COVID-19 to air travel has been much more acute than the decline in gross state product. In March 2020 there was a rapid and almost entire shutdown of Hawaii‘s tourism industry with a tempered re-opening beginning in October 2020. As such, an adjustment was made to 2020 emissions from aviation, based on the decline in visitor arrivals projected by DBEDT (2020a). DBEDT‘s third quarter forecast for 2020 projects there will be 2.9 million visitor arrivals to Hawaii, in contrast to 10.4 million in 2019. In addition, it was assumed that plane occupancy declines considerably, affecting the emissions efficiency of trips. Resident travel was assumed to decline by 75 percent from March to December 2020. Finally, air shipments of cargo were assumed to drop with the forecasted decline in gross state product from 2019 to 2020. The following equation assembles all these elements to calculate 2020 jet fuel consumption.

$$Jet_{2020} = Sum[type, Share(type) * Jet_{2019} * \Delta\mathrm{Trav}(\mathrm{type}, 2020)]$$

where,

type = Type of travel (visitor, resident, cargo)
Jet_{2020} = Total jet fuel consumption in 2020 (Bbtu)
Jet_{2019} = Total jet fuel consumption in 2019 (Bbtu)
Share(type) = Share of type of each traveler in 2019 (%)
$\Delta\mathrm{TRAV}(type, 2020)$ = Percentage change in travel by type from 2019 to 2020 (%)

By 2025, air travel is assumed to return to 2019 levels. Thus, jet fuel consumption in 2025 is assumed to equal jet fuel consumption in 2019 divided by the improvement in efficiency of air travel. Based on the International Civil Aviation Organization (ICAO 2016), it is assumed that there is a 0.5 percent energy efficiency gain annually.

$$Jet_{2025} = Jet_{2019} * (1 - \mathrm{E})\text{^}(2025 - 2019)$$

where,

Jet_{2025} = Total jet fuel consumption in 2025 (Bbtu)
E = Energy efficiency improvement in air travel

After 2025, air travel is assumed to grow at the rate of gross state product, also accounting for the annual efficiency improvement.

$$Jet_t = Jet_{2025} * \frac{GSP_t}{GSP_{2025}} * (1 - E)^{t-2025}$$

where,

t = year
Jet_t = Total jet fuel consumption in year t (Bbtu)
GSP_t = Gross state product in year t
GSP_{2025} = Gross state product in 2025
E = Energy efficiency improvement in air travel

Emissions from domestic aviation were then calculated by multiplying jet fuel consumption by emissions factors obtained from the U.S. Inventory (EPA 2020a).

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 2017. 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 gross state product, 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

Alternate scenarios 1A and 1B assess statewide impacts to the transportation sector based on *low* and *high* gross state product pathways. Whereas the baseline assumes that Hawaii‘s gross state product will return to 2019 levels by 2025, the *low* scenario (Alternate Scenario 1A) assumes that Hawaii‘s gross state product does not return to 2019 levels until 2030 and the *high* scenario (Alternate Scenario 1B) assumes that it is achieved by 2023. As described above, gross state product is used to project forward LDV, HDV, and motorcycle VMT that are used to calculate ground transportation emissions, and jet fuel consumed by domestic aviation.

Alternate Scenario 3A and 3B

In addition to the economic uncertainties caused by the COVID-19 pandemic, including major changes to travel behavior, there are a number of notable additional uncertainties associated with projecting emissions from the ground transportation end-use sector. To quantify these uncertainties, alternate scenario 3A and 3B account for potential variations in (1) the adoption of EVs; (2) the implementation of the U.S. Renewable Fuel Standard;[97] 3) the share of cars versus light trucks on the road; and (4) future

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[97] The U.S. Renewable Fuel Standard requires an increasing amount of biofuel to be blended with refined petroleum products in ground level transportation fuels (i.e., diesel and gasoline). The EPA has consistently granted compliance waivers so the baseline scenario assumes this policy will not be met. To comply, fuel producers will likely need to move more of their gasoline pool to E15 and diesel pool to B20.

VMT.[98] Specifically, to estimate a *low* GHG emissions (alternate scenario 3A) and a *high* GHG emissions (alternate scenario 3B) scenario, the following modifications to the baseline assumptions for statewide estimates were made:

Low GHG Emissions Scenario Assumptions (Alternate Scenario 3A)

- The share of miles traveled by EVs is 50 percent higher than the baseline for 2025 and 2030, reaching 13 percent by 2030.
- Diesel contains 20 percent biodiesel (B20) by 2025 and remains constant through 2030.
- Gasoline contains 15 percent ethanol (E15) by 2025 and remains constant through 2030.
- The share of new LDVs that are cars increases to 50 percent by 2025 and remains constant through 2030.
- VMT for LDVs and HDVs follow the *low* gross state product pathway (Alternate Scenario 1A).
- The share of VMT by new gasoline-powered LDVs is assumed to 10 percent by 2025 and remains constant through 2030.

High GHG Emissions Scenario Assumptions (Alternate Scenario 3B)

- The share of miles traveled by EVs in Hawaii grows at a much slower rate, given by the rate of the EIA's Annual Energy Outlook (AEO) 2020 forecast for national EV adoption (EIA 2020c), reaching 2.3 percent by 2030.
- Adoption of HDV EVs are 50 percent less than the baseline.
- There are no improvements in CAFE standards after 2026.
- The share of new car sales continues to decline linearly, reaching 25 percent by 2025 and remains at this level in 2030.
- VMT follows the *high* gross state product pathway (Alternate Scenario 1B).
- The share of VMT by new gasoline-powered LDVs is assumed to 6 percent by 2025 and remains constant through 2030.

County-level Projections

Projected statewide ground transportation and domestic aviation emissions were allocated to each county based on the ratio of county-level emissions in 2017, adjusted to account for the projected shift in the breakout of population by county (DBEDT 2018). Projected statewide emissions from domestic marine, military aviation, and military non-aviation transportation were allocated solely to Honolulu County, consistent with the 2017 inventory.

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[98] While this scenario 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; 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.

Uncertainties and Areas for Improvement

As highlighted by the alternate scenarios described above, there is uncertainty associated with economic conditions, the influence on 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 is currently addressing the possibility of being unable to complete the project as planned to Ala Moana Center (Star Advertiser 2020). This study does not account for the potential substitution of trips from vehicles to transit due to this project.

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 2017, which do not align with the activities of the overall economy. For the military, the data similarly show large year-to-year variability. Decisions regarding future military operations in Hawaii are largely external to Hawaii's economy and are not expected to correlate with gross state product. 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 average ratio of non-biogenic emissions to total emissions (37:100) from the 2010, 2015, 2016, and 2017 inventory results.

County-level Projections

Projected statewide emissions from incineration of waste were allocated to Honolulu County because HPOWER, the only operational waste-to-power plant in Hawaii, is located on the island of Oahu.

Uncertainties and Areas for Improvement

There are no notable uncertainties or areas for improvement.

Oil and Natural Gas Systems

Methodology

Fugitive emissions from the Par Hawaii petroleum refinery were projected forward from 2017 based on projected growth in aviation emissions (see the transportation section above for details on the method used to project aviation emissions).[99] Fugitive emissions from gas distribution and transmission pipelines were assumed to remain constant relative to 2017 emissions.

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[99] In 2018, Par Hawaii Inc. acquired Island Energy Services, LLC., which had recently ceased its refinery operations and converted to an import terminal (Mai 2018).

County-level Projections

Projected statewide emissions from oil and natural gas systems were allocated to Honolulu County because Par Hawaii, the only operational refinery in Hawaii, is located on the island of Oahu.

Uncertainties and Areas for Improvement

During the COVID-19 pandemic Par Hawaii invoked a contract clause leading to a renegotiation of rates with Hawaiian Electric due to shutting down part of its operations (Segal 2020). How the refinery continues to respond during the recession is an area of uncertainty. The methodology used to project emissions from oil and natural gas systems is based on the assumption that at least one oil refinery will remain in operation through 2030. Emissions from transmission pipelines are another area of uncertainty and will change based on the overall amount of gas and petroleum, as well as the changing ratio of refined versus imported products.

Non-Energy Uses

Methodology

Emissions from non-energy uses are assumed to grow at the rate of gross state product.

County-level Projections

Projected statewide emissions from non-energy uses were allocated to each county by assuming that the ratio of county-level emissions in 2017 remains constant through 2030.

Uncertainties and Areas for Improvement

The methodology used to project emissions from **n**on-**e**nergy **u**ses is based on the observation that emissions from this sector correlate with economic activity. This analysis does not account for policies or programs that could impact fuel consumption for **n**on-**e**nergy **u**ses.

IPPU

Cement Production

Methodology

Consistent with the 2017 inventory, emissions from cement production in Hawaii are projected to be zero through 2030.

Uncertainties and Areas for Improvement

There are no notable uncertainties or areas for improvement.

Electrical Transmission and Distribution

Methodology

Electrical transmission and distribution emissions were projected forward from 2017 based on the electricity sales forecast for 2017-2030 for each county, as described under the Stationary Combustion methodology section above. Due to rounding and the relatively small magnitude of emissions, the emission projections presented in Table 7-4 show that emissions from this source remain constant across the time series even though they are projected to decrease slightly.

County-level Projections

Projected county-level emissions from electrical transmission and distribution were calculated using the methodology described above.

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

Statewide emissions from the substitution of ozone depleting substances are assumed to grow at the rate of gross state product, and then were adjusted to account for the anticipated adoption of Hawaii House Bill 2492. Specifically, it is assumed that the adoption of Hawaii House Bill 2492 will reduce emissions from the substitution of ozone depleting substances by 12 percent in 2025 and 18 percent in 2030 relative to a business-as-usual scenario, based on an analysis conducted in support of the Significant New Alternatives Policy (SNAP) program (EPA 2016b).

County-level Projections

Projected statewide emissions from the substitution of ozone depleting substances were allocated to each county based on the projected ratio of county population to state population (DBEDT 2018).

Uncertainties and Areas for Improvement

While this analysis accounts for the anticipated impact of Hawaii House Bill 2492 on emissions from the substitution of ozone depleting substances (e.g., HFCs), due to the quantifiable impact of this state-specific policy, it does not consider the adoption of other international and federal programs and policies (e.g., the American Innovation and Manufacturing (AIM) Act of 2020, Kigali Amendment to the

Montreal Protocol) that aim to reduce emissions from the substitution of ozone depleting substances.[100] More research is needed to understand how national and international policies will affect HFC emissions at the state-level, particularly given the lag in retirement of appliances and other goods that use HFCs.

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 2017 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 2020) and the USDA Census of Agriculture (USDA 2009, 2014, and 2019). Annually variable enteric fermentation emission factors were projected using the ten-year average by cattle type from the U.S. Inventory (EPA 2020a). Emission factors for sheep, goats, horses, and swine, which come from IPCC (2006), are assumed to remain constant.

County-level Projections

County-level animal population data were estimated by disaggregating statewide animal population projections based on the breakout of the most recently available county-level population data from USDA for each animal type (USDA 2019, 2020). Projected county-level emissions from enteric fermentation were then calculated based on the county-level population data using the methodology described above.

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.

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[100] The AIM Act, which was passed by Congress in December 2020, requires the United States to phaseout the production and consumption of HFCs by 85 percent by 2035. This law along with the Kigali Amendment, which has not yet been adopted by Congress, were not considered in this analysis due to the timing of when the analysis was completed and the uncertainty associated with the adoption of national policies that target HFCs at that time.

Manure Management

Methodology

Emissions from manure management were projected by projecting activity data and emission factors, and applying the same methodology used to estimate 2017 emissions. Animal population data were projected based on the trend of the last ten years of data, as obtained from the USDA NASS (USDA 2020) and the USDA Census of Agriculture (USDA 2009, 2014, 2019). 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, typical animal mass (TAM) and maximum potential emissions are assumed to remain constant relative to 2017 values (EPA 2020a). Volatile solids (VS) excretion rates, nitrogen excretion (Nex) rates, weighted methane conversion factors (MCF), and the percent distribution of waste to animal waste management systems for non-cattle types were projected using the ten-year average by factor from the U.S. Inventory (EPA 2020a). 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 2020a), were projected using the ten-year average by factor.

County-level Projections

County-level animal population data were estimated by disaggregating statewide animal population projections based on the breakout of the most recently available county-level population data from USDA for each animal type (USDA 2019, 2020). Projected county-level emissions from manure management were then calculated based on the county-level population data using the methodology described above.

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 2017 emissions. Animal population data for cattle, swine, sheep, goats, and horses were projected based on the trend of the last ten years of data, as obtained from the USDA NASS (USDA 2020) and the USDA Census of Agriculture (USDA 2009, 2014, and 2019). 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, 2014, 2019). For pineapple production, which has been historically decreasing over time, an annualized percent change method was applied instead to maintain projections greater than zero. Seed crop production data were projected based on the average of the last five years of data, as obtained from the USDA NASS (USDA 2004b, 2015, 2016, 2018e).

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 2020a). Synthetic fertilizer consumption was projected based on the five-year historical trend (AAPFCO 2011, 2013, 2014, 2017) while commercial organic fertilizer consumption is assumed to remain at zero. Crop residue factors from IPCC (2006) are also assumed to remain constant.

County-level Projections

County-level animal population and crop data were estimated by disaggregating statewide animal population projections based on the breakout of the most recently available county-level population data from USDA for each animal and crop type (USDA 2019, 2020). Projected county-level emissions from agricultural soil management were then calculated using the methodology described above.

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, fertilizer consumption, and seed production 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 2017 based on data available through 2014. Further research into the accuracy and drivers of historical trends may be considered 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 2017 emissions. Fertilizer consumption data were projected based on the five-year historical trend (AAPFCO 2011, 2013, 2014, 2017).

County-level Projections

County-level urea fertilizer application data were estimated by disaggregating statewide urea fertilizer application data based on the percent of cropland area by county in 2015, as obtained from the Hawaii DOA (2016). Projected county-level emissions from urea application were then calculated using the methodology described above.

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 grassland and cropland area from 2011 to 2061 were annualized and applied to the 2017 emission estimates for grassland and cropland, respectively, to obtain 2020, 2025, and 2030 estimates.

County-level Projections

Projected statewide emissions from agricultural soil carbon were allocated to each county based on the percent area of cropland and percent area of grassland by county, as obtained from the Hawaii DOA (2016) for year 2015.

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 2017 emissions. Wildfire acres burned were projected based on the projected average area of land burned annually from 2012 to 2061, as obtained from USGS (Selmants et al. 2017). Forest and shrubland areas were projected based on projected changes in forest and shrubland area from 2011 to 2061 by the USGS (Selmants et al. 2017). Specifically, the percent change in forest and shrubland area from 2011 to 2061 was annualized and applied to the 2017 estimates of forest and shrubland area from the State of Hawaii Data Book to obtain 2020, 2025, and 2030 estimates (DBEDT 2020d).

The annual percent of area burned for each vegetation class were based on estimates from 1999 through 2019, which were obtained from USGS (Selmants 2020). The averages across the timeseries were used to project the percent of area burned for each vegetation class through 2030. Emission factors CO_2 for each vegetation class were based on estimates from USGS and were assumed to remain constant (Selmants et al. 2017). Emission factors for CH_4 and N_2O as obtained from IPCC (2006) were also assumed to remain constant.

County-level Projections

Projected statewide emissions from forest fires were allotted 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 in 2017 as obtained from DBEDT (2020b) and projected forward using forest and shrubland area growth factors from USGS (Selmants et al. 2017).

Uncertainties and Areas for Improvement

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

Landfilled Yard Trimmings and Food Scraps

Methodology

Estimates of carbon sequestration in landfilled yard trimmings and food scraps were projected by projecting activity data, emission factors, and other inputs, and applying the same methodology used to estimate 2017 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 2020c). 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 2020d) and annual growth rates in national population from the U.S. Census Bureau (2017).

The estimated carbon conversion factors and decomposition rates obtained from the State Inventory Tool (EPA 2020c) were assumed to remain constant over the projected time series.

County-level Projections

Projected statewide carbon sequestration in landfilled yard trimmings and food scraps were allocated to each county based on the projected ratio of county population to state population (DBEDT 2020z).

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 2017 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 2017 estimate of urban area to project 2020, 2025, and 2030 estimates. The estimated carbon sequestration rates for urban trees and the percent tree cover in urban areas in Hawaii were assumed to remain constant with 2017 estimates (Nowak et al. 2012; Nowak 2018a and 2018b; EPA 2020a).

County-level Projections

County-level tree canopy areas were estimated by disaggregating statewide tree canopy area projections based on the average breakout of tree canopy area by county for 2000 and 2010. Projected county-level carbon sinks from urban trees were then calculated using the methodology above.

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 2017 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 2017 estimates of forest and shrubland area by county from the State of Hawaii Data Book to obtain 2020, 2025, and 2030 estimates (DBEDT 2020d).

Average net C sequestration rates by forest type in Hawaii from 2011 through 2030 were calculated using net ecosystem production estimates from USGS (Selmants 2020). 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 net ecosystem production for forest and shrubland in Hawaii were divided by the projected area of the respective land cover type.

County-level Projections

Projected county-level carbon sequestration in forests and shrubland were estimated using the methodology described above.

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 multiple future scenarios (Selmants 2020). There is potential for these projections to change as the impacts of climate change are realized and policies evolve. 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 were projected by projecting forward waste generation and using the same First Order Decay model, consistent with the methodology used to estimate historical emissions. For Hawaii, Kauai, and Maui counties, landfill tonnage for years 2018-2030 were assumed to grow with population (DBEDT 2018). For Honolulu county, landfill tonnage projections were obtained from the City and County of Honolulu Department of Environmental Services (City & County of Honolulu 2017). Landfill waste composition assumptions and the ratio of flared methane to total methane generation are assumed to remain constant relative to 2017.

County-level Projections

Projected county-level emissions from landfills were calculated using the methodology described above.

Uncertainties and Areas for Improvement

This analysis does not account for waste diversion policies or programs that could impact future waste generation, except for the extent that such policies were taken into consideration for the county of Honolulu's landfill tonnage estimate (City & County of Honolulu 2017). Nor does it take into consideration 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

For each county, emissions from composting are assumed to grow at the rate of population (DBEDT 2018). County-level emissions were then summed together to estimate statewide emissions.

County-level Projections

Projected county-level emissions from composting were calculated using the methodology described above.

Uncertainties and Areas for Improvement

The methodology used to project emissions from composting is based on the assumption that per capita composting tonnage will remain constant through 2030. This analysis does not account for policies or programs that could impact composting activities but may be considered in future analyses.

Wastewater Treatment

Methodology

For each county, emissions from wastewater treatment are assumed to grow at the rate of population (DBEDT 2018).[101] County-level emissions were then summed together to estimate statewide emissions.

County-level Projections

Projected county-level emissions from wastewater treatment were calculated using the methodology described above.

Uncertainties and Areas for Improvement

The methodology used to project emissions from wastewater treatment is based on the assumption that wastewater flows are mainly impacted by population growth. Because wastewater N_2O emissions are primarily impacted by protein consumption, any economic, political, or social shifts that impact per capita protein consumption would change overall wastewater emissions.

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[101] 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, which is otherwise flared, is used to displace other fuel types used to generate energy and therefore leads to emission reductions from the energy sector, this activity does not lead to a reduction in GHG emissions from wastewater treatment.

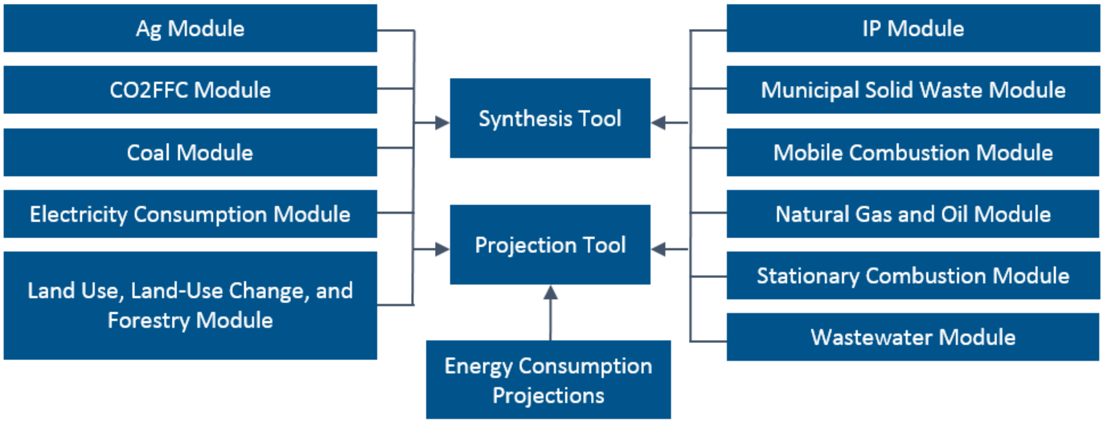
Appendix K. Comparison of Results with the State Inventory Tool and Projection Tool

EPA's State Inventory and Projection Tool is an interactive spreadsheet model designed to help states develop greenhouse gas (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 2050 based on historical emissions that are imported from the SIT modules, combined with projections of future energy consumption, population, and economic factors.

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

Figure K-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 2017 inventory and inventory projections for 2020 and 2025, as developed by ICF and the University of Hawaii Economic Research Organization (UHERO).[102] This document presents the results of this comparison.

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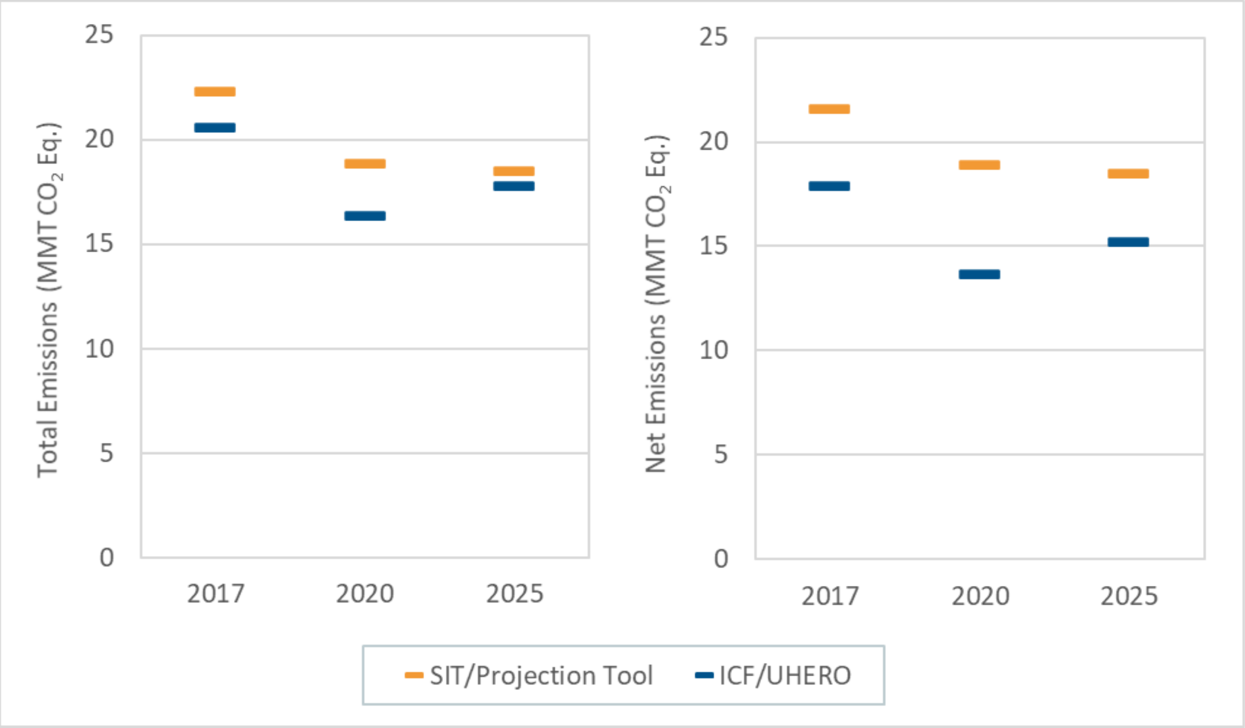
[102] The SIT and Projection Tool are available online at https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool. The SIT modules, Synthesis Tool, and Projection Tool used for this analysis were downloaded from EPA's website in August 2020.

Key Observations and Conclusions

The difference between the SIT and ICF's estimate of total GHG emissions for Hawaii in 2017 is 9 percent while the difference in net GHG emissions is 21 percent.[103] The difference in total emissions is largely due to the inclusion of international bunker fuels in the SIT default transportation fuel consumption estimates (ICF adjusts fuel consumption totals to exclude international bunker fuels, per IPCC guidance), 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 are 16 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, and 4 percent higher in 2025. Net GHG emissions for Hawaii are 38 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, and 22 percent higher in 2025. The Projection Tool notably does not estimate emissions from Land Use, Land Use Change, and Forestry (LULUCF) source and sink categories. Total and net emissions for 2017, 2020, and 2025, as estimated by ICF/UHERO and the SIT/Projection Tool, are shown in Figure K-2.

Figure K-2: Comparison of Total and Net GHG Emission Estimates (2017, 2020, and 2025)



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[103] Net emissions take into account both emission sources and carbon sinks.

Key observations from using the SIT for 2017 GHG estimates include the following:

- About 39 percent of the difference in total emissions is from Forest Carbon (see Table K-2). The SIT does not provide default data for estimating Forest Carbon sinks.
- About 49 percent of the difference in total emissions and 27 percent of the difference in net emissions is from Transportation (see Table K-2). The SIT includes emissions from international bunker fuels in its Transportation estimates.
- Estimates for seven categories comprise 89 percent of the difference in net emissions between the SIT and ICF analysis. These include Forest Carbon, Transportation, Oil and Natural Gas Systems, Incineration of Waste, Iron & Steel Production, Stationary Combustion, and Agricultural Soil Carbon.
- 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 70 percent of the difference in 2020 net emission projections is from Transportation, Forest Carbon, and Stationary Combustion source and sink categories (see Table K-4).
- The estimate for Transportation is 54 percent higher in 2020 using the SIT (however, it is only 9 percent higher in 2025).
- About 71 percent of the difference in 2025 net emission projections are from the Forest Carbon, Stationary Combustion, Transportation, Urban Trees, and Agricultural Soil Carbon source and sink categories (see Table K-6).
- Relative to ICF/UHERO's estimates, the Projection Tool estimates higher emissions from the Energy, IPPU, and Waste sectors in both 2020 and 2025.

Detailed results and observations can be found in the body of this report.

Comparison of Results

To compare the results from the SIT against the 2017 inventory developed by ICF, results from each of estimation modules were compared against the source and sink categories defined in the 2017 inventory.[104] Figure K-3 summarizes how the results from the SIT were mapped to the 2017 inventory.

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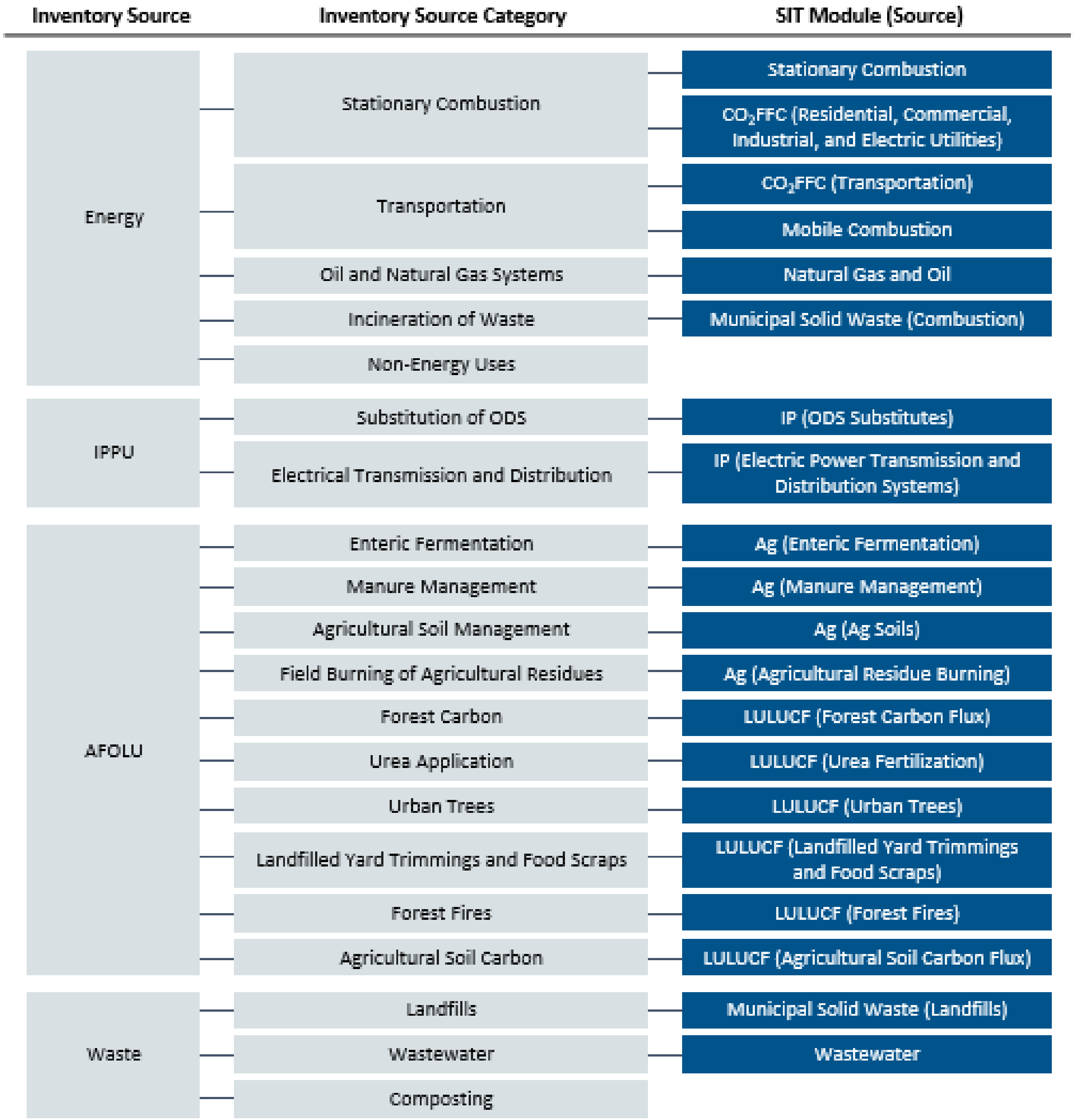
[104] All modules were run except for the Electricity Consumption Module and the Coal Module; the Electricity Consumption Module double counts emissions estimated by the Fossil Fuel Combustion Module and the Coal Module, which estimates emissions from coal mining, is not applicable to the state of Hawaii.

Figure K-3: Mapping of SIT Modules to Hawaii’s 2017 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)
	Non-Energy Uses	
IPPU	Substitution of ODS	IP (ODS Substitutes)
	Electrical Transmission and Distribution	IP (Electric Power Transmission and Distribution Systems)
AFOLU	Enteric Fermentation	Ag (Enteric Fermentation)
	Manure Management	Ag (Manure Management)
	Agricultural Soil Management	Ag (Ag Soils)
	Field Burning of Agricultural Residues	Ag (Agricultural Residue Burning)
	Forest Carbon	LULUCF (Forest Carbon Flux)
	Urea Application	LULUCF (Urea Fertilization)
	Urban Trees	LULUCF (Urban Trees)
	Landfilled Yard Trimmings and Food Scraps	LULUCF (Landfilled Yard Trimmings and Food Scraps)
	Forest Fires	LULUCF (Forest Fires)
	Agricultural Soil Carbon	LULUCF (Agricultural Soil Carbon Flux)
Waste	Landfills	Municipal Solid Waste (Landfills)
	Wastewater	Wastewater
	Composting	

2017 Inventory Comparison

For the state of Hawaii, ICF estimates that in 2017 total GHG emissions were 20.56 MMT CO_2 Eq., while the SIT estimates 22.31 MMT CO_2 Eq., a difference of 9 percent. ICF estimates that in 2017 net emissions were 17.87 MMT CO_2 Eq., while the SIT estimates 21.58 MMT CO_2 Eq., a difference of 21 percent. A summary of 2017 emissions and sinks by sector and category, as estimated by ICF and the SIT, are provided in Table K-1.

Table K-1: Comparison of 2017 Emission Results (MMT CO_2 Eq.)

Sector/Category	ICF	SIT	Difference	% Difference
Energy	**17.64**	**19.17**	**1.53**	**9%**
Stationary Combustion	8.09	8.26	0.17	2%
Transportation[a]	8.98	10.38	1.40	16%
Incineration of Waste	0.23	0.53	0.31	135%
Oil and Natural Gas Systems[b]	0.31	NE	(0.31)	NA
Non-Energy Uses[c]	0.04	NE	(0.04)	NA
IPPU	**0.83**	**1.00**	**0.16**	**19%**
Electrical Transmission and Distribution	0.01	0.01	+	9%
Substitution of ODS	0.82	0.67	(0.15)	(19%)
Soda Ash Manufacture and Consumption[d]	NO	0.01	0.01	NA
Urea Consumption[d]	NO	+	+	NA
Iron and Steel Production[d]	NO	0.30	0.30	NA
AFOLU	**(1.42)**	**0.43**	**1.85**	**NA**
Enteric Fermentation	0.26	0.25	(0.01)	(3%)
Manure Management	0.03	0.05	0.02	62%
Agricultural Soil Management	0.17	0.23	0.06	33%
Field Burning of Agricultural Residues	+	NO	+	NA
Urea Application	+	+	+	(8%)
Agricultural Soil Carbon	0.79	0.62	(0.17)	(22%)
Forest Fires[b]	0.01	NE	(0.01)	NA
Landfilled Yard Trimmings and Food Scraps	(0.04)	(0.05)	+	(7%)
Urban Trees	(0.61)	(0.68)	(0.07)	(11%)
Forest Carbon[b]	(2.03)	NE	2.03	NA
N_2O from Settlement Soils[e]	IE	0.01	0.01	NA
Waste	**0.82**	**0.99**	**0.17**	**20%**
Landfills	0.73	0.83	0.10	14%
Composting[c]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.07	0.16	0.08	114%
Total Emissions (Excluding Sinks)	**20.56**	**22.31**	**1.75**	**9%**
Net Emissions (Including Sinks)	**17.87**	**21.58**	**3.71**	**21%**

+ Does not exceed 0.005 MMT CO_2 Eq.

NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable); IE (Included Elsewhere).

[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] The SIT does not estimate emissions from Non-Energy Uses and Composting.

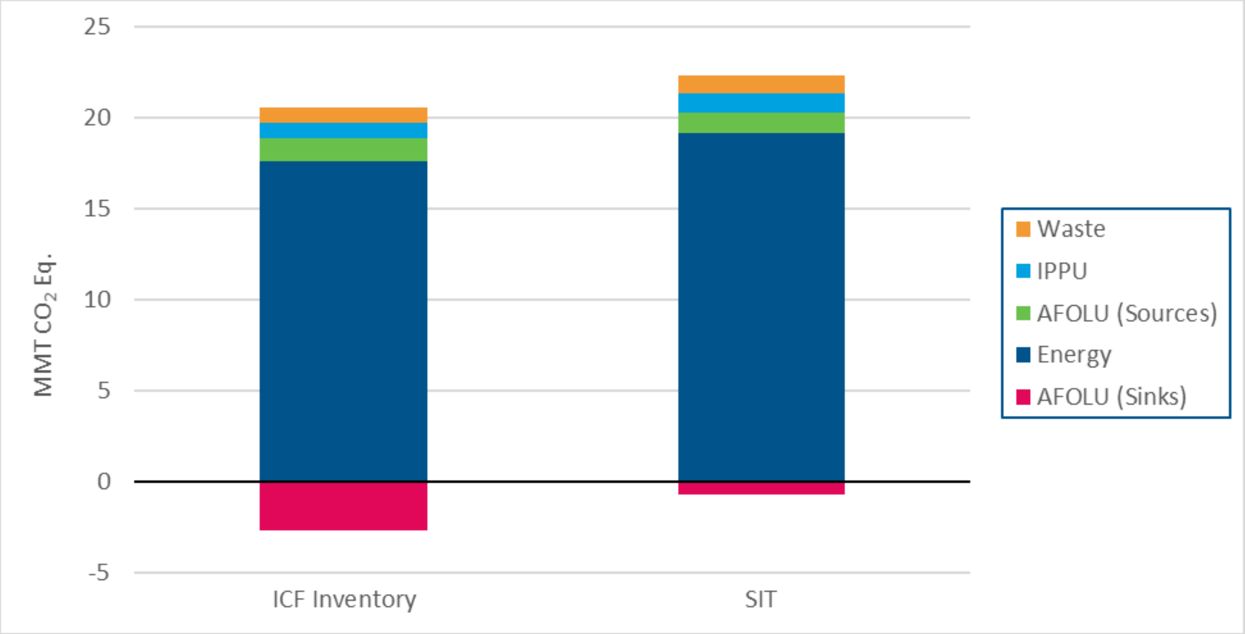
[d] ICF estimates that this activity is not applicable to Hawaii, and therefore emissions are not occurring.

[e] Emissions are included under Agricultural Soil Management.

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 K-4.

Figure K-4: Comparison of 2017 Emission Results (Including Sinks)



The difference in total emission estimates between ICF's Inventory and the SIT are driven by differences in seven source and sink categories, which account for 89 percent of the absolute difference. Table K-2 summarizes the absolute and cumulative difference in emission estimates for these seven categories.

Table K-2: Key Sources of Differences between ICF Inventory and SIT 2017 Emission Results

Category	ICF	SIT	Absolute Difference	Cumulative % of Total Difference
Forest Carbon	(2.03)	NE	2.03	39%
Transportation	8.98	10.38	1.40	65%
Oil and Natural Gas Systems	0.31	NE	0.31	71%
Incineration of Waste	0.23	0.53	0.31	77%
Iron & Steel Production	NO	0.30	0.30	83%
Stationary Combustion	8.09	8.26	0.17	86%
Agricultural Soil Carbon	0.79	0.62	0.17	89%
All Other Categories			0.58	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 16.32 MMT CO_2 Eq., while net emissions are projected to be 13.64 MMT CO_2 Eq. The Projection Tool, which does not project emissions from LULUCF categories, projects total and net emissions in 2020 to be 18.87 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 K-3.

Table K-3: Comparison of 2020 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**13.50**	**15.81**	**2.30**	**17%**
Stationary Combustion	6.65	5.22	(1.43)	(22%)
Transportation	6.49	9.99	3.51	54%
Incineration of Waste	0.27	0.58	0.31	113%
Oil and Natural Gas Systems	0.05	0.01	(0.04)	(78%)
Non-Energy Uses[a]	0.04	NE	(0.04)	NA
IPPU	**0.76**	**1.49**	**0.73**	**97%**
Electrical Transmission and Distribution	0.01	0.01	+	(16%)
Substitution of ODS	0.75	1.04	0.29	39%
Limestone and Dolomite Use	NO	+	+	NA
Soda Ash Production	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron & Steel Production	NO	0.44	0.44	NA
AFOLU[b]	**(1.43)**	**0.49**	**1.92**	**NA**
Enteric Fermentation	0.25	0.23	(0.02)	(9%)
Manure Management	0.03	0.05	0.02	91%
Agricultural Soil Management	0.17	0.21	0.04	21%
Urea Application	+	+	+	(24%)
Agricultural Soil Carbon[a]	0.75	NE	(0.75)	NA
Forest Fires[a]	0.05	NE	(0.05)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.04)	NE	0.04	NA
Urban Trees[a]	(0.64)	NE	0.64	NA
Forest Carbon[a]	(2.00)	NE	2.00	NA
Waste	**0.81**	**1.08**	**0.27**	**34%**
Landfills	0.71	0.92	0.21	29%
Composting[a]	0.02	NE	(0.02)	NA
Wastewater Treatment	0.08	0.16	0.08	109%
Total Emissions (Excluding Sinks)	**16.32**	**18.87**	**2.55**	**16%**
Net Emissions (Including Sinks)	**13.64**	**18.87**	**5.23**	**38%**

+ Does not exceed 0.005 MMT CO_2 Eq.

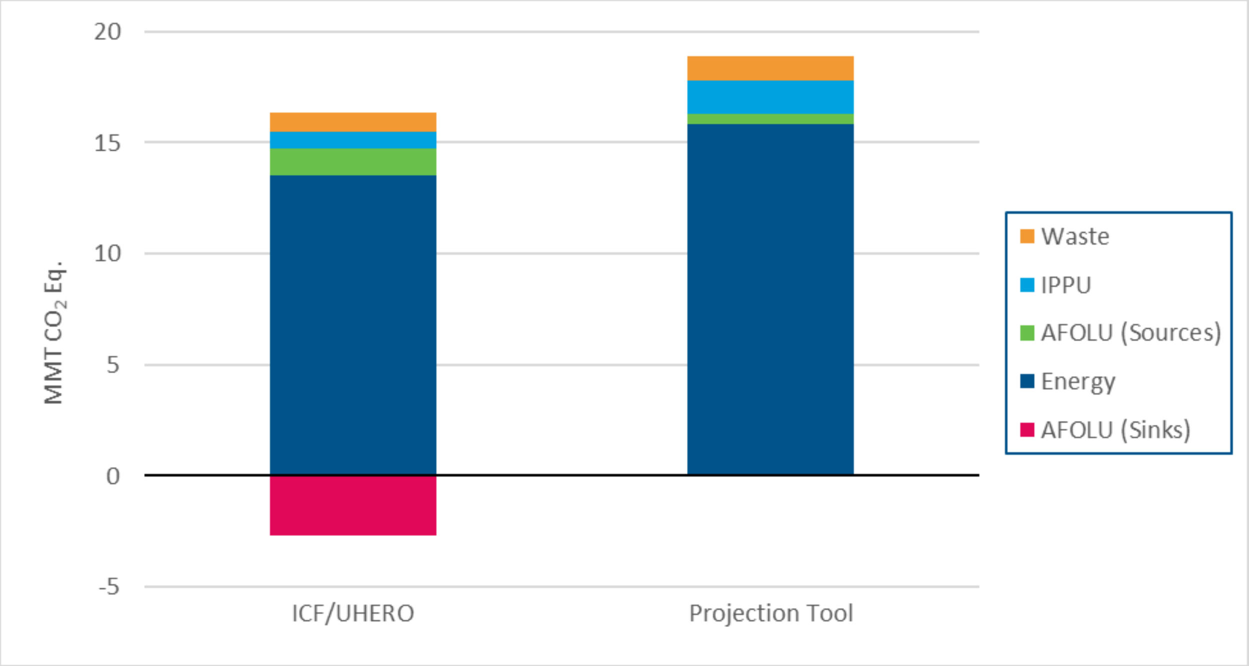
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[a] The Projection Tool does not project emissions from Non-Energy Uses, LULUCF categories, or 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 K-5.

Figure K-5: Comparison of 2020 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 91 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table K-4 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table K-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
Transportation	6.49	9.99	3.51	35%
Forest Carbon	(2.00)	NE	2.00	55%
Stationary Combustion	6.66	5.22	1.44	70%
Agricultural Soil Carbon	0.75	NE	0.75	77%
Urban Trees	(0.64)	NE	0.64	84%
Iron & Steel Production	NO	0.44	0.44	88%
Incineration of Waste	0.27	0.58	0.31	91%
All Other Categories			0.87	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 17.80 MMT CO_2 Eq., while net emissions are projected to be 15.17 MMT CO_2 Eq. The Projection Tool projects total and net emissions to be 18.47 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 for 2025, are provided in Table K-5.

Table K-5: Comparison of 2025 Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	% Difference
Energy	**15.06**	**15.12**	**0.06**	**0%**
Stationary Combustion	5.70	4.81	(0.89)	(16%)
Transportation	8.87	9.65	0.77	9%
Incineration of Waste	0.30	0.65	0.35	117%
Oil and Natural Gas Systems	0.14	0.01	(0.13)	(91%)
Non-Energy Uses[a]	0.04	NE	(0.04)	NA
IPPU	**0.76**	**1.82**	**1.06**	**138%**
Electrical Transmission and Distribution	0.01	0.01	+	(26%)
Substitution of ODS	0.75	1.33	0.58	77%
Soda Ash Production	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron & Steel Production	NO	0.47	0.47	NA
AFOLU[b]	**(1.45)**	**0.47**	**1.92**	**NA**
Enteric Fermentation	0.24	0.22	(0.02)	(10%)
Manure Management	0.02	0.05	0.02	101%
Agricultural Soil Management	0.18	0.20	0.02	13%
Urea Application	+	+	+	(33%)
Agricultural Soil Carbon[a]	0.69	NE	(0.69)	NA
Forest Fires[a]	0.05	NE	(0.05)	NA
Landfilled Yard Trimmings and Food Scraps[a]	(0.04)	NE	0.04	NA
Urban Trees[a]	(0.69)	NE	0.69	NA
Forest Carbon[a]	(1.91)	NE	1.91	NA
Waste	**0.80**	**1.06**	**0.26**	**33%**
Landfills	0.70	0.89	0.20	29%
Composting[a]	0.02	NA	(0.02)	NA
Wastewater Treatment	0.08	0.17	0.09	104%
Total Emissions (Excluding Sinks)	**17.80**	**18.47**	**0.66**	**4%**
Net Emissions (Including Sinks)	**15.17**	**18.47**	**3.30**	**22%**

+ Does not exceed 0.005 MMT CO_2 Eq.

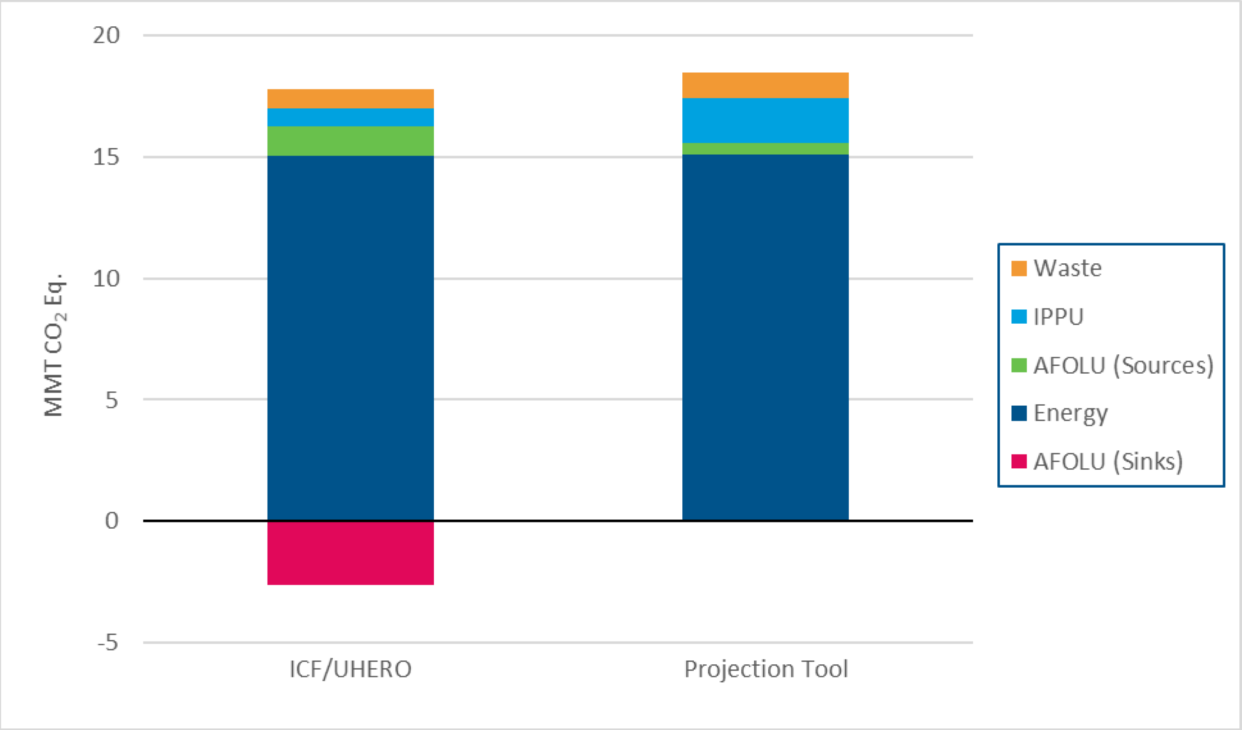
NO (emissions are Not Occurring); NE (emissions are Not Estimated); NA (Not Applicable).

[a] The Projection Tool does not project emissions from Non-Energy Uses, LULUCF categories or 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 K-6.

Figure K-6: Comparison of 2025 Emission Projection Results (Including Sinks)



Seven source and sink categories account for 86 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table K-6 summarizes the absolute and cumulative difference in emission estimates for these top seven categories.

Table K-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	(1.91)	NE	1.91	27%
Stationary Combustion	5.70	4.81	0.89	40%
Transportation	8.87	9.65	0.77	51%
Urban Trees	(0.69)	NE	0.69	61%
Agricultural Soil Carbon	0.69	NE	0.69	71%
Substitution of ODS	0.75	1.33	0.58	79%
Iron & Steel Production	NO	0.47	0.47	86%
All Other Categories			0.95	100%

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

Methodology Comparison - 2017 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 2017 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. The SIT does not provide estimates of emissions from non-energy uses. 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 K-7.

Table K-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 the Energy Information Administration's (EIA) State Energy Data System (SEDS) database, with naphtha and fuel gas data for the energy industries sector coming from the Environmental Protection Agency's Greenhouse Gas Reporting Program (GHGRP). • 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 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 the Department of Business, Economic Development, and Tourism (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 from refineries are taken from EPA's GHGRP. • Emissions from natural gas distribution and transmission pipelines are estimated using miles and services data from the Department of Transportation's Pipeline and Hazardous Materials Safety Administration database.	• Uses activity data on natural gas production, number of wells, the transmission and distribution of natural gas, and the refining and transportation of oil.
Non-Energy Uses	• The percentage of non-energy use consumption by fuel type are based on estimates from the U.S. Inventory.	• Does not estimate emissions from non-energy uses.

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 K-8.

Table K-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. • National emissions estimates are from the 1990-2018 U.S. Inventory.	• Both national and state-level population are taken from the U.S. Census Bureau. • National emissions estimates are from the 1990-2017 U.S. Inventory.
Soda Ash Manufacture and Consumption	• Emissions from soda ash manufacturing and consumption were determined to not occur in Hawaii.	• Allocates national emissions from soda ash consumption using the ratio of state population to national population.
Urea Consumption	• Emissions from urea consumption were determined to not occur in Hawaii.	• Multiplies the total urea applied to Ag Soils in each state (from LULUCF

		module) by 0.13 to obtain urea consumption.
Iron and Steel Production	- Emissions from iron and steel production were determined to not occur in Hawaii.	- Evenly distributes regional production data among states within the region.

AFOLU

For the AFOLU sector, the methodology used by ICF and SIT to calculate emissions and sinks from enteric fermentation 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 does not present emissions from N_2O from Settlement Soils but rather includes these emissions under the Agricultural Soil Management source category. A description of the key differences in methodology and data sources used by ICF and the SIT to estimate emissions and sinks for the AFOLU sector are presented in Table K-9.

Table K-9: Key Differences in Methodology and Data Sources for the AFOLU Sector

Source	ICF Inventory	SIT
Enteric Fermentation	- Obtains sheep and goat population data from the USDA Census of Agriculture.	- Obtains sheep population data from the U.S. Inventory.
Manure Management	- Includes hens within the chicken population but does not include turkeys. - Obtains chicken, sheep, and goat population data from the USDA Census of Agriculture. - Uses constant VS rates for non-cattle animal types.	- Estimates emissions from turkeys and hens greater than one year old. - Obtains sheep population data from the U.S. Inventory. - Uses volatile solids (VS) rates for breeding swine, poultry, and horses that vary slightly by year.
Agricultural Soil Management	- Assumes organic fertilizer is not consumed in Hawaii based on the Association of American Plant Food Control Officials (AAPFCO) Commercial Fertilizer reports. - Extrapolates 1990-2014 fertilizer consumption estimates from AAPFCO through 2017 based on a five-year trend. - Calculates emissions from sugarcane, pineapple, sweet potatoes, ginger root, taro, and seed production. - 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. - Uses the 2014 fertilizer consumption estimate from AAPFCO as a proxy for 2017. - Does not calculate emissions from sugarcane, pineapple, sweet potatoes, ginger root, taro, or seed production. - Obtains crop production data from USDA National Agricultural Statistics

		Service (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 2017 based on the historical five-year trend.	• Uses 2014 data from AAPFCO (2017) as a proxy for 2017 urea fertilization.
Agricultural Soil Carbon	• Emissions estimates are from the 1990-2018 U.S. Inventory.	• Emissions estimates are from the 1990-2017 U.S. Inventory.
Forest Fires	• Obtains forest area burned data from the Hawaii Department of Land and Natural Resources.	• Does not include default data of forest area burned.
Landfilled Yard Trimmings	• Hawaii population data were obtained from the State of Hawaii Data Book. • Extrapolates waste generation to 2017 based on the historical five-year trend.	• Hawaii population data were obtained from U.S. Census. • Uses 2016 waste generation data as a proxy for 2017.
Urban Trees	• Uses carbon sequestration rates are calculated based on state-specific values from the U.S. Inventory.	• 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	• Emissions included under Agricultural Soil Management.	• 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 K-10.

Table K-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 Department of Health (DOH), Solid & Hazardous Waste Branch.	• Estimates state-level waste disposal by allocating national waste data based on population.

	- 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.	- Flaring data is based on information from the U.S. GHG Inventory.
Composting	- Estimated based on the U.S. national average per capita composting rate from the U.S. GHG Inventory.	- Does not estimate emissions from composting.
Wastewater Treatment	- Data on non-National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants, including flow rate and BOD5 are provided by Hawaii DOH, Wastewater Branch. - Population data from the State of Hawaii Data Book were used to calculate wastewater treatment volumes. - The number of households on septic systems were calculated using data from the U.S. Census Bureau and Hawaii DOH, Wastewater Branch.	- Uses data from EPA and BioCycle.

Methodology Comparison - 2020 and 2025 Emission Projections

This section compares the methodology used by ICF/UHERO and the Projection Tool to develop the 2020 and 2025 inventory projections. While the projections developed by ICF/UHERO take into account the potential impact of COVID-19 on future emissions, the Projection Tool does not currently account for these impacts. In addition, 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 K-11. A more detailed description of the methodology and data sources used by ICF/UHERO can be found in Appendix J.

Table K-11: Key Differences in Methodology Used to Project Emissions

Sector	ICF/UHERO	Projection Tool
Energy	- For energy industries and incineration of waste, emissions were projected based on direct communication with the utilities and the utility's Power Supply Improvement Plan (PSIP). - For residential energy use, commercial energy use, industrial energy use, and non-energy uses, emissions were projected using forecasted gross state product, and adjusted to account for	- Forecasts regional energy consumption data based on EIA's AEO 2020. Allocates regional consumption to states based on 2018 state-level consumption taken from EIA's State Energy Data 2020.

	RNG consumption in place of SNG consumption. • For ground transportation, emissions were projected based on estimates of future vehicle miles traveled and fuel efficiency by vehicle type. • For domestic aviation, emissions were projected for 2020 based on projected reductions in visitor arrivals, resident travel, and cargo shipments as a result of COVID-19. By 2025, air travel is assumed to return to 2019 levels. • For oil and natural gas systems, emissions were project based on projected growth in aviation emissions.	
IPPU	• Emissions from Electric Power Transmission and Distribution Systems were projected based on the electricity sales forecast. • Emissions from ODS Substitutes were projected using forecasted gross state product and adjusted to account for the anticipated adoption of Hawaii House Bill 2492.	• Forecasts emissions from Soda Ash Manufacture and Consumption, Iron & Steel Production, and Urea Consumption based on historical trends. • Forecasts emissions from Electric Power Transmission and Distribution Systems and ODS Substitutes based on publicly available forecasts.
AFOLU	• Emissions were projected by forecasting activity data using historic trends and published information on future trends.	• Forecasts emissions based on either historical trends or publicly available forecasts (varies by category). Results differ due to minor differences in how activity data is projected and differences in historical estimates. • Emission sinks are not estimated.
Waste	• Emissions were projected based on DBEDT population growth projections.	• Forecasts activity data based on projected population from the U.S. Census Bureau.