JOSH GREEN, M.D.
GOVERNOR OF HAWAIʻI
KE KIAʻĀINA O KA MOKUʻĀINA ʻO HAWAIʻI

DEPT. COMM. NO. 296

KENNETH S. FINK, MD, MGA, MPH
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STATE OF HAWAIʻI
DEPARTMENT OF HEALTH
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In reply, please refer to:
File:

December 29, 2023

The Honorable Ronald D. Kouchi,
President and Members of the Senate
Thirty-second State Legislature
State Capitol, Room 409
Honolulu, HI 96813

The Honorable Scott K. Saiki, Speaker
And Members of the House of
Representatives
Thirty-second State Legislature
State Capitol, Room 431
Honolulu, HI 96813

Aloha President Kouchi, Speaker Saiki, and Members of the Legislature:

For your information, I am transmitting a copy of the following report.

Final Report on Hawaii Greenhouse Gas Emissions, 2023

Pursuant to section 93-16, Hawaii Revised Statutes, this report may be viewed online at:

https://health.hawaii.gov/opppd/department-of-health-reports-to-2024-legislature/

Sincerely,

Kenneth S. Fink, MD, MGA, MPH
Director of Health

Enclosures
C: Legislative Reference Bureau
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Hawai‘i Greenhouse Gas Emissions Report for 2005, 2018, and 2019

Final Report

April 2023

Prepared for:

Prepared by:

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Acronyms and Abbreviations

AAPFCO	Association of American Plant Food Control Officials
AD	Anaerobic Digestion
ADI	Airline Data Inc.
AFOLU	Agriculture, Forestry, and Other Land Use
AG	Aboveground Residue
BAU	Business-as-Usual
Bbtu	Billion British Thermal Units
BE	Burning Efficiency
B_O	Maximum Potential Emissions
BOD	Biochemical Oxygen Demand
BTS	Bureau of Transportation Statistics
C	Carbon
CARB	California Air Resources Board
CCAP	Coastal Change Analysis Program
CE	Collection Efficiency; Combustion Efficiency
CH_4	Methane
CF	Carbon Fraction; Correction Factor
CFCs	Chlorofluorocarbons
CKD	Cement Kiln Dust
CO_2	Carbon Dioxide
CO_2 Eq.	Carbon Dioxide Equivalent
CS	Carbon Stored
DBEDT	Department of Business, Economic Development, and Tourism
DE	Destruction Efficiency
DLNR	Department of Land and Natural Resources
dm	Dry Matter
DMF	Dry Matter Fraction
DOC	Department of Commerce
DOE	Department of Energy
DOH	Department of Health
DOT	Department of Transportation
ECHO	Enforcement and Compliance History Online
EF	Emission Factor
EIA	Energy Information Administration
EIIRP	Energy Industry Information Reporting Program
EPA	U.S. Environmental Protection Agency

FCF	Fossil Carbon Fraction
FHWA	Federal Highway Administration
FOD	First Order Decay
FOFEM	First-Order Wildland Fire Effect Model
g	Gram
gal	Gallon
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
GJ	Gigajoules
GWP	Global Warming Potential
ha	Hectare
HAR	Hawai'i Administrative Rule
HB	House Bill
HCFCs	Hydrochlorofluorocarbons
HECO	Hawaiian Electric Company
HELCO	Hawai'i Electric Light Company
HFCs	Hydrofluorocarbons
HHV	High Heat Value
H-POWER	Honolulu Program of Waste Energy Recovery
IBF	International Bunker Fuels
ICC	Initial Carbon Content
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IW	Incinerated Waste
Kg	Kilogram
Km	Kilometer
Kt	Kiloton
lb	Pound
KIUC	Kaua'i Island Utility Cooperative
LEV	Low-Emission Vehicle
LFC	Landfill Carbon
LMOP	Landfill Methane Outreach Program
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land Use Change, and Forestry
m	Meter
MC	Moisture Content
MCF	Methane Conversion Factor
MECO	Maui Electric Company
mi	Mile

MG	Methane Generated
MMBtu	Million Metric British Thermal Units
MMT	Million Metric Tons
MSW	Municipal Solid Waste
MT	Metric Tons
MWh	Megawatt Hour
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
OEMs	Original Equipment Manufacturers
OF; OX	Oxidation Factor
PDF	Probability Density Function
PFCs	Perfluorocarbons
PHMSA	Pipeline and Hazardous Materials Safety Administration
RDF	Refuse-Derived Fuel
RECS	Residential Energy Consumption Survey
RNG	Renewable Natural Gas
SEDS	State Energy Data System
SF_6	Sulfur Hexafluoride
SIT	State Inventory Tool
SNG	Synthetic Natural Gas
TAM	Typical Animal Mass
TJ	Terajoule
TVA	Tennessee Valley Authority
UNEP	United Nations Environment Programme
Urea	$CO(NH_2)_2$
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey

VMT	Vehicle Miles Traveled
VS	Volatile Solids
WF	Waste Fraction
WMS	Waste Management System
WWTP	Wastewater Treatment Plant

Acknowledgments

This inventory report was developed under the direction and oversight of the Hawaiʻi State Department of Health, Clean Air Branch. ICF and the University of Hawaiʻi Economic Research Organization would like to thank the Department of Health for its valuable input and guidance in the development of this report.

We would also like to thank key contributors to the report including Susan Asam, John Venezia, Jakub Zielkiewicz, Emily Adkins, Cara Blumenthal, Megan Miranda, Eliza Puritz, Bikash Acharya, and Ajo Rabemiarisoa from ICF as well as Makena Coffman, Paul Bernstein, Maja Schjervheim, and Muhammad Talal Khan from the Institute for Sustainability and Resilience and the University of Hawaiʻi Economic Research Organization.

Finally, we would like to thank the team of reviewers, which included representatives from the Hawaiʻi Department of Health (DOH), Department of Business, Economic Development and Tourism (DBEDT), Division of Consumer Advocacy (DCA), and Public Utilities Commission (PUC).

Executive Summary

The State of Hawaiʻi 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 Hawaiʻi passed Act 234, Session Laws of Hawaiʻi 2007 (Act 234 of 2007), to establish the state's policy framework and requirements to address GHG emissions. The law sought to achieve emission levels at or below Hawaiʻi's 1990 GHG emissions by January 1, 2020 (excluding emissions from airplanes). In 2008, the State of Hawaiʻi developed statewide GHG emission inventories for 1990 and 2007. To help Hawaiʻi meet the emissions target, Hawaiʻi 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 recent years, further GHG emissions goals have been set. Act 238, Session Laws of Hawaiʻi 2022 (Act 238 of 2022), established a goal for the level of statewide GHG emissions to be at least 50 percent below 2005 levels by the year 2030, and that the measurement of GHG emissions for the year 2005 include emissions from airplanes. Act 15, Session Laws of Hawaiʻi 2018 (Act 15 of 2018), established a statewide carbon net-negative goal by 2045. In an effort to track progress toward achieving the state's 2020, 2030, and 2045 GHG reduction goals, this report presents updated 1990, 2007, 2010, 2015, 2016, and 2017 emissions estimates;[1] emissions estimates developed for 2005, 2018, and 2019; and emission projections for 2020, 2025, 2030, 2035, 2040, and 2045.

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] Net GHG emissions (including aviation) in 2030 are projected to be greater than the target emissions level of 50 below 2005 levels (including aviation), and in 2045 are projected to be greater than the target of net-negative levels. While the development of future inventory reports as well as ongoing quantitative assessment of uncertainties will further inform whether Hawaiʻi met the 2020 statewide target and is going to meet the 2030 and 2045 statewide targets, this report finds that, under existing policies and economic projections, Hawaiʻi is currently expected to meet the 2020 target, but is not expected to meet the 2030 and 2045 targets.

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

[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 from sources and carbon sequestration from 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.

atmosphere. The Intergovernmental Panel on Climate Change (IPCC) developed the Global Warming Potential (GWP) concept to compare the ability of each GHG to trap heat in the atmosphere relative to the reference gas, CO_2 (IPCC 2014). Throughout this report the relative contribution of each gas is shown in million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). The GWP values used in this report are from the *IPCC Fourth Assessment Report* (IPCC 2007), assuming a 100-year time horizon.

Inventory Scope and Methodology

The GHG emission estimates presented in this report include anthropogenic[4] GHG emissions and sinks for the state of Hawai'i for 1990, 2005, 2007, 2010, 2015, 2016, 2017, 2018, and 2019 from the following four sectors: Energy; Industrial Processes and Product Use (IPPU); Agriculture, Forestry, and Other Land Use (AFOLU); and Waste, and primarily serve the federal mandatory GHG reporting requirements in accordance with 40 Code of Federal Regulations (CFR) 98 (EPA 2021c). This report includes on-island GHG emissions only. Lifecycle emission estimates are not included – only emissions occurring within the physical boundaries of the islands that constitute the State of Hawai'i. For example, all emissions estimated for the agriculture sector, such as farming activities, represent on-island emissions only, such as direct emissions from the fuel, energy, and farming operations, but exclude upstream emissions occurring outside Hawai'i from the production of fuel used by the farming equipment, or the emissions related to the manufacturing of fertilizers and pesticides.

As it is best practice to review GHG emission estimates for prior years, this report includes revised estimates for 1990, 2007, 2010, 2015, 2016, 2017 and newly developed estimates for 2005, 2018, and 2019. ICF relied on the best available activity data, emission 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 2022a). Key guidance and resources included the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, the 2019 Refinements to 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: 1990-2020*, 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

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

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.

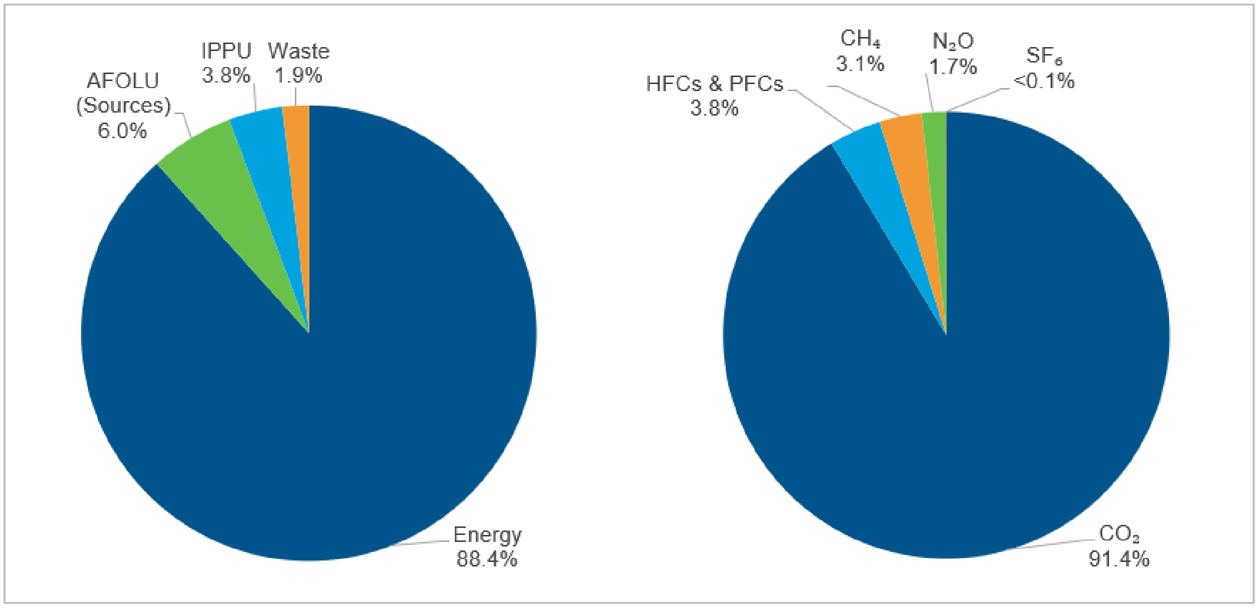
The intent of an uncertainty analysis is not to dispute the validity of the inventory estimates—which are developed using the best available activity data, emission factors, and methodologies available—but rather to guide prioritization of improvements to the accuracy of future inventories (EPA 2022a). 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. Uncertainties in the emission sources and sinks from the AFOLU sector are driving the overall uncertainty for net emissions.

Emission Results

In 2019, total GHG emissions in Hawaiʻi were 22.01 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). Net emissions, which take into account carbon sinks, were 19.42 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (88.4 percent) of total emissions in Hawaiʻi, followed by the AFOLU sector (6.0 percent), the IPPU sector (3.8 percent), and the Waste sector (1.9 percent). Carbon dioxide was the largest single contributor to statewide GHG emissions in 2019, accounting for roughly 91.4 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). HFCs and PFCs are the second largest contributing group of gases (3.8 percent), followed closely by methane (3.1 percent), N_2O (1.7 percent), and SF_6 (less than 0.1 percent). Figure ES-1 shows emissions for 2019 by sector and gas.

[5] The review team included representatives from the Hawaiʻi Department of Business, Economic Development and Tourism (DBEDT), Division of Consumer Advocacy (DCA), Public Utilities Commission (PUC), County of Honolulu, County of Hawaiʻi, County of Kauaʻi, County of Maui, and Department of Land and Natural Resources (DLNR).

Figure ES-1: Hawai'i 2019 GHG Emissions by Sector and Gas (Excluding Sinks, Including Aviation)

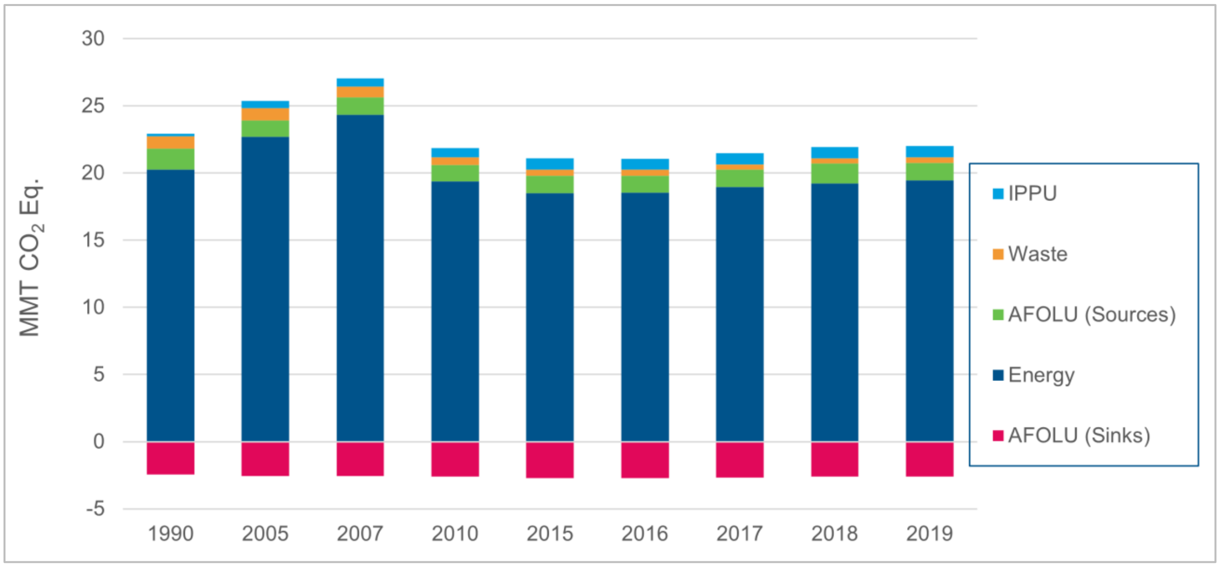


Note: Percentages represent the percent of total emissions excluding sinks and including aviation.

Emissions Trends

Total GHG emissions in Hawai'i grew by 18.0 percent between 1990 and 2007 before decreasing by about 18.6 percent between 2007 and 2019. Compared to 1990, total emissions in Hawai'i in 2019 were roughly 3.9 percent lower, while net emissions were lower by roughly 11.7 percent. Figure ES-2 shows emissions for each inventory year by sector. Emissions by sector and year are also summarized in Table ES-1.

Figure ES-2: Hawai'i GHG Emissions by Sector (1990, 2005, 2007, 2010, and 2015 - 2019) (Including Sinks and Aviation)



Note: Emission estimates include sinks and aviation.

Table ES-1: Hawai'i GHG Emissions by Sector/Category for 1990, 2005, 2007, 2010, and 2015 - 2019 (MMT CO_2 Eq.)

Sector/Category	1990	2005	2007	2010	2015	2016	2017	2018	2019
Energy[a]	20.26	22.71	24.35	19.38	18.50	18.52	18.97	19.23	19.44
IPPU	0.17	0.53	0.58	0.71	0.83	0.83	0.83	0.83	0.84
AFOLU (Sources)	1.55	1.22	1.29	1.24	1.28	1.29	1.28	1.48	1.31
AFOLU (Sinks)	(2.43)	(2.56)	(2.57)	(2.58)	(2.72)	(2.69)	(2.68)	(2.59)	(2.59)
Waste	0.93	0.91	0.82	0.55	0.47	0.43	0.40	0.38	0.41
Total Emissions (Excluding Sinks)	**22.91**	**25.37**	**27.04**	**21.88**	**21.08**	**21.07**	**21.48**	**21.92**	**22.01**
Net Emissions (Including Sinks)	**20.48**	**22.8[c]**	**24.47**	**19.29**	**18.37**	**18.38**	**18.80**	**19.33**	**19.42**
Aviation[b]	5.10	7.14	5.65	4.64	5.10	5.18	5.47	5.64	5.83
Net Emissions (Including Sinks, Excluding Aviation)[b]	**15.38[d]**	**15.66**	**18.81**	**14.65**	**13.27**	**13.20**	**13.33**	**13.69**	**13.59**

[a] Emissions from International Bunker Fuels are not included in the 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 Hawai'i's GHG emissions reduction goal established in Act 234 of 2007.
[c] Act 238 of 2022 aims for the level of statewide GHG emissions to be at least 50 percent below 2005 levels by the year 2030 (including aviation emissions).
[d] Act 234 of 2007 aims to achieve emission levels at or below Hawai'i's 1990 GHG emissions by January 1, 2020 (excluding aviation emissions).

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

As the largest source of emissions in Hawaiʻi, the Energy sector is a major driver of the overall emissions trends. Relative to 1990, emissions from the Energy sector in 2019 were lower by 4.0 percent. Transportation emissions—which increased between 1990 and 2007, decreased between 2007 and 2015, and then increased again between 2015 and 2019—accounted for the largest share of Energy sector emissions in all inventory years. The trend in transportation emissions is largely driven by domestic aviation and ground transportation emissions, which together account for roughly 82 percent of transportation emissions. Stationary combustion emissions—which increased between 1990 and 2005, before consistently decreasing between 2005 and 2016, and then slightly increasing again between 2016 and 2019—is the second largest share of Energy sector emissions. 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 2019 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, domestic aviation, and incineration of waste observed over the same period.

Emissions from the Waste sector also contributed to the overall reduction in emissions from 2007 to 2019, falling by about 49.6 percent, during that period, primarily driven by a decrease in emissions from landfills. These reductions more than offset growing emissions from the IPPU sector, which increased by 44.0 percent from 2007 to 2019. Relative to 1990, emissions from the IPPU sector in 2019 were more than three times higher, due entirely to the growth in HFC and PFC emissions, which are used as substitutes for ozone depleting substances (ODS) used primarily in refrigeration and air conditioning.[6] Carbon removals from AFOLU sinks have also increased since 1990, growing by roughly 6.5 percent between 1990 and 2019.

Emission Projections

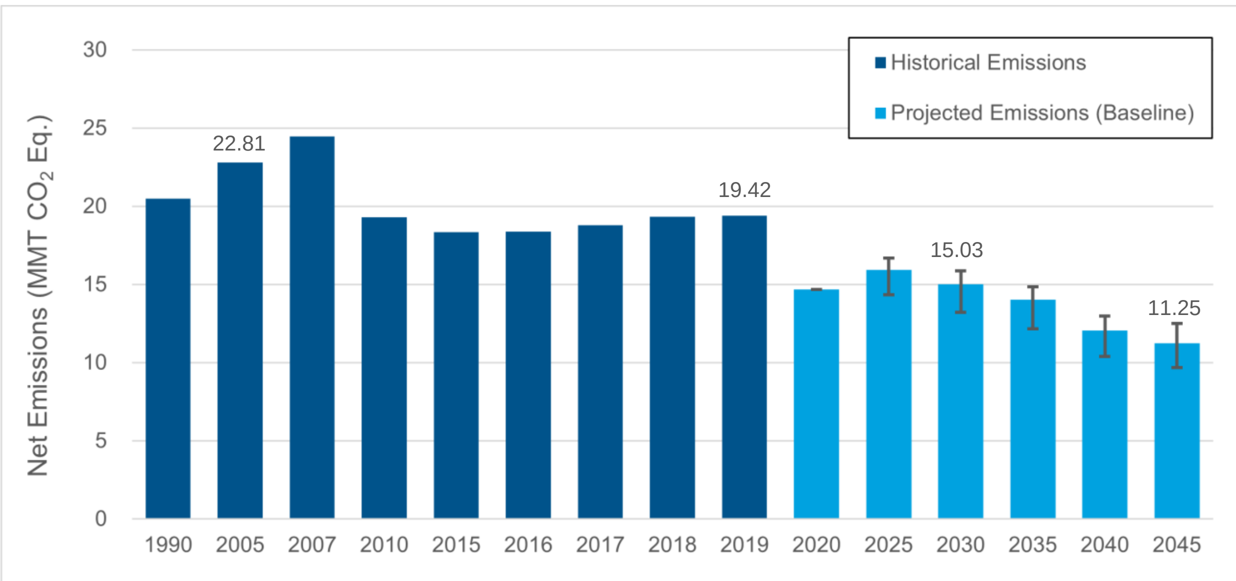
A combination of top-down and bottom-up approaches were used to develop baseline projections of statewide and county-level GHG emissions for the years 2020, 2025, 2030, 2035, 2040, and 2045.[7] Several sources (residential, commercial, and industrial energy use, domestic and international aviation, non-energy uses, composting and wastewater treatment) were projected based on either a long-range forecast for gross state/county product or future population (including visitor arrivals), using the 2019 statewide GHG inventory as a starting point. For several small categories, category-specific approaches were taken. For example, for electrical transmission and distribution, electricity sales forecasts were used to project GHG emissions. For 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. For GHG emitting sources for which there has been

[6] 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 Hawaiʻi and are presented in Appendix H.
[7] Some sector-specific data were available for 2020; in these cases, actual historical data were used to develop 2020 GHG emissions estimates. Details regarding data sources used are available in Appendix J.

substantial federal and state policy intervention (energy industries, substitution of ozone depleting substances, and transportation), bottom-up approaches were used. Due to policies that affect these sources, projected economic activities are only one component of future GHG emissions. Therefore, a more comprehensive sectoral approach was used to develop baseline projections for these emission sources.

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, 2030, 2035, 2040, and 2045 are summarized in Table ES-2.

Figure ES-3: Hawai'i Net GHG Emissions by Year (Including Sinks and Aviation)



Note: The uncertainty bars represent the range of emissions projected under the alternate scenarios. Emissions for the year 2020 were estimated to be a single point because the analysis was completed after 2020 and, therefore, the technology and policy variation modeled under the alternate scenarios is not applicable. Emissions estimates include sinks and aviation emissions.

Table ES-2: Hawaiʻi GHG Emission Projections by Sector under the Baseline Scenario, 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO_2 Eq.)

Sector	2020	2025	2030	2035	2040	2045
Energy[a]	14.78	16.03	15.30	14.59	12.85	12.16
IPPU	0.74	0.77	0.62	0.41	0.26	0.25
AFOLU (Sources)	1.30	1.22	1.14	1.08	1.03	0.98
AFOLU (Sinks)	(2.54)	(2.50)	(2.46)	(2.49)	(2.55)	(2.62)
Waste	0.42	0.43	0.43	0.45	0.47	0.49
Total Emissions (Excluding Sinks)	**17.24**	**18.44**	**17.49**	**16.52**	**14.61**	**13.88**
Net Emissions (Including Sinks)	**14.69**	**15.94**	**15.03**	**14.03**	**12.06**	**11.25**
Aviation[b]	3.11	5.47	5.65	5.75	5.82	5.89
Net Emissions (Including Sinks, Excluding Aviation)[b]	**11.58**	**10.46**	**9.38**	**8.28**	**6.24**	**5.36**

[a] Emissions from International Bunker Fuels are not included in the totals, as per IPCC (2006) guidelines.
[b] Domestic aviation and military emissions, which are reported under the Energy sector, are excluded from Hawaiʻi's GHG emission reduction goal established in Act 234 of 2007.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Total GHG emissions are projected to be 18.44 MMT CO_2 Eq. in 2025, 17.49 MMT CO_2 Eq. in 2030, and 13.88 MMT CO_2 Eq. in 2045. Net emissions, which take into account carbon sinks and are relevant for tracking progress toward the 2030 GHG target pursuant to Act 238 of 2022 are projected to be 15.94 MMT CO_2 Eq. in 2025, 15.03 MMT CO_2 Eq. in 2030, and 11.25 MMT CO_2 Eq. in 2045. Net emissions, which include carbon sinks, exclude aviation, and are relevant for tracking the progress toward the 2020 GHG target pursuant to Act 234 of 2007, are projected to be 11.58 MMT CO_2 Eq. in 2020.

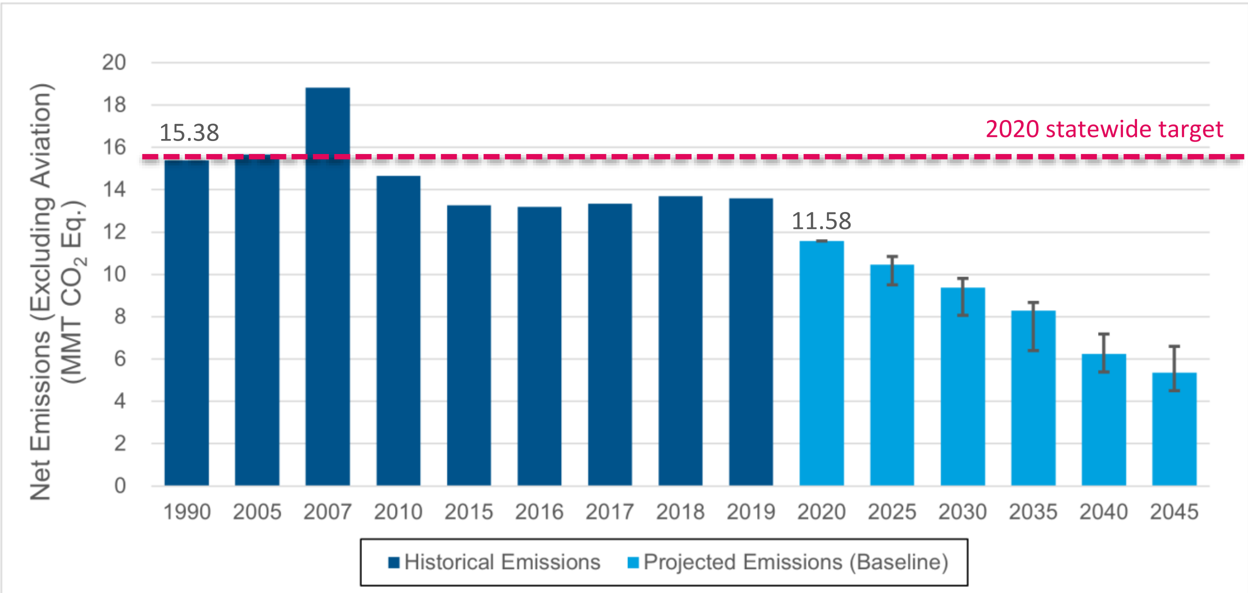
Relative to 2019, total emissions under the baseline scenario are projected to decrease by 16 percent by 2025, 21 percent by 2030, and 37 percent by 2045. Over the same period, net emissions are projected to decrease by 18 percent, 23 percent, and 42 percent, respectively. This trend is largely driven by the projected trend in emissions from energy industries (i.e., electric power plants and petroleum refineries), which are expected to decrease substantially between 2019 and 2045.

Hawaiʻi GHG Goals Progress

Progress Towards 2020 GHG Goal: Excluding aviation, 1990 statewide GHG emissions were estimated to be 15.38 MMT CO_2 Eq., which represents the 2020 emission target (statewide GHG emissions must be at or below this level). Net GHG emissions in 2019 (excluding aviation) were approximately 11.7 percent lower than the 2020 statewide goal (1990 levels). Figure ES-4 shows net GHG emissions (excluding aviation) in Hawaiʻi for the inventory years presented in this report as well as GHG emission projections for 2020, 2025, 2030, 2035, 2040, and 2045 and the 2020 statewide target, which is equal to 1990 emissions levels. As net GHG emissions excluding aviation are projected to be 11.58 MMT CO_2 Eq. in

2020, this report finds that, given existing policies, Hawaiʻi is currently expected to meet the 2020 statewide GHG emissions target set by Act 234 of 2007.[8]

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

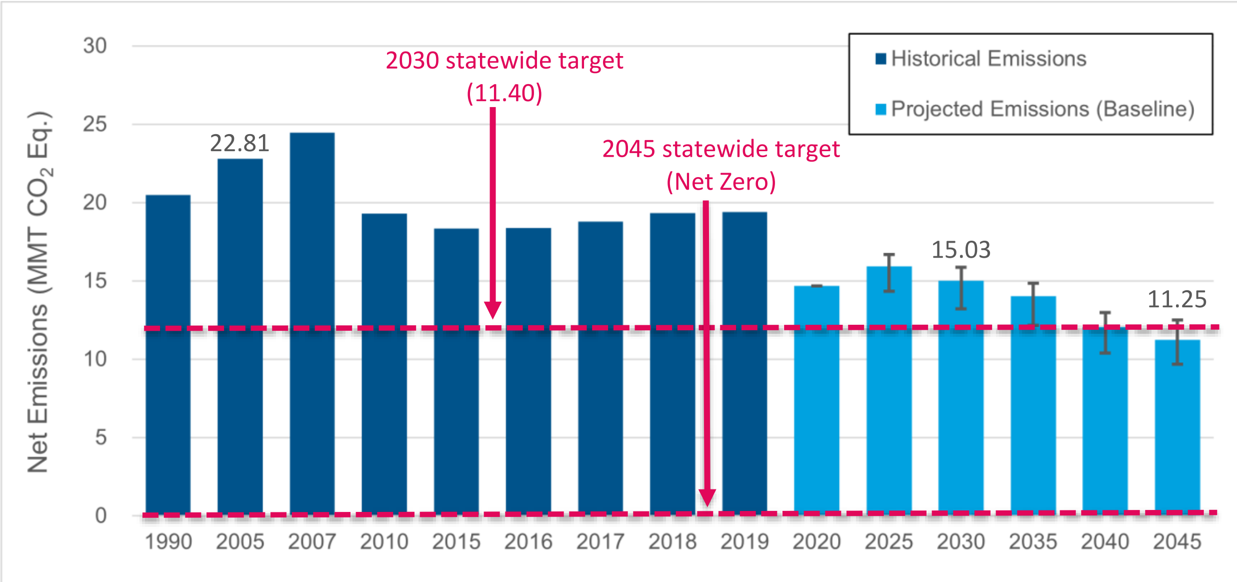


Note: The uncertainty bars represent the range of emissions projected under the alternative scenarios. Emissions for the year 2020 are estimated to a single point because the analysis was completed in 2020 and, therefore, the technology and policy variation modeled under the alternative scenarios is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

Progress Towards 2030 and 2045 GHG Goals: Figure ES-5 shows net GHG emissions (including aviation) in Hawaiʻi for the inventory years presented in this report (shown in darker blue); GHG emission projections (shown in lighter blue); and the 2030 and 2045 statewide targets (shown using the dashed red lines). The 2030 emission target was estimated to be 11.40 MMT CO_2 Eq. (statewide GHG emissions must be at or below this amount). This is equal to 50 percent of statewide emissions, including aviation, in 2005. In 2045, the target emission level is carbon net-negative (including aviation). Net GHG emissions including aviation are projected to be between 13.23 – 15.87 MMT CO_2 Eq. in 2030, and 9.69 – 12.49 MMT CO_2 Eq. in 2045; therefore, this report finds that Hawaiʻi is currently not on track to meet the 2030 or 2045 statewide emissions targets, set by Act 238 of 2022, and Act 15 of 2018 respectively.

[8] This will be assessed in the development of the Hawaiʻi Greenhouse Gas Emissions Report for 2020 and 2021, scheduled for publication in 2024, in which a complete inventory for 2020 will be developed.

Figure ES-5: Hawaiʻi Net GHG Emissions Estimates and Projections (Including Sinks and Aviation)



Note: Emission estimates include sinks and aviation.

There is some degree of uncertainty in both the historical and projected GHG 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 Hawaiʻi met the 2020 statewide target, and the likelihood of the State meeting the 2030 and 2045 statewide targets.

1. Introduction

The State of Hawaiʻi is committed to reducing our contribution to global climate change and has taken efforts to measure and reduce statewide greenhouse gas (GHG) emissions. In 2007, the State of Hawaiʻi passed Act 234, Session Laws of Hawaiʻi 2007 (Act 234 of 2007) to establish the state's policy framework and requirements to address GHG emissions. The law sought to achieve emission levels at or below Hawaiʻi's 1990 GHG emissions by January 1, 2020 (excluding emissions from airplanes). In 2008, the State of Hawaiʻi developed statewide GHG emission inventories for 1990 and 2007. To help Hawaiʻi meet the emissions target, Hawaiʻi 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 recent years, further GHG emissions goals have been set. Act 238, Session Laws of Hawaiʻi 2022 (Act 238 of 2022), established a goal for the level of statewide GHG emissions to be at least 50 percent below 2005 levels by the year 2030, and that the measurement of GHG emissions for the year 2005 include emissions from airplanes. Act 15, Session Laws of Hawaiʻi 2018 (Act 15 of 2018), established a statewide carbon net-negative goal by 2045. In an effort to track progress toward achieving the state's 2020, 2030, and 2045 GHG reduction goals, this report presents updated 1990, 2007, 2010, 2015, 2016, and 2017 emissions estimates;[9] emissions estimates for 2005, 2018, and 2019; and emission projections for 2020, 2025, 2030, 2035, 2040 and 2045.

Based on the analysis presented in this report, net GHG emissions (excluding aviation) in 2020 (11.58 MMT CO_2 Eq.) are projected to be lower than net GHG emissions (excluding aviation) in 1990 (15.38 MMT CO_2 Eq.).[10,11] While the development of future inventory reports as well as ongoing quantitative assessment of uncertainties will further inform whether Hawaiʻi met the 2020 statewide target, this report finds that, given existing policies, Hawaiʻi is expected to meet the 2020 target of reducing emissions to 15.38 MMT CO_2 Eq. or below.

Act 238 of 2022 aims to achieve emission levels of 11.40 MMT CO_2 Eq. (including sinks and aviation) by 2030. This is equal to 50 percent of statewide 2005 emission levels. The baseline goal (set in Act 238 of 2022), could change with future updates to the 2005 emission estimates, but it is not likely to change significantly. Act 15 of 2018 aims to achieve carbon net-negative emission levels by 2045. Net GHG emissions (including sinks and aviation) are projected to be between 13.23 – 15.87 MMT CO_2 Eq. in 2030, and 9.69 – 12.49 MMT CO_2 Eq. in 2045. As such, this report finds that Hawaiʻi is currently not on track to meet the 2030 or 2045 statewide emissions targets.

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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.

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 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* (AR4) (IPCC 2007), assuming a 100-year time horizon, as summarized in Table 1-1.

Table 1-1: AR4 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, uses GWPs with a 100-year time horizon in accordance with Mandatory GHG Reporting (EPA 2021c).
Source: *IPCC Fourth Assessment Report* (2007).

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.

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 2022a, IPCC 2013). Black carbon also influences cloud development, but the direction and magnitude of this forcing is an area of active research (EPA 2022a). 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.

1.2. Inventory Scope

The GHG emission estimates presented in this report include anthropogenic GHG emissions and sinks for the state of Hawaiʻi for 1990, 2005, 2007, 2010, 2015, 2016, 2017, 2018, and 2019 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] and the *2019 Refinements to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[13], to ensure completeness and allow for comparability of results with other inventories. The

[12] The *2006 IPCC Guidelines* are 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] The *2019 Refinements to the 2006 IPCC Guidelines* are the most recent inventory guidelines from the IPCC. They reflect the most up-to-date scientific information for estimating emissions, but do not include updates or refinements for each sector. These refinements have been incorporated into emissions calculation methodologies.

inventory accounts for GHG emissions and removals that take place within the physical boundary of the state. While Hawaiʻi 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, 2016, and 2017 and newly developed estimates for 2005, 2018, and 2019. The 1990, 2007, 2010, 2015, 2016, and 2017 estimates were updated to account for updated activity data and methods, and to ensure time-series consistency across all inventory years.[14] Changes in emission estimates from the 2017 inventory report estimates are largely due to the following:

1. updates to Domestic and Military Aviation and Aviation International Bunker Fuels category to reflect revised fuel consumption estimates,
2. updates to incorporate CH_4 emissions from industrial landfills and application of a back-casting method based on GHGRP-reported data for landfills,
3. updates to incorporate new sources of Hawaiʻi-specific data (e.g., tons of waste composted),
4. updates to the Nitrogen excretion (Nex) rates and weighted Methane Conversion Factors (MCFs) to incorporate Hawaiʻi specific data for agricultural soil carbon,
5. updates to incorporate top-down estimates for cattle population data for Enteric Fermentation and Manure Management, and
6. updates to historical urea fertilizer consumption for Urea Application.

Updates to the U.S. Inventory also resulted in some minor updates compared to the 2017 report for the sectors that utilize data from the U.S. Inventory, such as Agricultural Soil Carbon, Substitution of Ozone Depleting Substances (ODS), and Electric Transmission and Distribution. These and other updates that impacted emission 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 2017 inventory report.

1.3. Methodologies and Data Sources

ICF relied on the best available activity data, emission 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 per amount of activity (EPA 2022a).

[14] 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.

Key guidance and resources included the *2006 IPCC Guidelines for National Greenhouse Gas Inventories, 2019 Refinements to 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: 1990-2020* (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. Refinements to the methodologies and emission factors from the IPCC Guidelines were updated to reflect the *2019 Refinements to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

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 Hawaiʻi using default values and compared the output against the 2019 inventory and the inventory projections for 2020, 2025, 2030, and 2045. The results of this comparison are presented and discussed in Appendix J. In addition, the results were reviewed by representatives from the Department of Health (DOH) as well as a group of other government entities.[15] 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 2022a). 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

[15] The review team included representatives from the Hawaiʻi Department of Business, Economic Development and Tourism (DBEDT), Division of Consumer Advocacy (DCA), Public Utilities Commission (PUC), County of Honolulu, County of Hawaiʻi, County of Kauaʻi, County of Maui, and Department of Land and Natural Resources (DLNR).

uncertainty for total emissions. Uncertainties in the emission 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.[16] Appendix I 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	2019 Emission Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emission Estimate[a]				Mean[b]	Standard Deviation[b]
		(MMT CO_2 Eq.)		(percent)		(MMT CO_2 Eq.)	
		Lower Bound[c]	Upper Bound[c]	Lower Bound	Upper Bound		
Energy	19.4	19.1	19.9	-1.8%	2.3%	19.5	0.2
IPPU	0.8	0.8	0.9	-3.7%	8.0%	0.9	0.0
AFOLU (Sources)	1.3	(1.4)	3.8	-210.6%	187.5%	1.2	1.4
AFOLU (Sinks)	(2.6)	(3.1)	(2.3)	19.9%	-10.5%	(2.7)	0.2
Waste	0.4	0.4	0.4	-6.7%	7.7%	0.4	0.0
Total Emissions	**22.0**	**19.3**	**24.6**	**-12.4%**	**11.6%**	**21.9**	**1.4**
Net Emissions	**19.4**	**16.5**	**21.9**	**-14.8%**	**12.9%**	**19.2**	**1.4**
Net Emissions (Excl. Aviation)	**13.6**	**10.7**	**16.0**	**-21.0%**	**18.0%**	**13.4**	**1.4**

[a] The uncertainty estimates correspond to a 95 percent confidence interval, with the lower bound corresponding to 2.5th percentile and the upper bound corresponding to 97.5th percentile.
[b] Mean value indicates the arithmetic average of the simulated emission estimates; standard deviation indicates the extent of deviation of the simulated values from the mean.
[c] The lower and upper bound emission estimates for the sub-source categories do not sum to total emissions because the low and high estimates for total emissions were calculated separately through simulations.

1.6. Organization of Report

The remainder of this report is organized as follows:

- **Chapter 2: Emission Results –** Summarizes 2005 and 2019 inventory results for the state of Hawaiʻi, 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

[16] 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.

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, 2030, 2035, 2040, and 2045 under a baseline and three alternate scenarios. County-level GHG emissions and sinks for 2020, 2025, 2030, 2035, 2040, and 2045 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.

Appendices

- **Appendix A: IPCC 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 2017 Inventory Report –** Summarizes changes in emission estimates relative to the 2017 inventory report.
- **Appendix C: Inventory Improvements –** Proposed updates that will be reviewed for implementation in future inventory reports.
- **Appendix D: County Emissions Methodology –** Summarizes the methodology used to quantify Hawaiʻi's GHG emissions by county.
- **Appendix E: Hawaiʻi Administrative Rule (HAR) Facility Data –** Summarizes annual GHG emissions from HAR affected facilities for 2010 to 2019 and projections for 2020, 2025, 2030, 2035, 2040, and 2045.
- **Appendix F: Activity Data –** Summarizes by sector the activity data used to develop the inventory presented in this report.
- **Appendix G: Emission Factors –** Summarizes by sector the emission factors used to develop the inventory presented in this report.
- **Appendix H: ODS Emissions –** Summarizes for informational purposes estimated emissions from ozone depleting substances (ODS) for the state of Hawaiʻi.

- **Appendix I: 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 J: Emission Projections Methodology –** Summarizes the methodology used to project emissions for 2020, 2025, 2030, 2035, 2040, and 2045 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 Hawaiʻi generated by EPA's State Inventory and Projections Tool against the results of the 2019 inventory and the emission projections for 2020, 2025, 2030, and 2045.

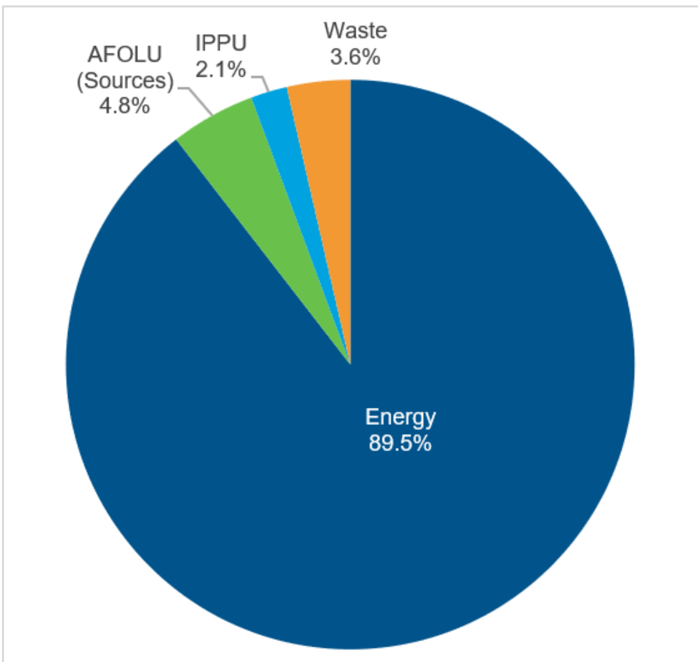
2. Emission Results

This chapter summarizes 2005 and 2019 inventory results for the state of Hawaiʻi, trends in GHG emissions and sinks across the inventory years since 1990, and emissions by county. Inventory year 2019 is the most recent year for which a full inventory has been developed. Additionally, 2005 is highlighted, as it is the baseline year against which emission reductions are measured, set by Act 238 of 2022.

2.1. Overview of 2005 GHG Emissions

In 2005, total GHG emissions in Hawaiʻi were 25.37 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 22.81 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (89.5 percent) of total emissions in Hawaiʻi, followed by the AFOLU sector (4.8 percent) when excluding sinks, the waste sector (3.6 percent), and the IPPU sector (2.1 percent). Figure 2-1 illustrates the breakdown of emissions by sector for 2005.

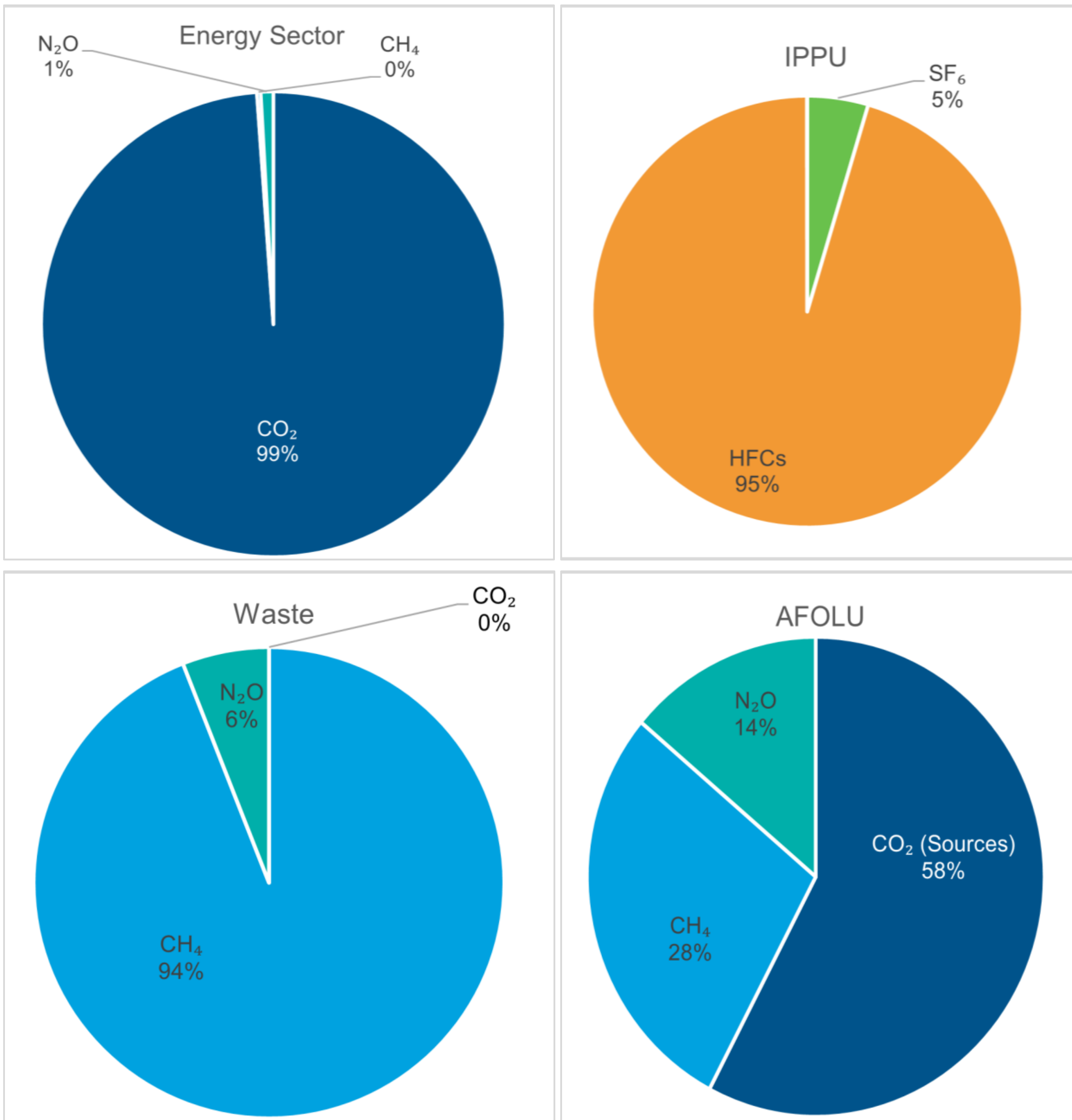
Figure 2-1: Hawaiʻi 2005 GHG Emissions by Sector (Excluding Sinks, Including Aviation)



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

Carbon dioxide was the largest single contributor to statewide GHG emissions in 2005, accounting for roughly 91.2 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). Methane was the second largest contributor (5.0 percent), followed by HFCs and PFCs (2.0 percent), nitrous oxide (1.7 percent), and sulfur hexafluoride (0.1 percent). Figure 2-2 illustrates the breakdown of emissions by gas from each sector for 2005.

Figure 2-2: Hawai'i 2005 GHG Emissions by Gas (Excluding Sinks, Including Aviation)

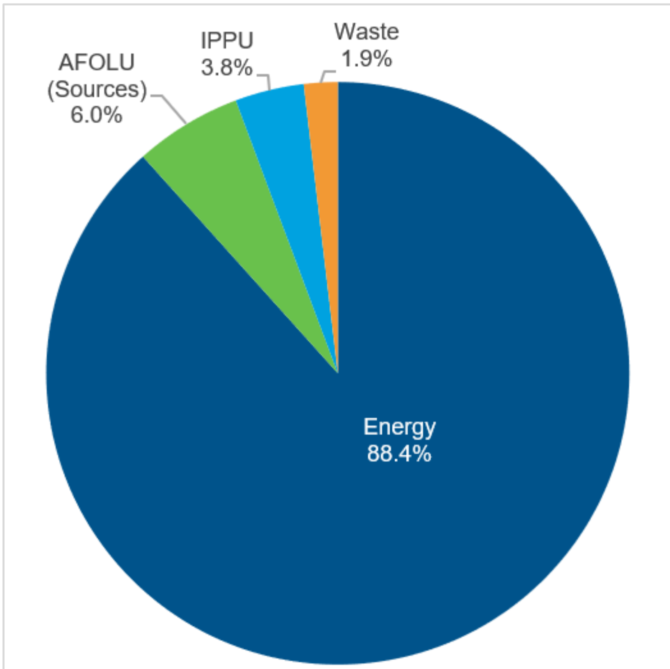


Note: Totals may not sum due to independent rounding. Percentages represent the percent of total emissions excluding sinks and including aviation.

2.2. Overview of 2019 GHG Emissions

In 2019, total GHG emissions in Hawaiʻi were 22.00 MMT CO_2 Eq. Net emissions, which take into account carbon sinks, were 19.41 MMT CO_2 Eq. Emissions from the Energy sector accounted for the largest portion (88.4 percent) of total emissions in Hawaiʻi, followed by the AFOLU sector (6.0 percent) when excluding sinks, the IPPU sector (3.8 percent), and the Waste sector (1.9 percent). Figure 2-3 illustrates the breakdown of emissions by sector for 2019.

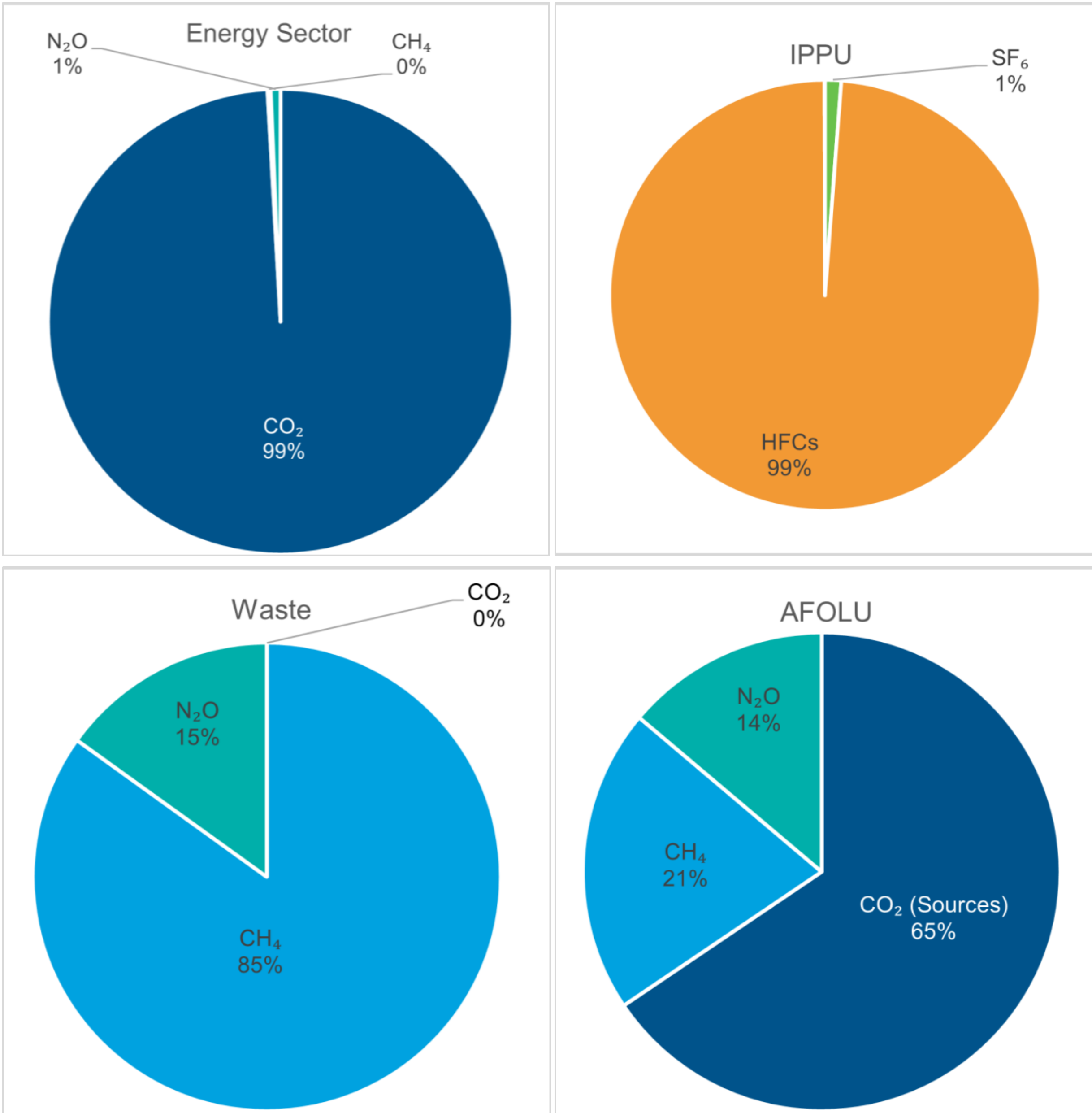
Figure 2-3: Hawaiʻi 2019 GHG Emissions by Sector (Excluding Sinks, Including Aviation)



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

Carbon dioxide was the largest single contributor to statewide GHG emissions in 2019, accounting for roughly 91.4 percent of total emissions on a GWP-weighted basis (CO_2 Eq.). HFCs and PFCs were the second largest contributor (3.8 percent), followed by methane (3.1 percent), nitrous oxide (1.7 percent), and sulfur hexafluoride (less than 0.1 percent). Figure 2-4 illustrates the breakdown of emissions by gas for 2019.

Figure 2-4: Hawaiʻi 2019 GHG Emissions by Gas (Excluding Sinks, Including Aviation)

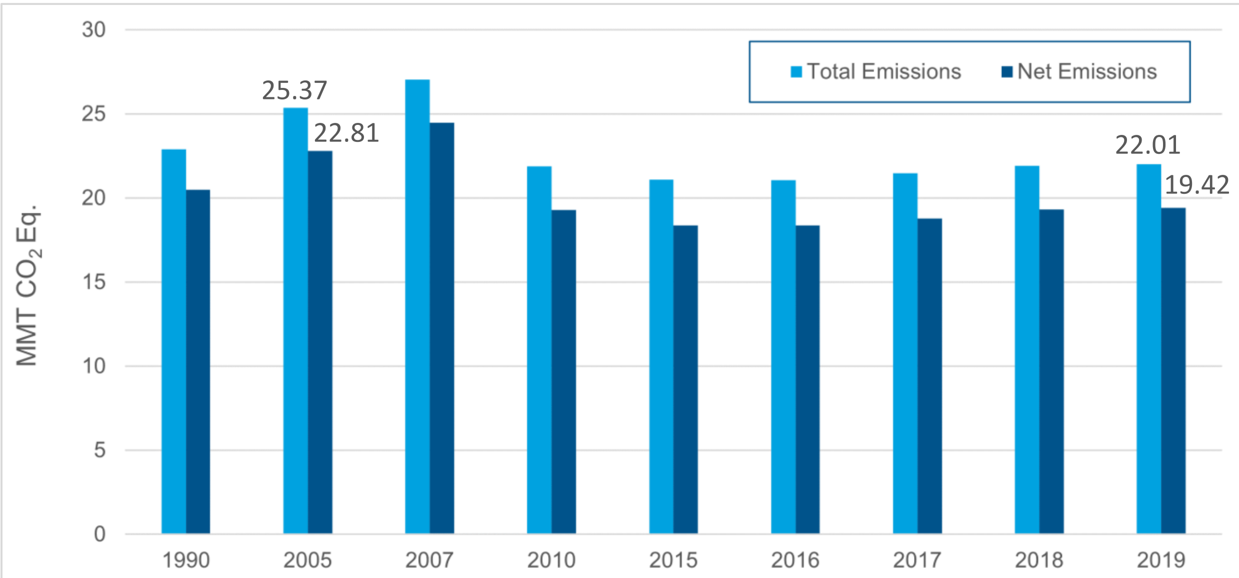


Note: Totals may not sum due to independent rounding. Percentages represent the percent of total emissions excluding sinks and including aviation.

2.3. Emissions Trends

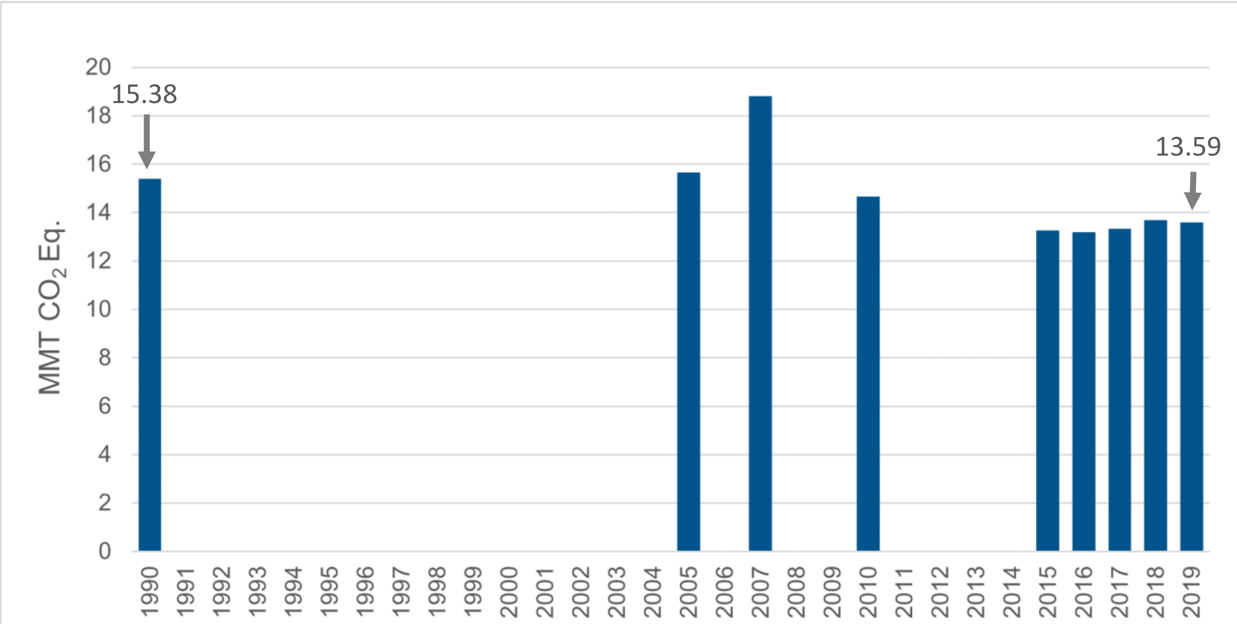
Total GHG emissions in Hawaiʻi grew by 18.0 percent between 1990 and 2007 before decreasing by about 18.6 percent between 2007 and 2019. Compared to 1990, total emissions in Hawaiʻi in 2019 were roughly 3.9 percent lower, while net emissions were lower by roughly 5.2 percent. Figure 2-5 below shows total and net GHG emissions for each inventory year compiled. Figure 2-6 shows the full time period over 1990-2019 and data for the years in which inventories have been compiled including sinks and excluding emissions from aviation.

Figure 2-5: Hawai'i Total and Net GHG Emissions by Year (Including Aviation)



Notes: Total and net emissions including aviation emissions. Sinks are included in net emissions.

Figure 2-6: Hawai'i Net GHG Emissions Inventory Estimates (Including Sinks, Excluding Aviation)

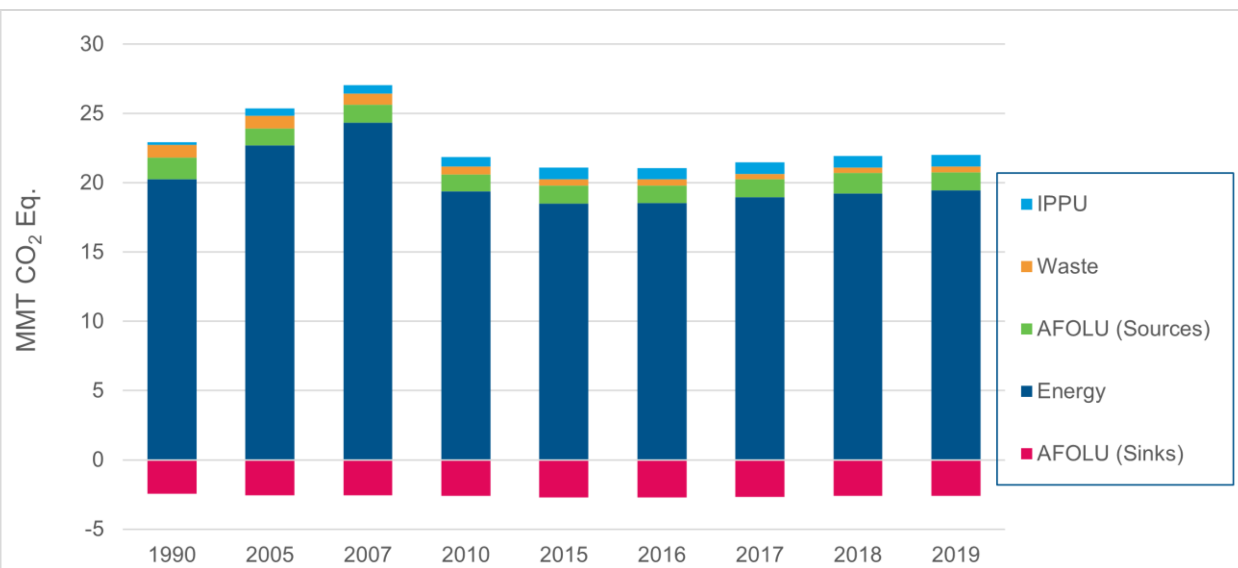


Note: Emission estimates include sinks and exclude aviation emissions.

2.4. Emissions by Sector

Figure 2-7 below shows emissions and sinks for each inventory year by sector. Emissions by sector, source/sink, and year are also summarized in Table 2-1.

Figure 2-7: Net Hawai'i GHG Emissions by Sector (1990, 2005, 2007, 2010, and 2015 – 2019) (Including Sinks and Aviation)



Notes: Emissions estimates represent net emissions including sinks and aviation.

Table 2-1: Hawai'i GHG Emissions by Sector/Category for 1990, 2005, 2007, 2010, and 2015-2019 (MMT CO_2 Eq.)

Sector/Category	1990	2005	2007	2010	2015	2016	2017	2018	2019
Energy	**20.26**	**22.71**	**24.35**	**19.38**	**18.50**	**18.52**	**18.97**	**19.23**	**19.44**
Stationary Combustion	8.47	9.56	9.37	8.89	8.16	7.95	8.09	8.15	8.32
Energy Industries[17]	6.38	8.33	8.31	7.86	7.11	7.01	7.00	7.12	7.21
Residential	0.05	0.07	0.06	0.09	0.06	0.07	0.07	0.06	0.06
Commercial	0.76	0.37	0.30	0.37	0.47	0.47	0.54	0.55	0.60
Industrial	1.29	0.80	0.69	0.56	0.51	0.39	0.48	0.43	0.45
Transportation	11.13	12.58	14.40	9.93	9.72	9.97	10.31	10.47	10.68
Ground	3.73	5.04	5.15	4.20	4.29	4.22	4.16	4.13	4.03
Domestic Marine	1.54	0.38	2.81	0.58	0.28	0.40	0.49	0.37	0.65
Domestic Aviation	3.68	6.12	4.85	3.98	4.29	4.38	4.61	4.78	4.95
Military Aviation	1.42	1.03	0.80	0.66	0.81	0.80	0.85	0.86	0.88
Military Non-Aviation	0.77	0.02	0.79	0.51	0.05	0.17	0.20	0.32	0.16
Incineration of Waste[a]	0.18	0.15	0.15	0.19	0.27	0.27	0.23	0.26	0.28
Oil and Natural Gas Systems	0.43	0.39	0.39	0.32	0.31	0.29	0.31	0.30	0.11
Non-Energy Uses	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04
International Bunker Fuels[b]	1.58	2.25	1.10	1.32	1.56	1.55	1.76	1.78	1.64
CO_2 from Wood Biomass and Biofuels Consumption[b]	2.43	0.59	0.88	1.24	1.40	1.49	1.26	1.29	1.28
IPPU	**0.17**	**0.52**	**0.58**	**0.71**	**0.83**	**0.83**	**0.83**	**0.83**	**0.84**
Cement Production	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Substitution of Ozone Depleting Substances	+	0.50	0.57	0.70	0.82	0.82	0.82	0.82	0.83
Electrical Transmission and Distribution	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
AFOLU (Sources)	**1.55**	**1.22**	**1.29**	**1.24**	**1.28**	**1.29**	**1.28**	**1.48**	**1.31**
Enteric Fermentation	0.31	0.28	0.29	0.27	0.24	0.25	0.25	0.25	0.25

[17] Energy Industries refer to the resources listed as generation units under Appendix E, with emissions of at least 100,000 tons per year, and the Par Refinery.

Sector/Category	1990	2005	2007	2010	2015	2016	2017	2018	2019
Manure Management	0.13	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Agricultural Soil Management	0.18	0.16	0.17	0.16	0.16	0.17	0.17	0.17	0.18
Field Burning of Agricultural Residues	0.03	0.03	0.01	0.01	0.01	0.01	+	0.00	0.00
Urea Application	+	+	+	+	+	+	+	+	+
Agricultural Soil Carbon	0.80	0.68	0.67	0.76	0.82	0.82	0.83	0.83	0.83
Forest Fires	0.10	0.03	0.12	0.01	0.04	0.02	0.01	0.20	0.04
AFOLU (Sinks)	**(2.43)**	**(2.56)**	**(2.57)**	**(2.58)**	**(2.72)**	**(2.69)**	**(2.68)**	**(2.59)**	**(2.59)**
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.06)	(0.05)
Urban Trees	(0.51)	(0.66)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)	(0.62)	(0.63)
Forest Carbon	(1.79)	(1.86)	(1.89)	(1.95)	(2.07)	(2.04)	(2.02)	(1.91)	(1.91)
Waste	**0.93**	**0.91**	**0.82**	**0.55**	**0.47**	**0.43**	**0.40**	**0.38**	**0.41**
Landfills	0.81	0.76	0.67	0.44	0.36	0.32	0.29	0.28	0.30
Composting	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03
Wastewater Treatment	0.11	0.12	0.12	0.07	0.07	0.07	0.07	0.07	0.07
Total Emissions (Excluding Sinks)	**22.91**	**25.37**	**27.04**	**21.88**	**21.08**	**21.07**	**21.48**	**21.92**	**22.01**
Net Emissions (Including Sinks)	**20.48**	**22.81[c]**	**24.47**	**19.29**	**18.37**	**18.38**	**18.80**	**19.33**	**19.42**
Aviation[d]	**5.10**	**7.14**	**5.65**	**4.64**	**5.10**	**5.18**	**5.47**	**5.64**	**5.83**
Net Emissions (Including Sinks, Excluding Aviation)	**15.38[e]**	**15.66**	**18.81**	**14.65**	**13.27**	**13.20**	**13.33**	**13.69**	**13.59**

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

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

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

[c] Act 238 of 2022 aims for the level of statewide GHG emissions to be at least 50 percent below 2005 levels by the year 2030 (including aviation emissions).

[d] Domestic aviation and military aviation emissions, which are reported under the transportation source category under the Energy sector, are excluded from Hawaiʻi's 2020 GHG emissions reduction goal established in Act 234 of 2007.

[e] Act 234 of 2007 aims to achieve emission levels at or below Hawaiʻi's 1990 GHG emissions by January 1, 2020 (excluding aviation emissions).

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

In all inventory years, emissions from the Energy sector accounted for the largest portion (more than 88 percent) of total emissions in Hawaiʻi. As the largest source of emissions in Hawaiʻi, the Energy sector is a major driver of the overall emissions trends, accounting for 99.0 percent of the emissions increase from 1990 to 2007 and 97.4 percent of reductions between 2007 and 2019. Transportation emissions—which increased between 1990 and 2007, decreased between 2007 and 2015, and then increased again between 2015 and 2019—accounted for the largest share of Energy sector emissions in all inventory years. Stationary combustion emissions—which increased between 1990 and 2005, before consistently decreasing between 2005 and 2016, and then slightly increasing again between 2016 and 2019—is the second largest share of Energy sector emissions. This trend is driven by emissions from energy industries (electric power plants and petroleum refineries) as well as industrial and commercial emissions.

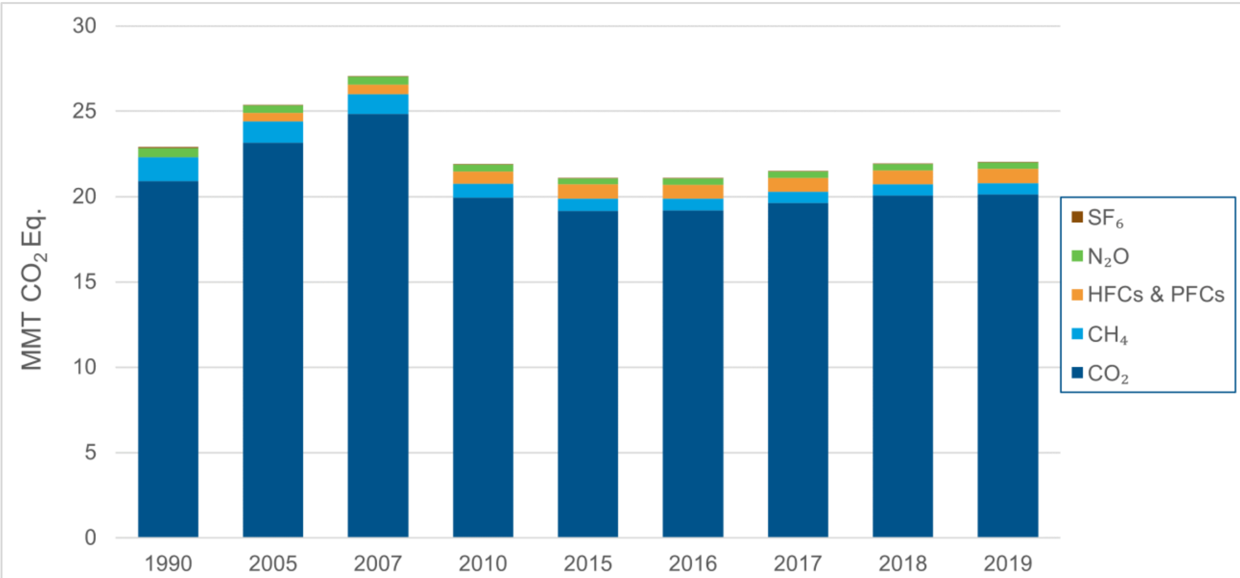
Emissions from AFOLU sources peaked in 1990 for the time period evaluated; emissions from AFOLU sources decreased by about 15.3 percent between 1990 and 2019. Similarly, emissions from the Waste sector peaked in 1990 for the time period evaluated; estimated emissions decreased by about 55.9 percent between 1990 and 2019. Emissions from the IPPU sector have steadily increased since 1990 and were almost four times higher in 2019 compared to 1990 levels. The increase in IPPU emissions is attributable to the growth in HFC and PFC emissions from substitution of ozone depleting substances (ODS), as there is no longer Cement Production in Hawaiʻi and emissions from Electrical Transmission and Distribution has decreased over the time period 1990 to 2019. Lastly, carbon removals from AFOLU sinks have also increased since 1990, growing by roughly 6.5 percent between 1990 and 2019.

Further discussion regarding trends specific to each sector and for source categories, are included in the Energy (Chapter 3), IPPU (Chapter 4), AFOLU (Chapter 5), and Waste (Chapter 6) chapters.

2.5. Emissions by Gas

In all inventory years, CO_2 comprised the vast majority of emissions. CO_2 emissions increased between 1990 and 2007, decreased between 2007 and 2015, and then increased between 2015 and 2019. Methane emissions decreased between 1990 and 2019. Emissions of HFCs and PFCs grew substantially from 1990 to 2019, while SF_6 emissions decreased over the same period. Emissions of N_2O similarly decreased between 1990 and 2007 and continue to decrease slightly between 2007 and 2019. Figure 2-8 shows emissions for each inventory year by gas.

Figure 2-8: Hawaiʻi Total GHG Emissions by Gas (1990, 2005, 2007, 2010, and 2015 – 2019) (Excluding Sinks and Including Aviation)



Notes: Emissions estimates represent total emissions excluding sinks and including aviation.

2.6. Emissions by County

In 2019, Honolulu County accounted for the largest share of net GHG emissions (71.3 percent), followed by Maui County[18] (14.3 percent), Hawaiʻi County (10.0 percent), and Kauaʻi County (4.4 percent). Figure 2-9 shows the breakout of net emissions by county in 2019. Emissions by county are also summarized in Table 2-2.

[18] Maui County includes emissions from Kalawao County.

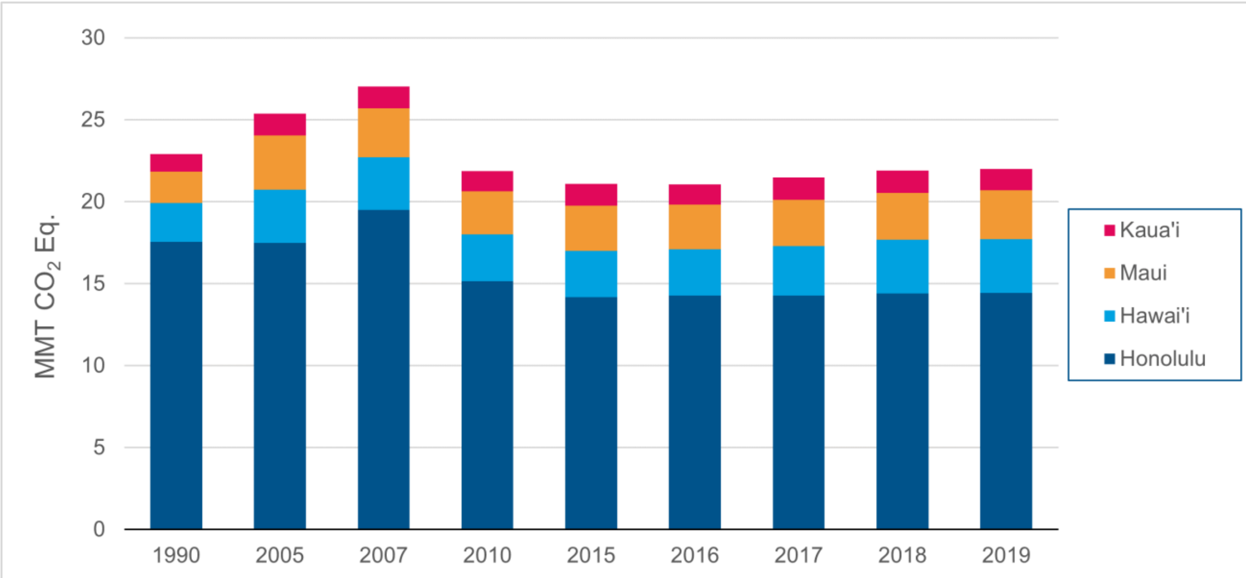
Table 2-2: GHG Emissions by County for 1990, 2005, 2007, 2010, and 2015 – 2019 (MMT CO_2 Eq.)

Sector/County	1990	2005	2007	2010	2015	2016	2017	2018	2019
Energy	**20.26**	**22.71**	**24.35**	**19.38**	**18.50**	**18.52**	**18.97**	**19.23**	**19.44**
Hawaiʻi	1.35	2.19	2.12	1.80	1.80	1.78	1.96	2.09	2.17
Honolulu	16.60	16.48	18.56	14.33	13.34	13.44	13.48	13.55	13.62
Kauaʻi	0.60	0.96	0.92	0.85	0.92	0.88	1.02	1.05	1.01
Maui	1.71	3.07	2.75	2.40	2.45	2.43	2.51	2.54	2.65
IPPU	**0.17**	**0.53**	**0.58**	**0.71**	**0.83**	**0.83**	**0.83**	**0.83**	**0.84**
Hawaiʻi	0.01	0.08	0.09	0.10	0.12	0.12	0.12	0.12	0.12
Honolulu	0.16	0.35	0.38	0.47	0.55	0.55	0.54	0.54	0.54
Kauaʻi	0.00	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05
Maui	0.01	0.07	0.08	0.10	0.11	0.12	0.12	0.12	0.12
Waste	**0.93**	**0.91**	**0.82**	**0.55**	**0.47**	**0.43**	**0.40**	**0.38**	**0.41**
Hawaiʻi	0.10	0.18	0.18	0.17	0.12	0.12	0.12	0.12	0.13
Honolulu	0.66	0.55	0.46	0.24	0.17	0.18	0.14	0.14	0.14
Kauaʻi	0.14	0.10	0.10	0.09	0.08	0.03	0.03	0.02	0.02
Maui	0.04	0.08	0.09	0.04	0.09	0.10	0.10	0.10	0.13
AFOLU (Sources)	**1.55**	**1.22**	**1.29**	**1.24**	**1.28**	**1.29**	**1.28**	**1.48**	**1.31**
Hawaiʻi	0.90	0.80	0.83	0.80	0.79	0.80	0.81	0.94	0.84
Honolulu	0.14	0.10	0.11	0.11	0.12	0.13	0.13	0.16	0.15
Kauaʻi	0.32	0.24	0.27	0.25	0.27	0.26	0.24	0.26	0.21
Maui	0.19	0.09	0.09	0.08	0.09	0.10	0.10	0.12	0.11
AFOLU (Sinks)	**(2.43)**	**(2.56)**	**(2.57)**	**(2.58)**	**(2.72)**	**(2.69)**	**(2.68)**	**(2.59)**	**(2.59)**
Hawaiʻi	(1.21)	(1.32)	(1.29)	(1.32)	(1.37)	(1.36)	(1.32)	(1.31)	(1.31)
Honolulu	(0.62)	(0.60)	(0.60)	(0.57)	(0.65)	(0.65)	(0.64)	(0.60)	(0.60)
Kauaʻi	(0.35)	(0.34)	(0.38)	(0.38)	(0.35)	(0.35)	(0.37)	(0.45)	(0.45)
Maui	(0.25)	(0.30)	(0.31)	(0.31)	(0.34)	(0.34)	(0.34)	(0.23)	(0.23)
Total Emissions (Excluding Sinks, IBF and CO_2 from Wood Biomass Burning)	**22.91**	**25.37**	**27.04**	**21.88**	**21.08**	**21.07**	**21.48**	**21.92**	**22.01**

Net Emissions (Including Sinks)	**20.48**	**22.81**	**24.47**	**19.29**	**18.37**	**18.38**	**18.80**	**19.33**	**19.42**
Net Emissions (Including Sinks, Excluding Aviation)	**15.38**	**15.66**	**18.81**	**14.65**	**13.27**	**13.20**	**13.33**	**13.69**	**13.59**

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

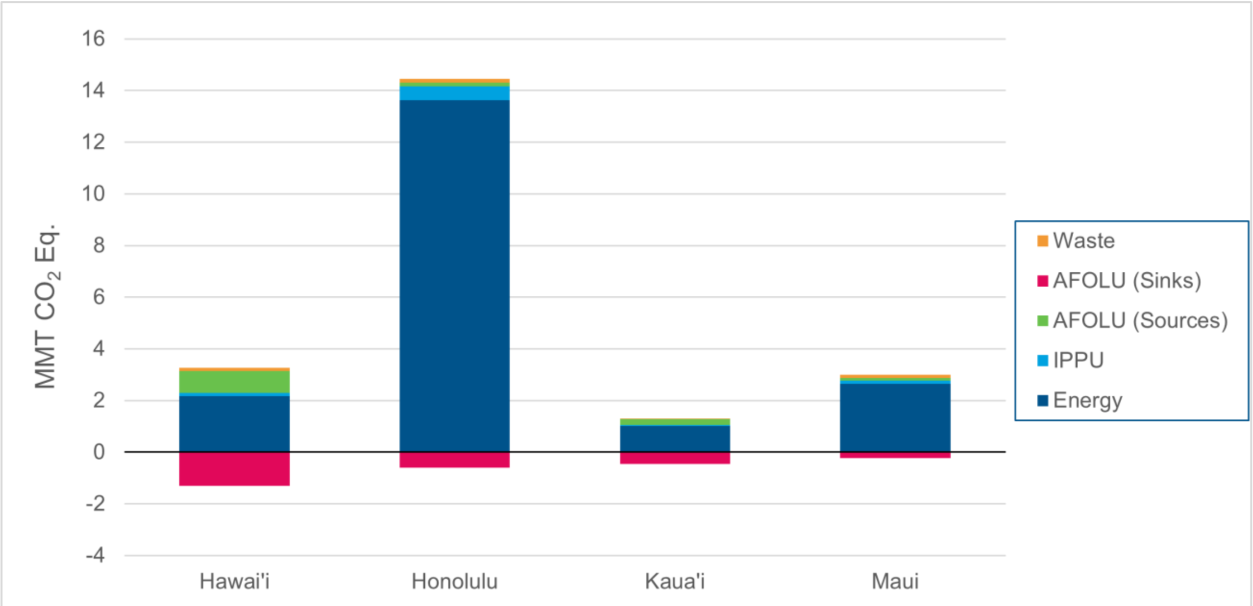
Figure 2-9: Total GHG Emissions by County (1990, 2005, 2007, 2010, and 2015 – 2019) (Excluding Sinks and Including Aviation)



Notes: Emissions estimates represent total emissions excluding sinks and including aviation.

Emissions from the Energy sector accounted for the largest portion of the total emissions from each county in all inventory years. In 2019, emissions from the Energy sector accounted for 94.3 percent of emissions from Honolulu County, 88.1 percent of emissions from Maui County, 77.6 percent of emissions from Kauaʻi County, and 66.6 percent of emissions from Hawaiʻi County. Emissions from AFOLU sources accounted for the second largest portion of emissions from Hawaiʻi County and Kauaʻi County. Emissions from the IPPU sector accounted for the second largest portion of emissions from Honolulu County and emissions from the Waste sector accounted for the second largest portion of emissions from Maui County. Figure 2-10 shows total emissions by county and sector in 2019.

Figure 2-10: Net Emissions by County and Sector, in 2019 (Including Sinks and Aviation)



Notes: Emissions estimates include sinks and aviation emissions.

The methodology used to develop estimates of emissions and sequestration varies by source/sink. 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 apportioned to each county using data such as population or vehicle miles traveled (VMT). Appendix D summarizes the methodology used to quantify Hawai'i's GHG emissions by county.

3. Energy

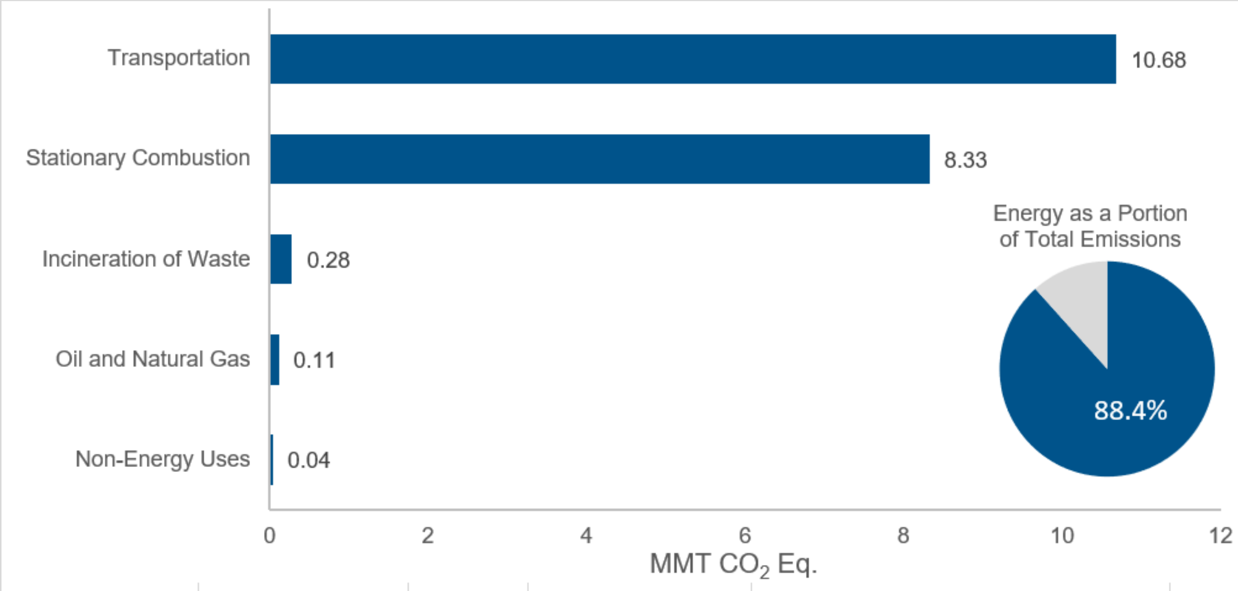
This chapter presents GHG emissions that result from energy-related activities, primarily fuel combustion for transportation and generation of electricity. For the state of Hawaiʻi, energy sector emissions are estimated from the following sources: stationary combustion (IPCC Source Categories 1A1, 1A2, 1A4, 1A5), transportation (IPCC Source Category 1A3), incineration of waste (IPCC Source Category 1A1a), oil and natural gas systems[19] (IPCC Source Category 1B2), and non-energy uses (NEUs) (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 2019, emissions from the Energy sector were 19.44 MMT CO_2 Eq., accounting for 88.4 percent of total Hawaiʻi emissions. Emissions from transportation accounted for the largest share of Energy sector emissions (54.9 percent), followed closely by stationary combustion (42.8 percent). Emissions from oil and natural gas systems, waste incineration, and non-energy uses comprised a relatively small portion of Energy sector emissions (2.2 percent). Figure 3-1 and Figure 3-2 show emissions from the Energy sector by source for 2019.

[19] The state of Hawaiʻi does not have any natural gas exploration, production, processing, or transmission systems present. Sources of emissions in the natural gas systems category include fugitive emissions from propane and synthetic natural gas.

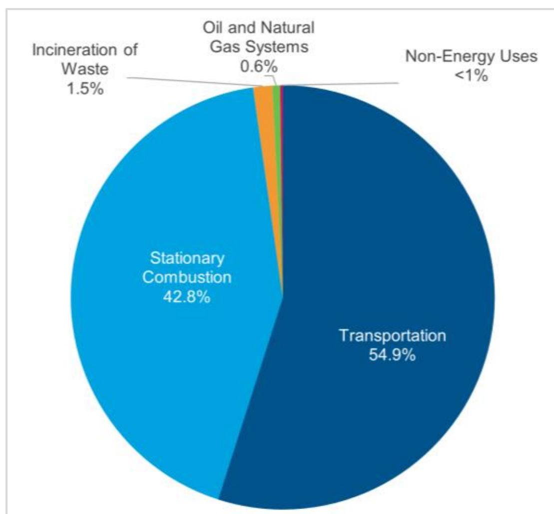
[20] IPCC Source Categories for which emissions were not estimated for the state of Hawaiʻi include: Fugitive emissions from Solid Fuels (1B1) and CO_2 Transport and Storage (1C). Appendix A provides information on why emissions were not estimated for these IPCC Source Categories.

Figure 3-1: 2019 Energy Emissions by Source (Including Aviation)



Note: Biogenic CO_2 emissions from Wood Biomass and Biofuel Consumption are not included in emission totals, as per IPCC (2006) guidelines. Aviation emissions are included in emission totals.

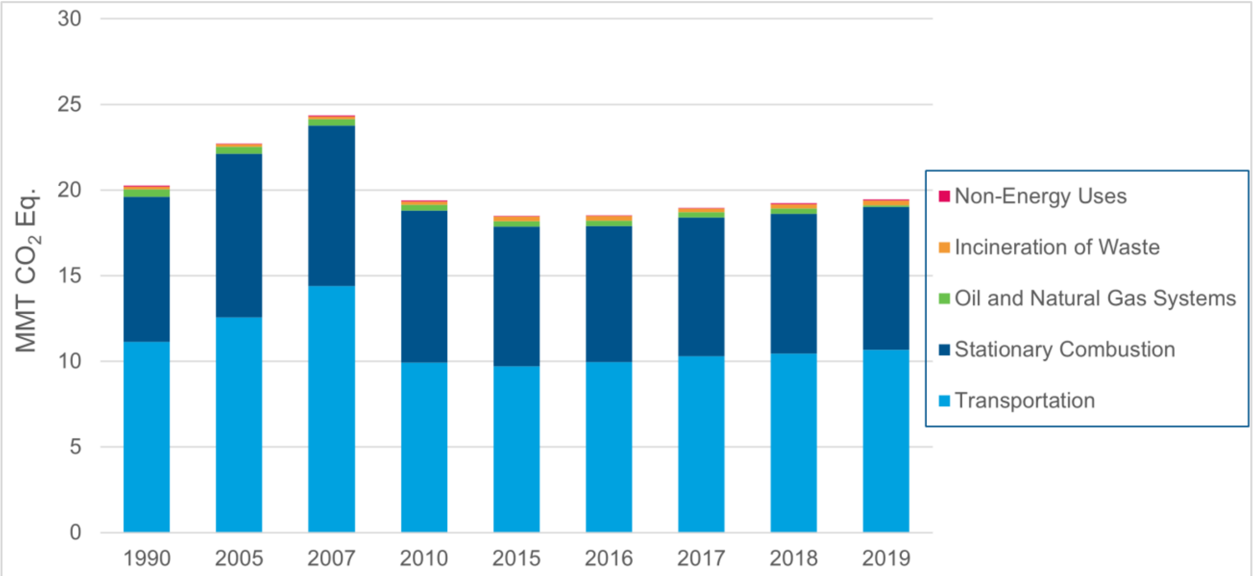
Figure 3-2: 2019 Energy Emissions by Source (Including Aviation)



Note: Percentages represent the percent of energy emissions including aviation.

Relative to 1990, emissions from the Energy sector in 2019 were lower by roughly 4.0 percent. Emissions from the Energy sector peaked in 2007 and were 20.2 percent higher compared to 1990. Between 2007 and 2019, Energy emissions decreased by 20.1 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. The trend in transportation emissions, which increased significantly from 1990 to 2007, decreased from 2007 to 2010, and then increased again between 2010 and 2019. Transportation emissions are largely driven by domestic aviation and ground transportation emissions, which together account for roughly 92.3 percent of transportation emissions. The trend in stationary combustion emissions, which increased between 1990 and 2005, and decreased between 2005 and 2019, 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 summarized in Table 3-1.

Figure 3-3: Energy Sector Emissions by Source and Year (Including Aviation)



Note: Emission estimates include aviation emissions.

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

Source	1990	2005	2007	2010	2015	2016	2017	2018	2019
Stationary Combustion	**8.47**	**9.56**	**9.37**	**8.89**	**8.16**	**7.95**	**8.08**	**8.15**	**8.33**
Energy Industries	6.38	8.33	8.31	7.86	7.11	7.01	7.00	7.12	7.21
Residential	0.05	0.07	0.06	0.09	0.06	0.07	0.07	0.06	0.06
Commercial	0.76	0.37	0.30	0.37	0.47	0.47	0.54	0.55	0.60
Industrial	1.29	0.80	0.69	0.56	0.51	0.39	0.48	0.43	0.45
Transportation[a]	**11.13**	**12.58**	**14.40**	**9.93**	**9.72**	**9.97**	**10.31**	**10.47**	**10.68**
Ground	3.73	5.04	5.15	4.20	4.29	4.22	4.16	4.13	4.03
Marine	1.54	0.38	2.81	0.58	0.28	0.40	0.49	0.37	0.65
Aviation	3.68	6.12	4.85	3.98	4.29	4.38	4.61	4.78	4.95
Military Aviation	1.42	1.03	0.80	0.66	0.81	0.80	0.85	0.86	0.88
Military Non-Aviation	0.77	0.02	0.79	0.51	0.05	0.17	0.20	0.32	0.16
Incineration of Waste	**0.18**	**0.15**	**0.15**	**0.19**	**0.27**	**0.27**	**0.23**	**0.26**	**0.28**
Oil and Natural Gas[b]	**0.43**	**0.39**	**0.39**	**0.32**	**0.31**	**0.29**	**0.31**	**0.30**	**0.11**
Non-Energy Uses	**0.04**	**0.04**	**0.04**	**0.05**	**0.05**	**0.04**	**0.04**	**0.04**	**0.04**
International Bunker Fuels[c]	*1.58*	*2.25*	*1.10*	*1.32*	*1.56*	*1.55*	*1.76*	*1.78*	*1.64*
CO_2 from Wood Biomass and Biofuels Consumption[c]	*2.43*	*0.59*	*0.88*	*1.24*	*1.40*	*1.49*	*1.26*	*1.29*	*1.28*
Total	**20.26**	**22.71**	**24.35**	**19.38**	**18.50**	**18.52**	**18.97**	**19.23**	**19.44**

[a] Includes CH_4 and N_2O emissions from 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.

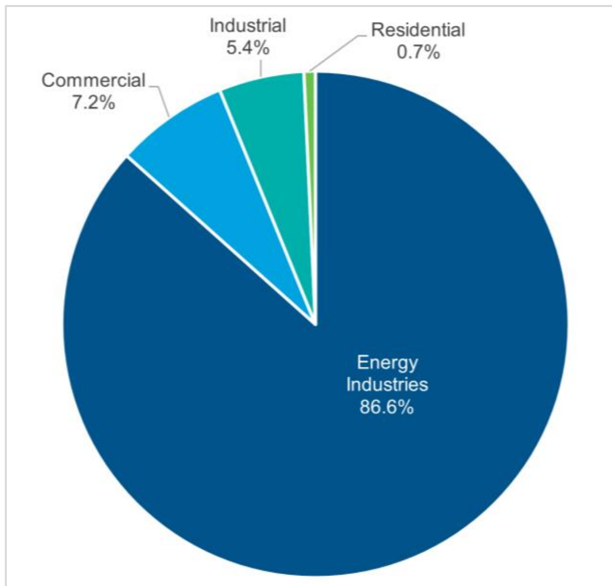
Notes: Totals may not sum due to independent rounding.

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. Facility-level data for Hawaiʻi Administrative Rule (HAR) affected facilities are provided in Appendix E.[21] Activity data and emission factors used in the analysis are summarized in Appendix F and Appendix G, respectively.

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

Fossil fuels are burned to generate energy from a variety of stationary sources, including electric power plants, industrial facilities, commercial businesses, and homes. When fossil fuels are combusted, they release CO_2, CH_4, and N_2O emissions. Stationary combustion emissions can be broken out by economic sector (i.e., energy industries, residential, commercial, and industrial). In 2019, emissions from stationary combustion in Hawaiʻi were 8.33 MMT CO_2 Eq., accounting for 42.8 percent of Energy sector emissions. The vast majority of these emissions are from energy industries (86.6 percent), which includes both electric power plants (i.e., facilities that generate electricity for the residential, commercial, and industrial economic sectors) and petroleum refineries. The commercial sector accounted for the next largest portion of stationary combustion emissions (7.2 percent), followed by the industrial (5.4 percent) and residential sectors (0.7 percent). Figure 3-4 shows the breakout of stationary combustion emissions by economic sector for 2019.

Figure 3-4: 2019 Stationary Combustion Emissions by Economic Sector



Relative to 1990, emissions from stationary combustion in 2019 were lower by roughly 1.8 percent. This trend is largely driven by emissions from residual fuel consumption associated with energy industries, which decreased from 1990 to 2019. Emissions from the industrial sector decreased from 1990 to 2019. Emissions from the residential sector followed an inconsistent trend, fluctuating between 0.05 and 0.09 MMT CO_2 Eq. over the time period. Emissions from the commercial sector decreased from 1990 to 2007, and then consistently increased from 2007 to 2019. Figure 3-5 presents emissions from stationary combustion in Hawaiʻi by economic sector for 1990, 2005, 2007, 2010, and 2015 – 2019. Table 3-2

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

summarizes emissions from stationary combustion in Hawaiʻi by economic sector and gas for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

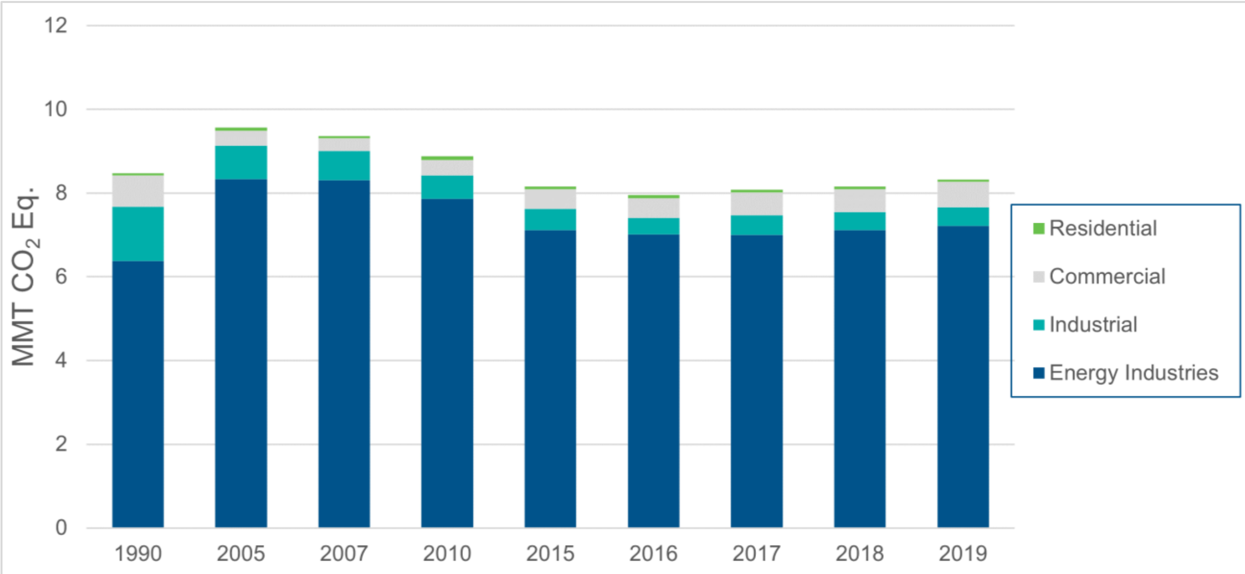


Table 3-2: GHG Emissions from Stationary Combustion by Economic Sector and Gas (MMT CO_2 Eq.)

Economic Sector/Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
Energy Industries	**6.38**	**8.33**	**8.31**	**7.86**	**7.11**	**7.01**	**7.00**	**7.12**	**7.21**
CO_2	6.35	8.30	8.28	7.83	7.09	6.98	6.97	7.09	7.18
CH_4	0.01	0.01	0.01	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	0.02	0.02	0.02
Residential	**0.05**	**0.07**	**0.06**	**0.09**	**0.06**	**0.07**	**0.07**	**0.06**	**0.06**
CO_2	0.05	0.07	0.06	0.09	0.06	0.07	0.07	0.06	0.06
CH_4	+	+	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+	+	+
Commercial	**0.76**	**0.37**	**0.30**	**0.37**	**0.47**	**0.47**	**0.54**	**0.55**	**0.60**
CO_2	0.76	0.33	0.28	0.34	0.44	0.44	0.51	0.52	0.57
CH_4	+	0.03	0.02	0.02	0.02	0.03	0.03	0.03	0.03
N_2O	+	+	+	+	+	0.01	0.01	0.01	0.01
Industrial	**1.29**	**0.80**	**0.69**	**0.56**	**0.51**	**0.39**	**0.48**	**0.43**	**0.45**
CO_2	1.25	0.79	0.68	0.55	0.50	0.39	0.47	0.43	0.45
CH_4	0.01	+	+	+	+	+	+	+	+
N_2O	0.02	+	0.01	0.01	0.01	+	+	+	+
Total	**8.47**	**9.56**	**9.37**	**8.89**	**8.16**	**7.95**	**8.08**	**8.15**	**8.33**

\+ 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[22]:

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

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[23]:

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

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 2022a). 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 2022a) for ethanol.

Fuel consumption data by end-use sector were obtained from Energy Information Administration's State Energy Data System (SEDS) (EIA 2022a) for all years.[24] 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 Hawaiʻi Department of Business, Economic Development, and Tourism (DBEDT 2008a) for 2007.[25] Fuel gas and naphtha consumption estimates for 2005 were proxied based on 2007 estimates. For 2010, and 2015 – 2019, CO_2, CH_4, and N_2O emissions from fuel gas and naphtha consumption were obtained directly from EPA's GHGRP (EPA 2022b). Methane and N_2O emissions from biodiesel consumption at the Hawaiian Electric Company (HECO), Hawaiʻi Electric Light

[22] All CO_2 emissions have been converted to MMT CO_2 Eq. based on the conversion factor for pounds to MMT, which is 0.00045359 lb/MMT.
[23] All methane and N_2O emissions have been converted to MMT CO_2 Eq. based on the GWPs provided in Table 1-1.
[24] Motor gasoline consumption obtained from EIA (2022a) includes blended ethanol. Pure ethanol consumption obtained from EIA (2022a) was subtracted from motor gasoline prior to estimating emissions.
[25] 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.

Company (HELCO), and the Maui Electric Company (MECO) were estimated based on biodiesel consumption data obtained from DBEDT's Data Warehouse (DBEDT 2022a) and Hawai'i Department of Health (DOH) (2020).[26]

Changes in Estimates since the Previous Inventory Report

Energy industries totals for 2016 have changed from the estimates in the 2017 inventory due to a change in the underlying reporting data reported to EPA's GHGRP by Par East Refinery. Fuel-specific emission factors were updated based on the most recent version of the U.S. Inventory (EPA 2022a). The resulting changes in historical emission estimates are presented in Table 3-3.

Table 3-3: Change in Emissions from Stationary Combustion Relative to 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	8.47	9.37	8.89	8.16	8.01	8.09
This Inventory Report (MMT CO_2 Eq.)	8.47	9.37	8.89	8.16	7.95	8.09
Percent Change	0.0%	0.0%	0.0%	0.0%	-0.7%	0.0%

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. DBEDT data on fuel gas and naphtha consumption was not available for 2005, so 2007 DBEDT data is used as a proxy. 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, 2017, 2018, and 2019 that were obtained from EPA's GHGRP (EPA 2022b) 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.

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.

[26] Carbon dioxide emissions from Wood Biomass and Biofuels Consumption are reported in section 3.7.

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 8.26 and 8.45 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately one percent below and one percent above the emission estimate of 8.33 MMT CO_2 Eq.

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

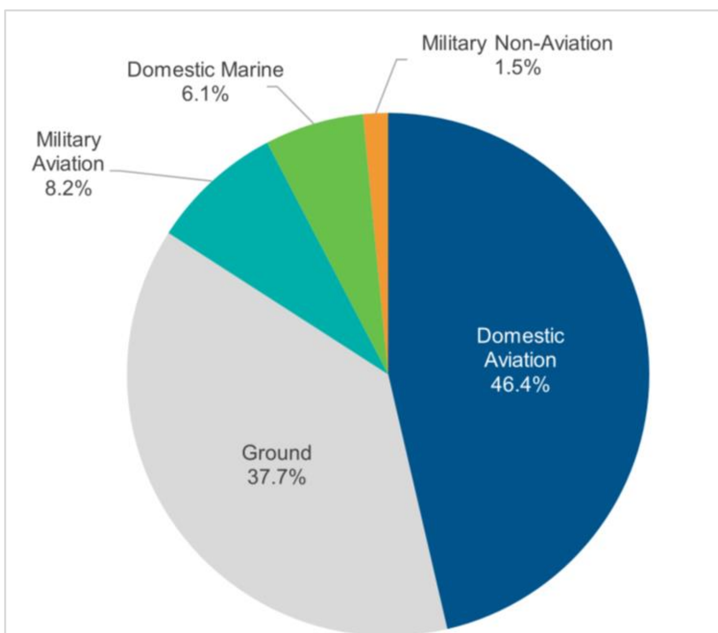
2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
8.33	8.26	8.45	-1%	+1%

[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). In 2019, emissions from transportation activities in Hawaiʻi were 10.68 MMT CO_2 Eq, accounting for 54.9 percent of Energy sector emissions. Domestic aviation accounted for the largest portion of transportation emissions (46.4 percent) followed by ground transportation (37.7 percent), military aviation (8.2 percent), domestic marine (6.1 percent), and military non-aviation (1.5 percent). Figure 3-6 shows the breakout of transportation emissions by end-use sector for 2019.

Figure 3-6: 2019 Transportation Emissions by End-Use Sector (Including Aviation)



Relative to 1990, emissions from transportation in 2019 were lower by 4.1 percent. Emissions from ground and domestic aviation transportation increased from 1990 to 2005 before decreasing from 2005 to 2019, largely due to a similar trend in consumption of motor gasoline, diesel fuel, and jet fuel kerosene. Emissions from domestic marine and military transportation increased from 1990 to 2007 and decreased between 2007 and 2019, largely due to a similar trend in consumption of residual fuel, diesel fuel, and jet fuel kerosene. Figure 3-7 presents emissions from transportation in Hawaiʻi by end-use sector for 1990, 2005, 2007, 2010, and 2015 – 2019. Table 3-5 summarizes emissions from transportation in Hawaiʻi by end-use sector and gas for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

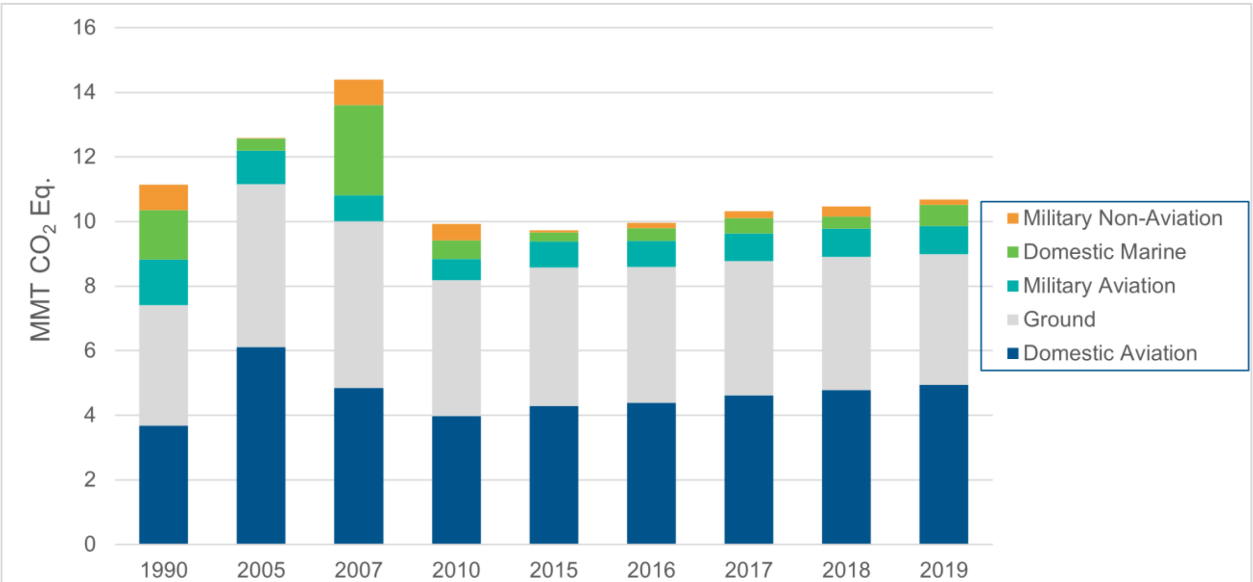


Table 3-5: GHG Emissions from Transportation by End-Use Sector and Gas (MMT CO_2 Eq.)

End-Use Sector/Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
Ground	**3.73**	**5.04**	**5.15**	**4.20**	**4.29**	**4.22**	**4.16**	**4.13**	**4.03**
CO_2	3.56	4.93	5.04	4.12	4.24	4.18	4.12	4.10	4.00
CH_4	0.02	0.01	0.01	0.01	+	+	+	+	+
N_2O	0.15	0.10	0.10	0.08	0.04	0.04	0.04	0.03	0.03
Domestic Marine	**1.54**	**0.38**	**2.81**	**0.58**	**0.28**	**0.40**	**0.49**	**0.37**	**0.65**
CO_2	1.52	0.36	2.77	0.57	0.28	0.40	0.48	0.37	0.64
CH_4	+	0.01	0.01	+	+	+	+	(+)[a]	+
N_2O	0.02	0.01	0.03	0.01	+	+	+	+	0.01
Domestic Aviation	**3.68**	**6.12**	**4.85**	**3.98**	**4.29**	**4.38**	**4.61**	**4.78**	**4.95**
CO_2	3.64	6.06	4.81	3.94	4.25	4.34	4.57	4.74	4.91
CH_4	+	+	+	+	+	+	+	+	+
N_2O	0.03	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Military Aviation	**1.42**	**1.03**	**0.80**	**0.66**	**0.81**	**0.80**	**0.85**	**0.86**	**0.88**
CO_2	1.41	1.02	0.79	0.66	0.80	0.79	0.84	0.86	0.87
CH_4	+	+	+	+	+	+	+	+	+
N_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

End-Use Sector/Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
Military Non-Aviation	**0.77**	**0.02**	**0.79**	**0.51**	**0.05**	**0.17**	**0.20**	**0.32**	**0.16**
CO_2	0.75	0.02	0.77	0.50	0.05	0.16	0.20	0.31	0.16
CH_4	+	+	+	+	+	+	+	+	+
N_2O	0.02	+	0.01	0.01	+	+	+	0.01	+
Total	**11.13**	**12.58**	**14.40**	**9.93**	**9.72**	**9.97**	**10.31**	**10.47**	**10.68**

+ Does not exceed 0.005 MMT CO_2 Eq.
[a] In 2018, diesel fuel consumed by international marine voyages originating in Hawai'i was slightly greater than consumed by domestic traveling marine vessels. As international consumption is not included in this inventory and subtracted from emissions, this value is negative.
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 Hawai'i Inventory Totals:** All transportation activities that occur within Hawai'i (e.g., flights from O'ahu to Maui) and domestic interstate activities originating in Hawai'i (e.g., flights from Honolulu to Los Angeles).
- **Estimated but Excluded from Hawai'i Inventory Totals:** Any fuel combustion used for international flights and marine voyages that originate in Hawai'i (e.g., flights from Honolulu to Hong Kong).
- **Not Estimated:** All transportation activities that originate outside Hawai'i (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 2022a). Fuel consumption data for transportation were obtained from EIA's SEDS (EIA 2022a) for all years.[27] 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 (2022a) 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 and naphtha-type jet fuel for military were obtained from EIA (2019) for all years prior to 2017.[28] Diesel fuel and residual fuel consumption were obtained from EIA's Petroleum and Other Liquids dataset for all years (EIA 2022c). 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 (2022a) prior to estimating emissions for the other subcategories.[29]

EIA's SEDS follows an updated methodology for the 2020 data publication to estimate state-level jet fuel consumption for 2010 onwards. While conversations with EIA indicated that this update produces more accurate fuel estimates, EIA did not make this adjustment for years prior to 2010, and therefore updated fuel consumption for 2010 onwards in EIA SEDS is not compatible with the estimates for years prior to 2010 (EIA 2022a). EIA revised these estimates using data from the U.S. Bureau of Transportation Statistics which is not available prior to 2010. This revision impacts fuel consumption for domestic and military aviation, as well as aviation international bunker fuels for the years 1990, 2005, and 2007. To maintain time series consistency, jet fuel consumption was back-casted for the years 1990 – 2009 using the overlap splicing technique as prescribed by IPCC 2006. There is a high correlation between post-2010 estimates developed using the 2020 data publication and the 2018 data publication methodology which allows for this technique to be used. The estimates were developed using IPCC's overlap method (IPCC 2006) as described by equation 5.1:

$$y_0 = x_0\left(\frac{1}{n-m+1} \times \sum_{i=m}^{n} \frac{y_i}{x_i}\right)$$

where,

y_0 = recalculated jet fuel kerosene consumption (Bbtu)

x_0 = the original SEDS jet fuel kerosene consumption estimate (Bbtu)

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[27] Diesel fuel consumption data obtained from EIA (2022a) includes blended biodiesel within the transportation sector. Biodiesel consumed by the transportation sector was subtracted from diesel fuel consumption from EIA to estimate pure diesel consumption.

[28] Unpublished military fuel consumption data from SEDS for 2017 through 2019 were not available, therefore consumption for these fuel types were proxied to 2016 data.

[29] EIA SEDS (2022a) does not include any naphtha consumption for Hawai'i, so naphtha-type jet fuel consumption in 1990 obtained from EIA (2022c) was assumed to be excluded from SEDS.

y_i, x_i = estimates of jet fuel kerosene consumption prepared using the new and previous used SEDS methodology for years 2010 – 2018 (Bbtu)

m, n = years in which the overlap of SEDS data were exampled (2010 – 2018)

For 1990 and 2007, kerosene-type jet fuel consumption data for military were collected by DBEDT (2008a). These values were used with the unadjusted SEDS jet fuel consumption data to develop an estimate of the fraction of emissions from military aviation.[30] This fraction was used to subtract military aviation consumption from total transportation jet fuel consumption data from EIA (2022a); emission estimates for military are reported separately. For 2010 and 2015 – 2019, total transportation jet fuel consumption data from EIA (2022a) were allocated to military transportation and non-military transportation using the 2007 proportional breakout, as estimates for military jet fuel consumption were not available for these years.

For all years, aviation and marine fuel consumption were categorized as either domestic or international consumption for the purposes of estimating emissions from international bunker fuels. The methodology used to apportion aviation and marine fuel consumption into domestic or international consumption is discussed in section 3.6.

Calculating CH_4 and N_2O emissions from highway vehicles

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

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

where,

VMT = Vehicle Miles traveled by vehicle, fuel, model year and control technology (mi)

EF_t = Control Technology Emission Factor (kg CH_4 or N_2O/mi)

For 2005, 2010, 2015 – 2019, 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 Hawai'i were obtained from the Federal Highway Administration's (FHWA) Annual Highway Statistics (FHWA 2005; 2010; 2015 – 2020). The distribution of annual VMT by vehicle type for each functional class for the state of Hawai'i, which was also obtained from FHWA (2005; 2010; 2015 – 2020), was then used to calculate VMT by vehicle type. For 1990 and 2007, VMT estimates by vehicle type were provided by the Hawai'i Department of Transportation (DOT) (Hawai'i 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 2022a).

[30] Prior research has shown that the DBEDT and SEDS data developed using the method employed prior to the 2019 update were closely aligned and thus could be compared, Appendix C of Hawai'i DOH (2021).

Calculating CH_4 and N_2O emissions from non-highway vehicles

Methane and N_2O emissions from non-highway vehicles[31] were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:

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

where,

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

Default emission factors for estimating emissions from non-highway vehicles were obtained from the U.S. Inventory (EPA 2022a). This source was used because the *2006 IPCC Guidelines* does not include updated emission factors for non-highway vehicles.

Calculating CH_4 and N_2O emissions from alternative fuel vehicles

Methane and N_2O emissions from alternative fuel (i.e., biodiesel and ethanol) vehicles were estimated using the following equation, consistent with the IPCC (2006) Tier 1 methodology:[32]

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

where,

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

Methane and N_2O emission factors were taken from IPCC (2006) and EPA (2017) for ethanol and biodiesel, respectively. Biodiesel consumption was estimated based on consumption data obtained from EIA (2022a). Biodiesel consumed by energy industries, as obtained from DBEDT's Economic Data Warehouse (DBEDT 2022a) and Hawaiʻi DOH (2020), 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 2017 inventory report include the following:

- Since development of the 2017 inventory report, EIA's SEDS has adopted a new methodology to estimate state-level jet fuel consumption for 2010 onwards (EIA 2022a). This change impacts fuel consumption for domestic and military aviation, as well as aviation international bunker

[31] 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.

[32] Carbon dioxide emissions from Wood Biomass and Biofuels Consumption are reported in section 3.7.

fuels for years 2010 – 2017. Updated estimates of jet fuel consumption are higher than prior estimates, resulting in an increase in emissions estimates. For 1990 and 2007, jet fuel consumption estimates were estimated using a back-casting method, as described in the methodology description of section 3.2.

- Marine fuel consumption by American vessels that travelled internationally are now incorporated into international bunker fuel estimates. Because emissions estimated for international marine consumption are subtracted from total marine fuel consumption, totals have changed from the 2017 report.

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

Table 3-6: Change in Emissions from Transportation Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
Ground						
2017 Inventory Report (MMT CO_2 Eq.)	3.73	5.12	4.21	4.32	4.25	4.19
This Inventory Report (MMT CO_2 Eq.)	3.73	5.15	4.20	4.29	4.22	4.16
Percent Change	0.0%	0.6%	-0.2%	-0.8%	-0.9%	-0.6%
Domestic Marine						
2017 Inventory Report (MMT CO_2 Eq.)	1.55	2.81	0.58	0.29	0.41	0.49
This Inventory Report (MMT CO_2 Eq.)	1.54	2.81	0.58	0.28	0.40	0.49
Percent Change	-1.0%	-0.2%	-0.6%	-0.6%	-1.1%	-1.2%
Domestic Aviation						
2017 Inventory Report (MMT CO_2 Eq.)	2.73	3.83	2.91	3.54	3.57	3.46
This Inventory Report (MMT CO_2 Eq.)	3.68	4.85	3.98	4.29	4.38	4.61
Percent Change	34.7%	26.8%	36.4%	21.1%	22.7%	33.2%
Military Aviation						
2017 Inventory Report (MMT CO_2 Eq.)	1.38	0.63	0.49	0.66	0.65	0.64
This Inventory Report (MMT CO_2 Eq.)	1.42	0.80	0.66	0.81	0.80	0.85
Percent Change	2.7%	27%	37%	22.4%	23.1%	33.3%
Military Non-Aviation						
2017 Inventory Report (MMT CO_2 Eq.)	0.79	0.78	0.51	0.05	0.17	0.20
This Inventory Report (MMT CO_2 Eq.)	0.77	0.79	0.51	0.05	0.17	0.20
Percent Change	-2.0%	0.7%	0.7%	0.7%	0.6%	0.6%
Total						
2017 Inventory Report (MMT CO_2 Eq.)	10.18	13.18	8.70	8.86	9.05	8.98
This Inventory Report (MMT CO_2 Eq.)	11.13	14.40	9.93	9.72	9.97	10.31
Percent Change	9.4%	9.3%	14.1%	9.7%	10.2%	14.9%

Uncertainties

Uncertainties associated with transportation estimates include the following:

- 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 SEDS fuel consumption data from EIA into air, 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 are not impacted by this uncertainty.
- Due to a SEDS methodology change for years prior to 2010, SEDS kerosene-type jet fuel for 1990, 2005, and 2007 was back casted to remain compatible with data for years after and including 2010.
- Kerosene-type jet fuel consumption for military was 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 1990 data collected by DBEDT were used to disaggregate the jet fuel consumption from EIA into military or non-military for 1990. The 2007 data collected by DBEDT were used to disaggregate the jet fuel consumption from EIA into military or non-military for 2005, 2007, 2010, 2015, 2016, 2017, 2018, and 2019. This 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 10.31 and 11.09 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately four percent below and four percent above the emission estimate of 10.68 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
10.68	10.31	11.09	-4%	+4%

[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.
Note: Uncertainty estimates include aviation emissions.

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 2019, emissions from the incineration of waste in Hawaiʻi were 0.28 MMT CO_2 Eq., accounting for 1.5 percent of Energy sector emissions.[33] In 1990, MSW was combusted in Hawaiʻi 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 Hawaiʻi 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 before increasing again from 2017 to 2019. Table 3-8 summarizes emissions from the incineration of waste in Hawaiʻi by gas for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.17	0.15	0.15	0.18	0.26	0.26	0.21	0.25	0.27
CH_4	+	+	+	+	+	+	+	0.01	0.01
N_2O	+	+	+	0.01	0.01	0.01	0.01	0.01	0.01
Total	**0.18**	**0.15**	**0.15**	**0.19**	**0.27**	**0.27**	**0.23**	**0.26**	**0.28**

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

Methodology

2010 and 2015 – 2019

Emissions for the H-POWER plant for 2010 and 2015 – 2019 were obtained directly from EPA's GHGRP (EPA 2022b). This includes non-biogenic CO_2, CH_4, and N_2O emissions and biogenic CH_4 and N_2O emissions.

1990, 2005, 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.,

[33] Consistent with the U.S. Inventory (EPA 2022a), emissions from waste incineration are reported under the Energy sector because the waste is used to produce energy.

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

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

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

where,

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

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

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

where,

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

Data on the quantity of waste combusted at the Waipahu Incinerator was provided by Steve Serikaku, Honolulu County Refuse Division (Serikaku 2008). Emission factors and the proportion of plastics, synthetic rubber, and synthetic fibers in the waste stream were taken from the U.S. EPA’s State Inventory Tools – Solid Waste Module (EPA 2022c).

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, 2005, 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 H-POWER to estimate CO_2, CH_4, and N_2O emissions from the combustion of refuse-derived fuel (RDF) 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, 2005, and 2007 was obtained directly from Covanta Energy, which operates 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 2017 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 2022a) 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 0.26 and 0.32 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately eight percent below and 13 percent above the emission estimate of 0.28 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.28	0.26	0.32	-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)

Refinery activities release CO_2, CH_4, and N_2O to the atmosphere as fugitive emissions, vented emissions, and emissions from operational upsets.[34] Two refineries, Par West and Par East,[35] operate in Hawaiʻi that contribute to these emissions (EIA 2022c). In addition, CH_4 fugitive emissions occur from natural gas distribution and transmission pipelines, as well as propane and synthetic natural gas. In 2019, emissions from oil and natural gas systems in Hawaiʻi were 0.11 MMT CO_2 Eq., accounting for 0.6 percent of Energy sector emissions. Relative to 1990, emissions from oil and natural gas systems in 2019 were lower by roughly 73.5 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 Hawaiʻi by gas for 1990, 2005, 2007, 2010, 2015 – 2019.[36]

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.42	0.37	0.37	0.31	0.30	0.29	0.30	0.29	0.11
CH_4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
N_2O	+	+	+	+	+	+	+	+	+
Total	**0.43**	**0.39**	**0.39**	**0.32**	**0.31**	**0.29**	**0.31**	**0.30**	**0.11**

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

Methodology

Refinery emissions for 2010, 2015 – 2019

Emissions from oil and gas systems for 2010, 2015 – 2019 were taken directly from EPA's GHGRP (EPA 2022b). This includes non-biogenic CO_2, CH_4, and N_2O fugitive emissions from petroleum refining and hydrogen production for Hawaiʻi's two refineries.

Refinery emissions for 1990, 2005, and 2007

Emissions from oil and gas systems for 1990, 2005, and 2007 were estimated by scaling 2010 emissions data from EPA's GHGRP (EPA 2022b) based on the ratio of crude oil refined (i.e., throughput) each year for the two refineries relative to 2010. 2005 estimates are proxied based on 2007 data. 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).

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[34] The state of Hawaiʻi does not have any natural gas exploration, production, processing, or transmission systems present. Sources of emissions in the natural gas systems category include fugitive emissions from propane and synthetic natural gas.
[35] The Par West Refinery was previously known as the Island Energy Services Refinery and, prior to that, as the Chevron Products Company Hawaiʻi Refinery; the Par East Refinery was previously known as Refinery Kapolei which was previously known as the Hawaiʻi Independent Energy Petroleum Refinery.
[36] Emissions from fuels combusted at refineries are included in under the Stationary Combustion source category.

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 (2022) and applying pipeline leak factors obtained from the U.S. Inventory (EPA 2022a).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from oil and gas operations since the 2017 inventory report.

Uncertainties

Fugitive emissions from petroleum refining for 1990, 2005, 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, 2005, and 2007. Additionally, annual throughput for the Par West Refinery was not available for 1990; for the purposes of this analysis, it was assumed that 1990 throughput was consistent with 2007 levels. Lastly, annual throughput for the Par West Refinery and Par East Refinery was not available for 2005; for the purposes of this analysis, it was assumed that 2005 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 Par East Refinery contributed the vast majority to the quantified uncertainty estimates. The remaining input variables had a minor impact on the overall uncertainty of this source category. The results of the quantitative uncertainty analysis are summarized in Table 3-11. Emissions from oil and natural gas systems were estimated to be between 0.11 and 0.11 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 0.1 percent below and 0.1 percent above the emission estimate of 0.11 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.11	0.11	0.11	-0.1%	+0.1%

[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 Hawaiʻi. 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 2019, emissions from non-energy uses of fuels in Hawaiʻi were 0.04 MMT CO_2 Eq., accounting for less than one 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 2022a). Table 3-12 summarizes emissions from non-energy uses of fuels in Hawaiʻi by gas for 1990, 2005, 2007, 2010, and 2015 – 2019.

Table 3-12: Emissions from Non-Energy Uses (MMT CO_2 Eq.)

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.04	0.04	0.04	0.05	0.05	0.04	0.04	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):[37]

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

where,

Fuel Consumption = total consumption by fuel type and end-use sector (Bbtu)
NEU Consumption % = percentage of non-energy use of fuel consumption (percent)
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 (percent)

The percentage of non-energy use consumption by fuel type were obtained from the U.S. Inventory (EPA 2022a) and applied to total consumption values for fuels by end use sector obtained from EIA's SEDS (EIA 2022a).[38] Carbon content coefficients for estimating CO_2 emissions, which are specific to each fuel type, were taken from the U.S. Inventory (EPA 2022a). The percentage of C stored in non-energy uses of fuels were also obtained from EPA (2022a).

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from oil and gas operations since the 2017 inventory report.

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[37] Methane and N_2O emissions from non-energy uses are not estimated, consistent with IPCC Guidance (2006) and the U.S. Inventory (EPA 2022a).
[38] Consumption values for fuels included in the stationary combustion source category from EIA's SEDS (EIA 2022a) were adjusted to subtract non-energy uses.

Uncertainties

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

- Non-energy use CO_2 emission factors are not available from the U.S. Inventory (EPA 2022a), 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 Hawaiʻi-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 3-13. 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 25 percent below and one percent above the emission estimate of 0.04 MMT CO_2 Eq.

Table 3-13: Quantitative Uncertainty Estimates for Emissions from Non-Energy Uses

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.04	0.03	0.04	-25%	+1%

[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 (IBFs) are defined as marine and aviation travel originating in Hawaiʻi 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 2019, emissions from international bunker fuels in Hawaiʻi were 1.64 MMT CO_2 Eq., which is 4.0 percent greater than 1990 levels. Table 3-14 summarizes emissions from international bunker fuels in Hawaiʻi for 1990, 2005, 2007, 2010, 2015 – 2019.

Table 3-14: Emissions from International Bunker Fuels by Gas (MMT CO_2 Eq.)

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	1.56	2.23	1.09	1.31	1.55	1.54	1.75	1.76	1.63
CH_4	+	+	+	+	+	+	+	+	+
N_2O	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Total	**1.58**	**2.25**	**1.10**	**1.32**	**1.56**	**1.55**	**1.76**	**1.78**	**1.64**

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

Methodology

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

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

where,

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

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

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

where,

IBF Consumption = total amount of International Bunker Fuel combusted (Bbtu)
EF_{fuel} = emission factor of CH_4 and N_2O by fuel type (MT/Bbtu)

Carbon dioxide emission factors were obtained from the U.S. Inventory (EPA 2022a), while CH_4 and N_2O emission factors were obtained from IPCC (2006). The following sections describe how IBF consumption was derived for aviation and marine bunker fuel.

Aviation Bunker Fuel

Aviation bunker fuel consumption was calculated based on the estimated amount of jet fuel used for international trips in each year. 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 2022a) into domestic and international bunker fuel consumption. EIA's SEDS follows a new methodology and revised estimates for state-level jet fuel consumption for 2010 onwards (EIA 2022a). This change impacts fuel consumption for domestic and military aviation, as well as aviation international bunker fuels. The method employed to back-cast SEDS consumption data prior to 2010 is described in section 3.2.

The annual fuel efficiency for each aircraft type for both domestic and international flights was calculated using Airline Data Inc.’s (ADI) Form 41 Fuel Statistics dataset (ADI 1990 – 2019). 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 Hawaiʻi (ADI 1990 – 2019). That ratio was multiplied by total non-military jet fuel consumption in Hawaiʻi, as derived from EIA (2022a and 2019), 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 Hawaiʻi
$Gallons_D$	= gallons consumed for domestic trips originating in Hawaiʻi

Marine Bunker Fuel

Marine bunker fuel consumption was calculated based on the estimated amount of diesel and residual fuel consumption used for international trips. Fuel consumption is included for both vessels flying American and foreign flags. For all inventory years except 1990, marine bunker fuel consumption for Hawaiʻi was obtained directly from the Census Bureau (DOC 2008, 2018, and 2020). For 1990, marine bunker fuel consumption for all international traveling vessels was estimated by applying the average of 2006 and 2007 Hawaiʻi marine bunker fuel consumption (the earliest available years for Hawaiʻi 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 2022a).

Changes in Estimates since the Previous Inventory Report

Upon internal review, data for American-flagged vessels making international trips was not included in the marine fuel consumption estimates in the 2017 and previous inventory reports. For this inventory report, these data are now included. Marine bunker fuel consumption for American vessels in 1990 was estimated following the same method previously described for foreign vessels. In addition, EIA’s SEDS follows a new methodology to estimate state-level jet fuel consumption for 2010 onwards (EIA 2022a) and estimates for years prior to 2010 were estimated using back-casting. These updates impact fuel consumption for international aviation bunker fuels. The resulting changes in historical emission estimates are presented in Table 3-15 and Table 3-16.

Table 3-15: Change in Emissions from Marine Bunker Fuels Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.09	0.05	0.39	0.10	0.06	0.12
This Inventory Report (MMT CO_2 Eq.)	0.11	0.05	0.39	0.10	0.06	0.12
Percent Change	13.7%	1.0%	2.1%	1.0%	6.1%	2.4%

Table 3-16: Change in Emissions from Aviation Bunker Fuels Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	1.08	0.82	0.67	1.19	1.19	1.22
This Inventory Report (MMT CO_2 Eq.)	1.47	1.05	0.93	1.46	1.49	1.65
Percent Change	36.9%	28.3%	38.0%	22.9%	25.7%	34.6%

Uncertainties

Uncertainties associated with international bunker fuel estimates include the following:

- Due to a SEDS methodology change for years prior to 2010, SEDS kerosene-type jet fuel for 1990, 2005, and 2007 was back casted to remain compatible with data for years after and including 2010. Jet fuel consumption was then disaggregated into domestic and international for all years.
- Kerosene-type jet fuel consumption for military was 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 also uncertainty associated with data collected by DBEDT. The data collected by DBEDT were used to disaggregate total jet fuel consumption from EIA into military or non-military for all years. Non-military jet fuel consumption was then disaggregated into domestic and international for all years.
- 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 Hawaiʻi 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 2022a).

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 1.48 and 1.82 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 10 percent below and 11 percent above the emission estimate of 1.64 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1.64	1.48	1.82	-10%	+11%

[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.[39,40] According to IPCC (2006), since these emissions are biogenic, CO_2 emissions from biomass in 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 2019, CO_2 emissions from wood biomass and biofuel consumption in Hawaiʻi were 1.28 MMT CO_2 Eq. Table 3-18 summarizes CO_2 emissions from wood biomass and biofuel consumption in Hawaiʻi for 1990, 2005, 2007, 2010, 2015 – 2019.

[39] Ethanol is blended with motor gasoline at oil refineries. Hawaiʻi began blending ethanol into motor gasoline supply in 2006.

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

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

Gas	1990[a]	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	2.43	0.59	0.88	1.24	1.40	1.49	1.26	1.29	1.28

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

Methodology

Biofuel

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

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

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 2022a) for all years. Carbon dioxide combustion emission factors were obtained from the U.S. Inventory (EPA 2022a).

Changes in Estimates since the Previous Inventory Report

In the 2017 inventory report, 2017 CO_2 emissions from wood biomass were inadvertently excluded. The current inventory has updated 2017 emissions to include these emissions. 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 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	2.43	0.88	1.24	1.40	1.49	0.75
This Inventory Report (MMT CO_2 Eq.)	2.43	0.88	1.24	1.40	1.49	1.26
Percent Change	0.0%	0.0%	0.0%	0.0%	0.0%	67.4%

Uncertainties

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 1.21 and 1.37 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately six percent below and seven percent above the emission estimate of 1.28 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1.28	1.21	1.37	-6%	+7%

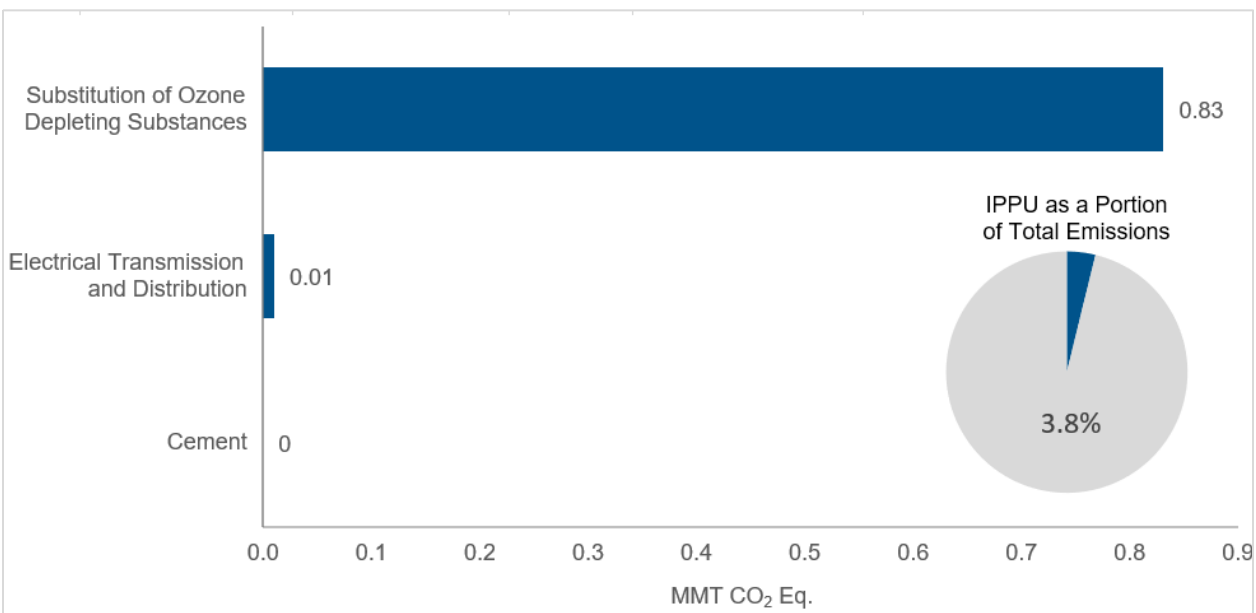
[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

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 Hawaiʻi, 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).[41]

In 2019, emissions from the IPPU sector were 0.84 MMT CO_2 Eq., accounting for 3.8 percent of total Hawaiʻi emissions. Emissions from the substitution of ozone depleting substances accounted for the majority of emissions from the IPPU sector, representing 98.8 percent of total emissions. The remaining 1.2 percent of emissions are from electrical transmission and distribution. Clinker production in Hawaiʻi ceased in 1996 and, as a result, emissions from cement production in 2019 were zero. Figure 4-1 and Figure 4-2 show emissions from the IPPU sector by source for 2019.

Figure 4-1: 2019 IPPU Emissions by Source (MMT CO_2 Eq.)



[41] IPCC Source Categories for which emissions were not estimated for the state of Hawaiʻi 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 2019 were higher by nearly 400 percent. The increase is due entirely to the growth in HFC and PFC emissions which are used as a substitute for ozone depleting substances used primarily in refrigeration and air conditioning. These substitutes have grown steadily in line with national emissions as ozone depleting substances are phased out under the Montreal Protocol (EPA 2022a). Sulfur hexafluoride emissions from electrical transmission and distribution decreased by 85.6 percent from 1990 to 2019, also consistent with national emissions. This decrease is attributed to increasing SF_6 prices and industry efforts to reduce emissions (EPA 2022a). 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: 2019 IPPU Emissions by Source

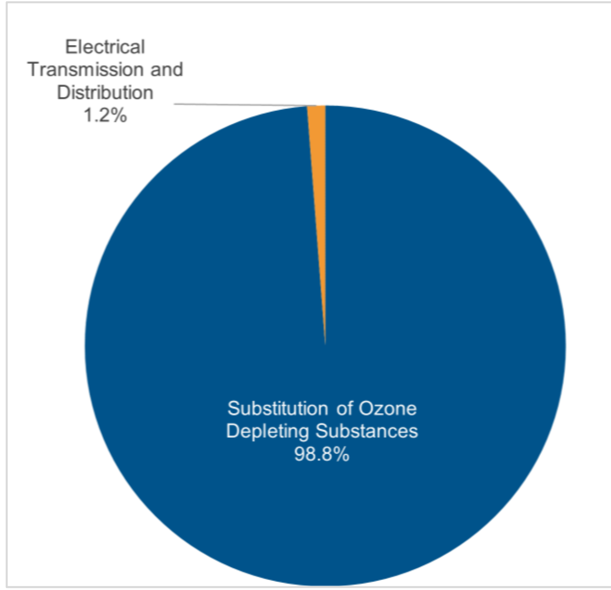


Figure 4-3: IPPU Emissions by Source and Year

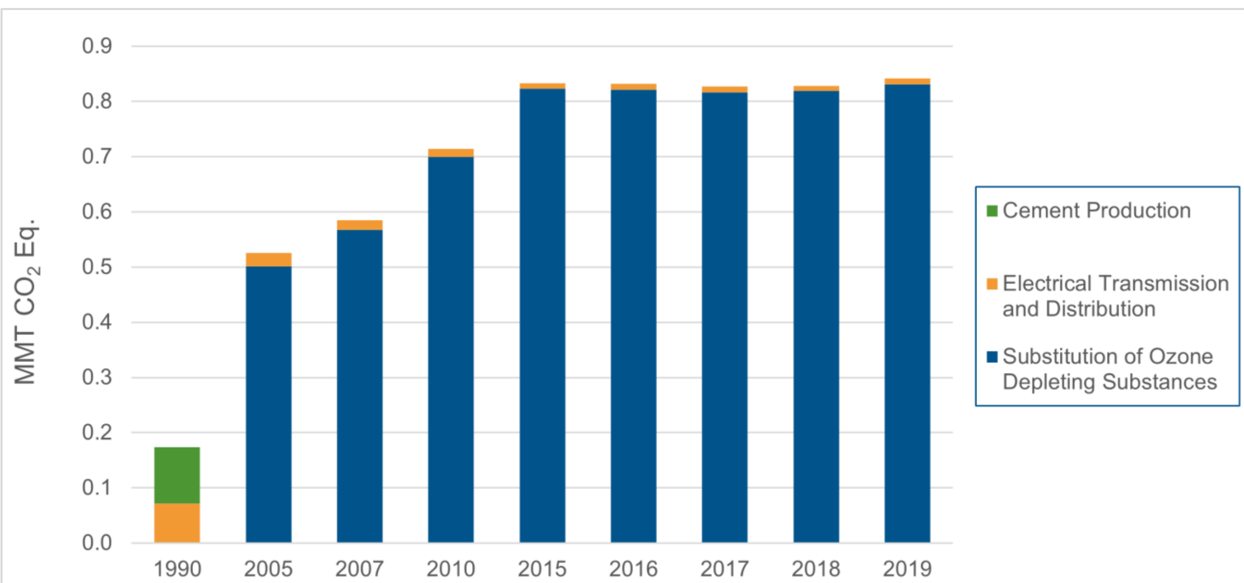


Table 4-1: GHG Emissions from the IPPU Sector by Source and Year (MMT CO_2 Eq.)

Source	1990	2005	2007	2010	2015	2016	2017	2018	2019
Cement Production	0.10	NO	NO	NO	NO	NO	NO	NO	NO
Electrical Transmission and Distribution	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	+	0.50	0.57	0.70	0.82	0.82	0.82	0.82	0.83
Total	**0.17**	**0.52**	**0.58**	**0.71**	**0.83**	**0.83**	**0.83**	**0.83**	**0.84**

+ 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. Activity data and emission factors used in the analysis are summarized in Appendix F and Appendix G, 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 Hawai‘i, clinker was produced on-site in O‘ahu until production ceased in 1996, after which clinker was imported (Wurlitzer 2008). Portland cement production ended in Hawai‘i in 2001 (Wurlitzer 2008). As a result, in 2019, emissions from cement production in Hawai‘i were zero. Table 4-2 summarizes emissions from cement production in Hawai‘i for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.10	NO	NO	NO	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 (CKD) from the *2006 IPCC Guidelines* (IPCC 2006). Emissions were calculated using the following equation:

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

where:

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

Changes in Estimates since the Previous Inventory Report

No changes were made to emissions from cement production since the 2017 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 2019, emissions from electrical transmission and distribution systems in Hawaiʻi were 0.01 MMT CO_2 Eq., accounting for 1.2 percent of IPPU sector emissions. Relative to 1990, emissions from electrical transmission and distribution systems in 2019 were lower by 85.6 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 2022a). Table 4-3 summarizes emissions from electrical transmission and distribution systems in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
SF_6	0.07	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01

Methodology

Emissions were calculated by apportioning U.S. emissions from this source to Hawaiʻi based on the ratio of Hawaiʻi electricity sales to U.S. electricity sales. Estimates of national SF_6 emissions data were taken from the U.S. Inventory (EPA 2022a). National electricity sales data come from the U.S. Department of Energy (DOE), Energy Information Administration (EIA 2021). Hawaiʻi electricity sales data come from the State of Hawaiʻi Data Book (DBEDT 2020a).

Changes in Estimates since the Previous Inventory Report

National emissions data were recently updated in EPA (2021a and 2022a), based on revisions to reported historical data in EPA's Greenhouse Gas Reporting Program (GHGRP). As the estimates for Hawaiʻi are calculated by apportioning U.S. emissions from this source to Hawaiʻi, this resulted in a change to the estimates. Additional updates included an improvement to the methodology used to calculate historical estimates for transmission mileage and the addition of emissions of CF_4 from Original Equipment Manufacturers (OEMs). 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 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01	0.01	0.01
This Inventory Report (MMT CO_2 Eq.)	0.07	0.02	0.02	0.01	0.01	0.01
Percent Change	-0.2%	-0.8%	-0.6%	-0.9%	-1.2%	1.3%

Uncertainties

The apportionment method was used to estimate emissions from electrical transmission and distribution systems in Hawaiʻi 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 emission 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) U.S. SF_6 electricity transmission and distribution emissions, (2) U.S. electricity sales, and (3) Hawaiʻi electricity sales. 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 25 percent below and 32 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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.010	0.008	0.013	-25%	+32%

[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)

HFCs and PFCs are used as alternatives to 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 2019, emissions from ODS substitutes in Hawaiʻi were 0.83 MMT CO_2 Eq., accounting for 98.8 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 2022a). Table 4-6 summarizes emissions from HFCs and PFCs that are used as substitutes of ODS in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019. While not included in the inventory totals, estimated emissions from ODS in Hawaiʻi are presented in Appendix H.[42]

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
HFC/PFC	+	0.50	0.57	0.70	0.82	0.82	0.82	0.82	0.83

+ Does not exceed 0.005 MMT CO_2 Eq.

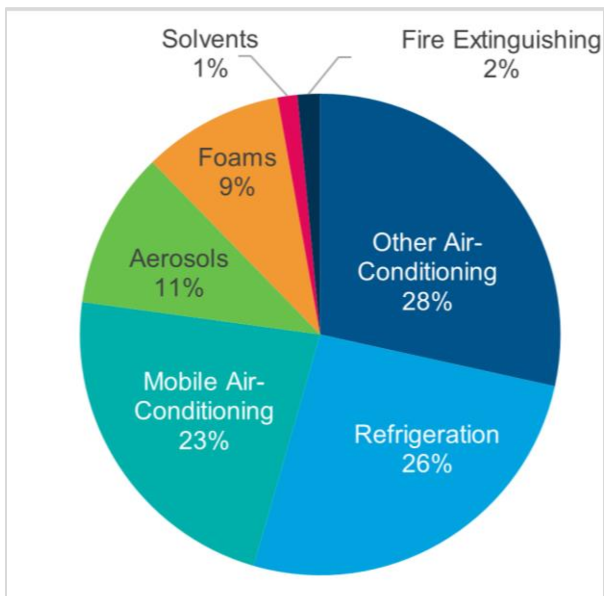
Methodology

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.

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 2022a), emissions are presented for the following sub-categories:

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

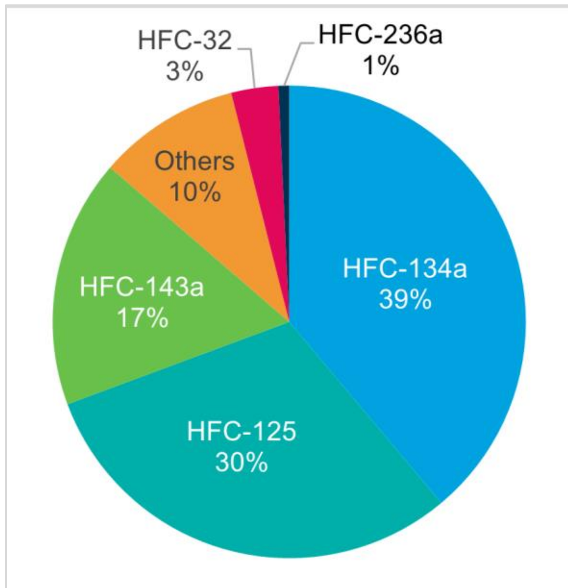
Figure 4-4: 2019 Emissions from ODS Substitutes by Sub-Category



[42] 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 Hawaiʻi and are presented in Appendix H.

Hawaiʻi emissions from mobile air-conditioning systems were estimated by apportioning national emissions from the U.S. Inventory (EPA 2022a) to Hawaiʻi based on the ratio of Hawaiʻi vehicle registrations from the State of Hawaiʻi Data Book (DBEDT 2020b) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2020). Hawaiʻi 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 2022a) to Hawaiʻi based on the ratio of the number of houses with air conditioners in Hawaiʻi to the number of houses with air conditioners in the United States. The number of houses in Hawaiʻi 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, 2015, and 2020 Residential Energy Consumption Survey (RECS) and U.S. Department of Energy's (DOE) Guide to Determining Climate Regions by County (DOE 2015; EIA 2013; EIA 2018; EIA 2022d). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2022a) were apportioned to Hawaiʻi based on the ratio of Hawaiʻi population from DBEDT (2020b) to U.S. population from the U.S. Census Bureau (2021). Emissions by gas are shown in Figure 4-5.

Figure 4-5: 2019 Emissions from ODS Substitutes by Gas



Changes in Estimates since the Previous Inventory Report

Changes to emission estimates were minor. Population data for the United States was updated based on the most recent available data, as published by the U.S. Census Bureau (2021). National emissions data were also updated based on updated values published by EPA (2021a and 2022a). Specifically, U.S. emissions estimates were updated based on updates to 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, aerosols, and foams sectors. Updates were made to various assumptions for ice makers, unitary air conditioners, metered dose inhaler aerosols, and polyurethane and polyisocyanurate boardstock foams. Additionally, ten new end-uses were added to the model to replace commercial refrigeration foam: vending machine foam, stand-alone equipment foam, ice machine foam, refrigerated food processing and dispensing equipment foam, small walk-in cooler foam, large walk-in cooler foam, display case foam (CFC-11) and display case foam (CFC-12), road transport foam, and intermodal container foam (EPA 2021a).

In the 2017 inventory report, national emissions from ‘other air conditioners’ were apportioned to Hawai‘i based on number of houses with air conditioners, which were in turn calculated using the 2009 and 2015 RECS data, such that 2009 values were used as a proxy for all years 1990 – 2014 and 2015 values were used as a proxy for all years 2015 – 2017. To improve upon this estimate, the number of houses with air conditioners is now instead calculated individually for each year by interpolating between available data years and back-projecting. 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 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	+	0.57	0.70	0.82	0.82	0.82
This Inventory Report (MMT CO_2 Eq.)	+	0.57	0.70	0.82	0.82	0.82
Percent Change	0.9%	-0.3%	0.4%	0.3%	-0.4%	-0.9%

+ Does not exceed 0.005 MMT CO_2 Eq.

Uncertainties

The apportionment method was used instead of the IPCC methodology due to the complexity of the source category and lack of sufficient data. This approach is consistent with the approach used in EPA’s State Inventory Tool (EPA 2022c). 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 Aerosols, (2) U.S. emissions from substitutes of ODS from refrigeration and air conditioning, and (3) U.S. homes in hot and humid climates with air conditioners.

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 0.90 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately four percent below and eight percent above the emission estimate of 0.83 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.83	0.80	0.90	-4%	+8%

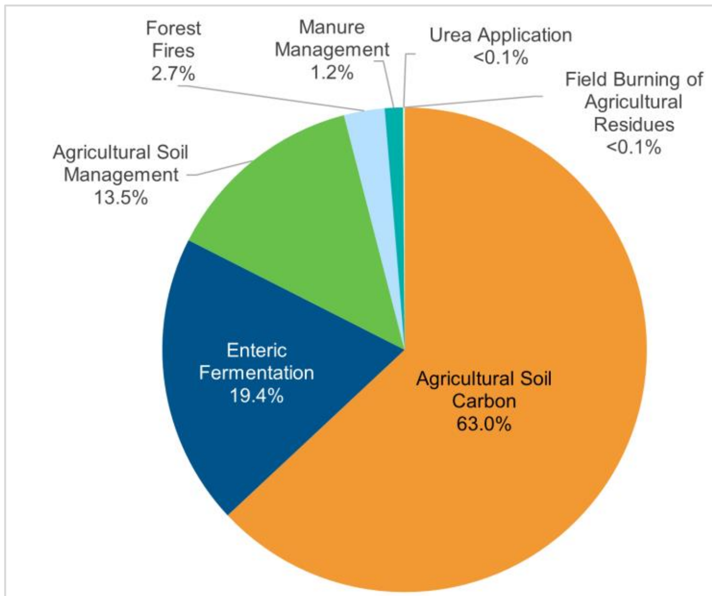
[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

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

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

For the state of Hawaiʻi, emissions and removals from agriculture, forestry, and other land uses (AFOLU) are estimated from the following source and sink categories:[43] 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 Hawaiʻi, 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.

Figure 5-1: 2019 AFOLU Emissions by Source (Excluding Sinks)



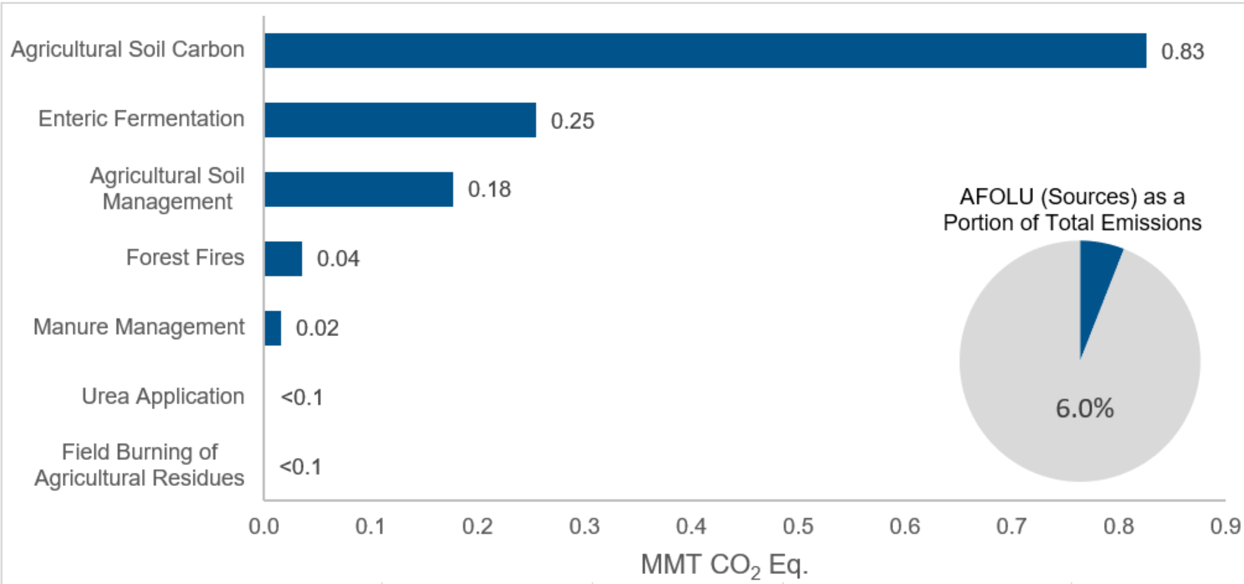
Note: Percentages represent the percent of AFOLU emissions not including emission sinks.

In 2019, total emissions (excluding sinks) from the AFOLU sector were 1.31 MMT CO_2 Eq., accounting for 6.0 percent of total Hawaiʻi emissions. Agricultural soil carbon accounted for the largest share of AFOLU emissions, followed by enteric fermentation, agricultural soil management, forest fires, manure management, urea application, and field burning of

[43] IPCC Source and Sink Categories for which emissions were not estimated for the state of Hawaiʻi 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.

agricultural residues. Figure 5-1 and Figure 5-2 show emissions from the AFOLU sector by source for 2019.

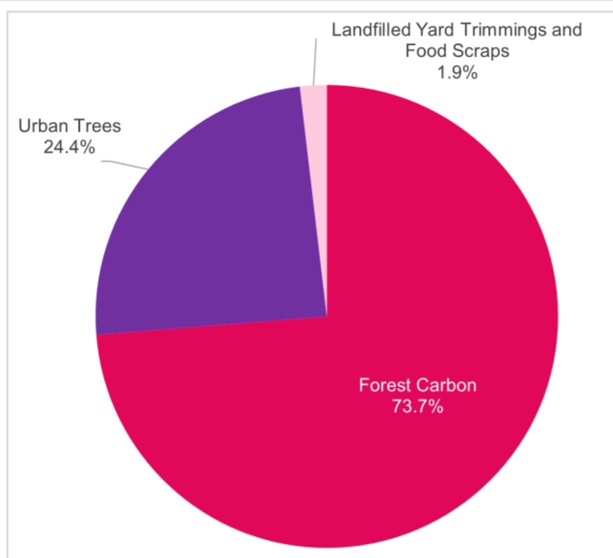
Figure 5-2: 2019 AFOLU Emissions by Source (MMT CO_2 Eq.) (Excluding Sinks)



Note: Emission estimates do not include emission sinks.

Carbon removals by sinks were 2.59 MMT CO_2 Eq. in 2019. Therefore, the AFOLU sector resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 1.28 MMT CO_2 Eq. in 2019. 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 2019.

Figure 5-3: 2019 AFOLU Removals by Carbon Sink



Relative to 1990, emissions from AFOLU sources in 2019 were lower by roughly 15.3 percent. Carbon removals from AFOLU sinks in 2019 were higher by roughly 6.5 percent relative to 1990 sinks. As a result, net removals (including sources and sinks) from AFOLU increased by 44.7 percent in 2019 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 Hawaiʻi for each inventory year. Emission sources and sinks by category and year are also summarized in Table 5-1.

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

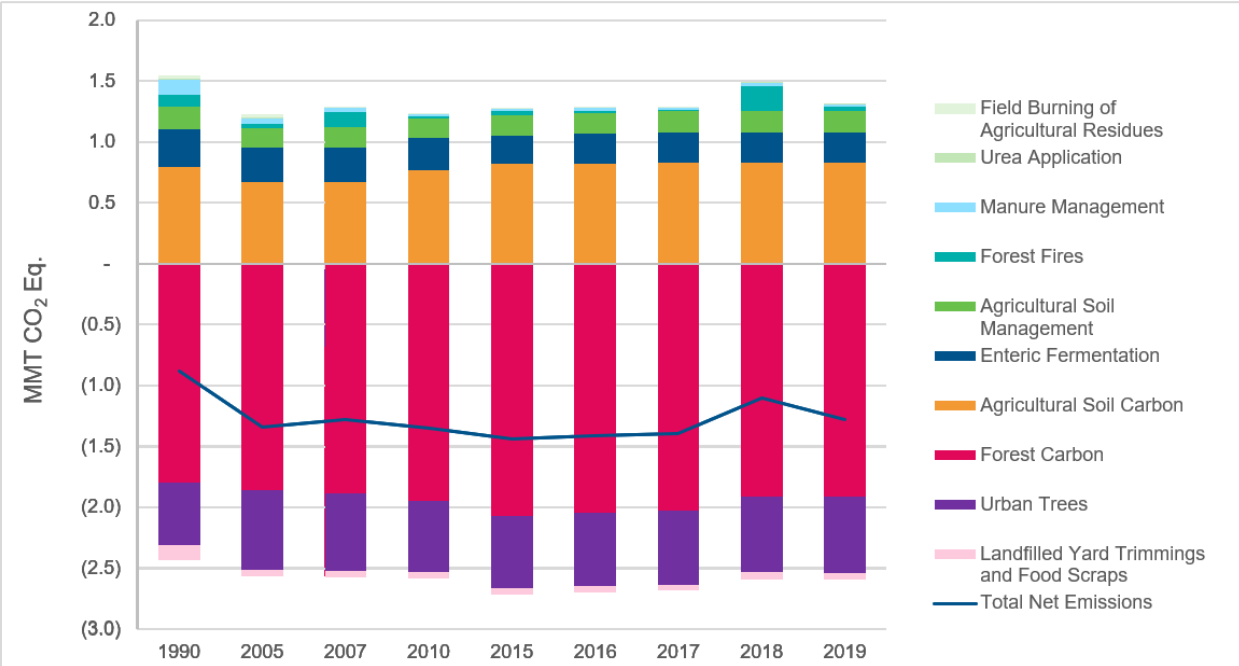


Table 5-1: GHG Emissions from the AFOLU Sector by Category (MMT CO_2 Eq.)

Category	1990	2005	2007	2010	2015	2016	2017	2018	2019
Agriculture	**0.65**	**0.52**	**0.50**	**0.46**	**0.43**	**0.44**	**0.45**	**0.45**	**0.45**
Enteric Fermentation	0.31	0.28	0.29	0.27	0.24	0.25	0.25	0.25	0.25
Manure Management	0.13	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Agricultural Soil Management	0.18	0.16	0.17	0.16	0.16	0.17	0.17	0.17	0.18
Field Burning of Agricultural Residues	0.03	0.03	0.01	0.01	0.01	0.01	+	0.00	0.00
Urea Application	+	+	+	+	+	+	+	+	+
Land Use, Land-Use Change, and Forestry	**(1.53)**	**(1.85)**	**(1.78)**	**(1.81)**	**(1.86)**	**(1.85)**	**(1.84)**	**(1.56)**	**(1.73)**
Agricultural Soil Carbon	0.80	0.68	0.67	0.76	0.82	0.82	0.83	0.83	0.83
Landfilled Yard Trimmings and Food Scraps	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.06)	(0.05)
Urban Trees	(0.51)	(0.66)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)	(0.62)	(0.63)
Forest Carbon	(1.79)	(1.86)	(1.89)	(1.95)	(2.07)	(2.04)	(2.02)	(1.91)	(1.91)
Forest Fires	0.10	0.03	0.12	0.01	0.04	0.02	0.01	0.20	0.04
Total (Sources)	**1.55**	**1.22**	**1.29**	**1.24**	**1.28**	**1.29**	**1.28**	**1.48**	**1.31**
Total (Sinks)	**(2.43)**	**(2.56)**	**(2.57)**	**(2.58)**	**(2.72)**	**(2.69)**	**(2.68)**	**(2.59)**	**(2.59)**
Total Net Emissions	**(0.88)**	**(1.34)**	**(1.28)**	**(1.35)**	**(1.44)**	**(1.41)**	**(1.39)**	**(1.11)**	**(1.28)**

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

5.1. Enteric Fermentation (IPCC Source Category 3A1)

Methane is produced as part of the digestive processes in ruminant animals, which is a microbial fermentation process referred to as enteric fermentation. The amount of CH_4 emitted by an animal depends both upon the animal's digestive system, and the amount and type of feed it consumes (EPA 2022a). This source includes CH_4 emissions from enteric fermentation in dairy and beef cattle, sheep, goats, swine, and horses.

In 2019, CH_4 emissions from enteric fermentation were 0.25 MMT CO_2 Eq., accounting for 19.4 percent of AFOLU sector emissions. Table 5-2 summarizes emissions from enteric fermentation in Hawai'i for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.31	0.28	0.29	0.27	0.24	0.25	0.25	0.25	0.25

Methodology

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

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

where,

P = animal population (head)

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

Population data for swine were obtained directly from the U.S. Department of Agriculture's (USDA) National Agriculture Statistics Service (NASS) (USDA 2022). Population data for cattle were obtained from the US Inventory through a data request to EPA (EPA, 2022a). 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 1987, 1992, 1997, 2002, 2007, 2012, and 2017 were obtained directly from USDA (2009 and 2019) while population estimates for 1990, 2005, 2010, and 2015 – 2019 were interpolated and extrapolated based on available data.

Yearly emission factors for all cattle types available for the state of Hawaiʻi for all years were obtained from the U.S. Inventory through a data request to U.S. EPA (EPA 2022a).[44] Constant emission factors for sheep, goats, horses, and swine were also obtained from the U.S. Inventory (EPA 2022a).

Changes in Estimates since the Previous Inventory Report

Changes to emission estimates were minor. In alignment with potential improvements to the Enteric Fermentation subsector identified in the 2017 inventory report, the 2019 inventory was updated to obtain state-level cattle population estimates for each cattle subgroup directly from the U.S. Inventory (EPA 2022a). In previous inventories, cattle populations were estimated using a bottom-up approach that used historical county-level data from USDA NASS data to estimate cattle populations in each county, which were then totaled to estimate the number of cattle in each subgroup at the state level. However, USDA NASS stopped publishing county-level population estimates of beef and dairy cows annually in 2012 and instead switched to releasing information on the total population of cattle in each county in the Census of Agriculture, which is only released every 5 years. Because USDA no longer publishes robust county-level data, the 2019 inventory was updated to instead use state-level cattle populations for each cattle subgroup from the US Inventory, which is updated annually. Cattle were then apportioned to each county based on a county scaling factor, which was developed from historical USDA NASS data on the population of dairy and beef cattle in each county from 1990 – 2007, 2012, and 2017.

Emission factors for methane emissions from cattle enteric fermentation were also updated to use Hawaiʻi-specific emission factors from the U.S. Inventory (EPA 2022a). The resulting changes in historical emissions estimates are presented in Table 5-3.

Table 5-3: Change in Emissions from Enteric Fermentation Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.32	0.30	0.27	0.24	0.25	0.26
This Inventory Report (MMT CO_2 Eq.)	0.31	0.29	0.27	0.24	0.25	0.25
Percent Change	-2.5%	-2.8%	-2.6%	-2.9%	-2.9%	-2.7%

Uncertainties

Uncertainties associated with enteric fermentation estimates include the following:

- There is uncertainty associated with animal population data. Population data for sheep, goats, and horses are reported every five years in the USDA Census of Agriculture, with the latest data available in 2017. As a result, population data for these animals were interpolated between

[44] 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.

census years to obtain estimates for 1990, 2010, 2015, 2016 and extrapolated for 2018 and 2019.

- There is some uncertainty associated with state-level cattle populations. USDA NASS does not maintain detailed cattle data by age, class, and diet. As a result, Hawaiʻi specific cattle population data by class (e.g., steer stocker, dairy heifer) was obtained through a data request to EPA (2022a).
- 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 2022a). In addition, the emission factors for non-cattle animal types, also obtained from the U.S. Inventory, are not specific to Hawaiʻi.

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

The results of the quantitative uncertainty analysis are summarized in Table 5-4. Emissions from enteric fermentation were estimated to be between 0.22 and 0.29 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 15 percent below and 15 percent above the emission estimate of 0.25 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.25	0.22	0.29	-15%	+15%

[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 2022a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. In 2019, emissions from manure management were 0.02 MMT CO_2 Eq., accounting for 1.2 percent of AFOLU sector emissions. Table 5-5 summarizes emissions from manure management in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.11	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.01
N_2O	0.01	+	+	+	+	+	+	+	+
Total	**0.13**	**0.05**	**0.03**	**0.02**	**0.02**	**0.02**	**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

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 (percent)
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 (percent)
WMS VS = fraction volatile solids distribution by animal type and waste management system (percent)
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.

- Cattle population data at the state level for all years was obtained from the U.S. Inventory and scaled to the county level using scaling factors developed from USDA NASS cattle populations. County level cattle population data from USDA NASS was released annually from 1990 – 2012.

After 2012, USDA stopped reporting annual county level population estimates for Hawaiʻi and switched to reporting county level cattle populations in the Census of Agriculture, which are released every 5 years. County scaling factors were interpolated between 2012 and 2017 and proxied to 2017 for all years after 2017.

- Swine population data for all years were obtained directly from USDA NASS (USDA 2022).
- Chicken population data for 1990 through 2010, for all subgroups except broilers, were obtained from USDA NASS (USDA 2018a). Chicken population data for 2012 and 2017 were obtained from USDA Census of Agriculture (USDA 2014 and 2019) and population data for 2015, 2016, 2018 and 2019 were estimated by extrapolating data available from 2012 and 2017. Broiler population data was obtained from the USDA Census of Agriculture for 1997, 2002, 2007, 2012, and 2017 (USDA 1999a, 2004, 2009, 2014, and 2019). Population data for 1990-1997, 2001-2005, 2008-2011, 2013-2016 were interpolated based on available data and population data for 2018 and 2019 were extrapolated based on historic data.
- 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 1987, 1992, 2007, 2012 and 2017 were obtained directly from USDA and population estimates for 1990, 2010, 2015, 2016, 2018, and 2019 were interpolated based on available data.

To calculate CH_4 emissions from manure management, typical animal mass (TAM) and maximum potential emissions (B_0) by animal for all animal types were obtained from the U.S. Inventory through a data request to EPA (EPA 2022a). Weighted methane conversion factors (MCFs) for all cattle types, sheep, goats, horses, swine, and chicken were obtained from the U.S. Inventory (EPA 2022a). Volatile solids (VS) excretion rates were obtained from the U.S. Inventory (EPA 2022a).

To calculate N_2O emissions from manure management, nitrogen excretion (Nex) rates for all animal types were obtained from the U.S. Inventory (EPA 2022a). The distributions of waste by animal in different waste management systems (WMS) were obtained from the U.S. Inventory (EPA 2022a). 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_0 factors, based on the percentage of each chicken type in Hawaiʻi from USDA (2018a), were applied to total Hawaiʻi chicken population data. Similarly, the weighted averages of swine VS rates, Nex rates, TAM and B_0 factors, based on the percentage of each swine type from the U.S. Inventory (EPA 2022a), were applied to total Hawaiʻi swine population data.

Changes in Estimates since the Previous Inventory Report

Changes that were implemented relative to the 2017 inventory report are summarized below.

- The methodology to estimate cattle population data was changed from a bottom-up estimate to a top-down estimate as described in section 5.1 Enteric Fermentation. Cattle populations are now lower compared to previous inventories, resulting in lower emission estimates.

- Nex rates and weighted MCFs were updated to use Hawaiʻi specific data from the U.S. Inventory (EPA 2022a).

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 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.14	0.04	0.03	0.03	0.03	0.03
This Inventory Report (MMT CO_2 Eq.)	0.13	0.03	0.02	0.02	0.02	0.02
Percent Change	-6.4%	-18.8%	-23.7%	-19.7%	-19.1%	-21.6%

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 and extrapolated to obtain estimates for 2018 and 2019. Similarly, chicken population data (excluding broilers) are available through 2010 from USDA NASS and then from the USDA Census of Agriculture for years 2012 and 2017; population estimates for broilers were interpolated to obtain estimates for 2015, 2016 and extrapolated to obtain estimates for 2018 and 2019.
- There is some uncertainty associated with state-level cattle populations. USDA NASS does not maintain detailed data on cattle by age, class, and diet. As a result, Hawaiʻi specific cattle population data by class (e.g., steer stocker, dairy heifer) was obtained through a data request to EPA (2022a).
- 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.
- 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. 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 Hawaiʻi. Finally, according to the U.S. Inventory, B_0 data used to estimate emissions from manure management are dated (EPA 2022a).

To estimate uncertainty associated with emissions from manure management, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on expert judgment and IPCC (2006). The following parameters contributed the most to the quantified uncertainty estimates: (1) the emission factors for dry lot manure systems, (2) the heifer stocker volatilize solids conversion rate, and (3) the B_0 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 0.01 and 0.02 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 20 percent below and 22 percent above the emission estimate of 0.02 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.02	0.01	0.02	-20%	+22%

[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)

Although nitrous oxide is produced naturally in soils through the nitrogen (N) cycle, many agricultural activities increase the availability of mineral N in soils, which leads to direct N_2O emissions from nitrification and denitrification (EPA 2022a). An example of such an activity would be the application of N fertilizers to agricultural soils. This category includes N_2O emissions from synthetic fertilizer, organic fertilizer, manure N, as well as crop residue inputs from sugarcane, pineapples, sweet potatoes, ginger root, taro, corn for grain, and seed production. In 2019, emissions from agricultural soil management were 0.18 MMT CO_2 Eq., accounting for 13.5 percent of AFOLU sector emissions. Table 5-8 summarizes emissions from agricultural soil management in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
N_2O	0.18	0.16	0.17	0.16	0.16	0.17	0.17	0.17	0.18

Methodology

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

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

The following equations were used to calculate direct emissions:

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

where,

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

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

where,

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

The following equations were used to calculate indirect emissions:

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

where,

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

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

where,

N_F	= N inputs to agricultural soils from synthetic fertilizers
N_O	= N inputs to agricultural soils from organic fertilizers
N_{CR}	= N inputs to agricultural soils from crop residues
N_{PRP}	= N inputs to agricultural soils from pasture, range, and paddock manure from all animals
$L_{vol\text{-}F}$	= fraction N lost through volatilization from synthetic fertilizer inputs
$L_{vol\text{-}O}$	= 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 2018b). 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, 2014, and 2019), which is compiled every five years. Specifically, data for 1987, 1992, 1997, 2007, 2012, and 2017 were obtained directly from USDA while production estimates for 1990, 2005, 2010, 2015, 2016, 2018, and 2019 were interpolated and extrapolated based on available data. Pineapple crop production and crop acreage were not available in the 2007 or 2012 Census of Agriculture, so pineapple data for 2010, 2015, and 2016 were estimated by extrapolating data between 2002 and 2017 (USDA 2004a and USDA 2019). 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 2022a).

Seed crop acreage for 1990 through 2019 were obtained from the USDA (USDA 2020a). According to the USDA, seed corn accounts for over 95 percent of the value of Hawaiʻi's seed industry (USDA 2020a). Therefore, 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. 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 1995 – 2019, TVA 1991 – 1994). Synthetic fertilizer N application data were not available after 2014, so 2015 – 2019 data were extrapolated based on 2014 data. According to these data sources, commercial organic fertilizer is not applied in Hawaiʻi.

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 Hawaiʻi, 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:

- Swine population data for all years were obtained directly from USDA NASS (USDA 2022).
- Cattle population data at the state level for all years was obtained from the U.S. Inventory and scaled to the county level using scaling factors developed from USDA NASS cattle populations. County level cattle population data from USDA NASS was released annually from 1990 – 2012. After 2012, USDA stopped reporting annual county level population estimates for Hawaiʻi and switched to reporting county level cattle populations in the Census of Agriculture, which are released every 5 years. County scaling factors were interpolated between 2012 and 2017 and proxied to 2017 for all years after 2017.
- Chicken population data was available from USDA NASS for 1990 – 2010, 2012, and 2017. Population estimates for 2011, and 2013 – 2016 were interpolated and 2018 and 2019 were extrapolated based on available population data. 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, 2005, 2010, 2015, and 2016 were interpolated and 2018 and 2019 were extrapolated based on 1987, 1992, 2007, 2012, and 2017 data.

Changes in Estimates since the Previous Inventory Report

Cattle population estimates were updated as described in section 5.1. The resulting changes to emissions from agricultural soil management after updating cattle populations are shown in Table 5-9.

Table 5-9: Change in Emissions from Agricultural Soil Management Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.18	0.17	0.16	0.16	0.17	0.17
This Inventory Report (MMT CO_2 Eq.)	0.18	0.17	0.16	0.16	0.17	0.17
Percent Change	1.2%	1.4%	1.1%	0.9%	1.0%	0.9%

Uncertainties

Uncertainties associated with agricultural soil 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, 2005, 2010, 2015 and 2016 and extrapolated to obtain estimates for 2018 and 2019. Similarly, chicken population data (excluding broilers) are available through 2010 from USDA NASS and then from the USDA Census of Agriculture for years 2012 and 2017; population estimates for broilers were interpolated to obtain estimates for 2015, 2016 and extrapolated to obtain estimates for 2018 and 2019.
- There is some uncertainty associated with state-level cattle populations. USDA NASS does not maintain detailed data on cattle data by age, class, and diet. As a result, Hawaiʻi specific cattle population data by class (e.g., steer stocker, dairy heifer) was obtained through a data request to EPA (2022a).
- 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 census 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 2019 were extrapolated using 1997 and 2002 data.
- There is uncertainty associated with the extrapolation of synthetic fertilizer N application data to 2019 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 Hawaiʻi 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 2022a), 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) total fertilizer consumption in 2014.

The results of the quantitative uncertainty analysis are summarized in Table 5-10. Emissions from agricultural soil management were estimated to be between 0.12 and 0.31 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 33 percent below and 76 percent above the emission estimate of 0.18 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.18	0.12	0.31	-33%	+76%

[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 2022a).[45] This source includes CH_4 and N_2O emissions from sugarcane burning, which is the only major crop in Hawaiʻi 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 2019, emissions from field burning of agricultural residues were 0 MMT CO_2 Eq., due to the closure of the last sugarcane mill in Hawaiʻi in 2016. Table 5-11 summarizes emissions from field burning of agricultural residues in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.03	0.02	0.01	+	+	0.01	+	0.0	0.0
N_2O	+	+	+	+	+	+	+	0.0	0.0
Total	**0.03**	**0.03**	**0.01**	**0.01**	**0.01**	**0.01**	**+**	**0.0**	**0.0**

+ 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 2022a). Emissions were calculated using the following equation:

[45] 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).

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

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 2018b). 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 2017 inventory report.

Uncertainties

This analysis assumes that sugarcane is the only major crop in Hawaiʻi whose residues were regularly burned and that sugarcane burning is no longer practiced as the last sugarcane mill closed in 2016 (Hudson 2008). Therefore, emissions from the field burning of crop residues are assumed to be zero.

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 2019, emissions from urea application were 0.0014 MMT CO_2 Eq., accounting for slightly less than 0.1 percent of AFOLU sector emissions. Table 5-12 summarizes emissions from urea application in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	+	+	+	+	+	+	+	+	+

+ Does not exceed 0.005 MMT CO_2 Eq.

Methodology

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

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

where:

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

Fertilizer sales data were obtained from the annual *Commercial Fertilizers* publication by the Association of American Plant Food Control Officials (AAPFCO 1995 – 2019, TVA 1991 – 1994). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[46] 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 2016, so 2017, 2018 and 2019 were estimated based on 2016 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

Historical urea fertilizer consumption was updated for 2015 and 2016 based on the 2015 and 2016 Commercial Fertilizers reports released by the Association of American Plant Food Control Officials. Urea fertilizer consumption trend estimates for 2017 and beyond were updated to include reported consumption in 2015 and 2016 in future consumption projections. The impact on emissions was not significant.

Uncertainties

There is uncertainty associated with the extrapolation of urea fertilizer application data to 2019 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).

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

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) the share of annual fertilizer application between January and June, (2) the share of annual fertilizer application between July and December, and (3) urea consumption in 2012. 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 5-13. Emissions from urea application were estimated to be between 0.0008 and 0.001 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 44 percent below and four percent above the emission estimate of 0.001 MMT CO_2 Eq.

Table 5-13: Quantitative Uncertainty Estimates for Emissions from Urea Application

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.001	0.001	0.001	-44%	+4%

+ Does not exceed 0.005 MMT CO_2 Eq.
[a] Range of emission estimates predicted by Monte Carlo Stochastic Simulation for a 95 percent confidence interval.

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 one to six percent organic carbon by weight (EPA 2022a). 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 2019, emissions from agricultural soils were 0.83 MMT CO_2 Eq., accounting for 63.0 percent of AFOLU sector emissions. Table 5-14 summarizes emissions from agricultural soils in Hawai‘i for 1990, 2005, 2007, 2010, and 2015 – 2019.

Table 5-14: Emissions from Agricultural Soil Carbon by Gas (MMT CO_2 Eq.)

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.80	0.68	0.67	0.76	0.82	0.82	0.83	0.83	0.83

Methodology

Emission estimates from Hawaiʻi's agricultural soils are based on state-level data obtained from the 1990 – 2020 U.S. Inventory (EPA 2022a). All the emissions and sinks from mineral and organic sources from land converted to grassland, grassland remaining grassland, land converted to cropland, and cropland remaining cropland for the state of Hawaiʻi were summed to get the net carbon emissions from agricultural soil carbon in Hawaiʻi. This methodology was confirmed by Dr. Susan Crow, a member of the Hawaiʻi Greenhouse Gas Sequestration Task Force. State-level emission estimates from the U.S. Inventory (EPA 2022a) developed using the DAYCENT model continue to reflect the best available estimates of emissions from agricultural soil carbon in Hawaiʻi.

Changes in Estimates since the Previous Inventory Report

Relative to the 2017 inventory report, agricultural soil emissions were revised based on the latest U.S. Inventory data through 2019 (EPA 2022a). An update to the U.S. Inventory and how it accounts for agricultural soil carbon resulted in slight changes in historical emissions estimates (Table 5-15).

Table 5-15: Change in Emissions from Agricultural Soil Carbon Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.83	0.72	0.80	0.82	0.81	0.79
This Inventory Report (MMT CO_2 Eq.)	0.80	0.67	0.76	0.82	0.82	0.83
Percent Change	-4.7%	-6.8%	-4.1%	-0.8%	1.2%	4.3%

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 2022a).

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 (2022a) and Selmants et al. (2017). The following parameters contributed the most to the quantified uncertainty estimates: (1) carbon stock changes in organic soils in grassland (from 1990-2020 U.S. Inventory estimates), (2) carbon stock changes in mineral soils in grassland (from 1990-202 U.S. Inventory estimates), and (3) carbon stock changes in organic soils in cropland (from 1990-2020 U.S. Inventory estimates).

The results of the quantitative uncertainty analysis are summarized in Table 5-16. Emissions from agricultural soil carbon were estimated to be between -1.86 and 3.27 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 325 percent below and 295 percent above the emission estimate of 0.83 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.83	(1.86)	3.27	-325%	+295%

[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 Hawaiʻi Department of Land and Natural Resources (DLNR 1994 – 2008, 2011, 2015, 2016, 2017, 2018, 2019, and 2020).[47] In 2019, emissions from forest fires were 0.04 MMT CO_2 Eq., accounting for 2.7 percent of AFOLU sector emissions. Table 5-17 summarizes emissions from forest fires in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	0.09	0.03	0.11	0.01	0.03	0.02	0.01	0.18	0.03
CH_4	0.01	+	0.01	+	+	+	+	0.01	+
N_2O	+	+	0.01	+	+	+	+	0.01	+
Total	**0.10**	**0.03**	**0.12**	**0.01**	**0.04**	**0.02**	**0.01**	**0.20**	**0.04**

+ 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, 2005, 2007, 2010, and 2015 – 2019 was obtained from the DLNR *Annual Wildfire Summary Report,* published by the Fire Management Program

[47] 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 limitations in data availability and because prescribed burning is not a common practice in Hawaiʻi. Emissions from this activity are expected to be marginal.

of the DLNR (also found in DBEDT's Hawaiʻi Data Book) (DLNR 1994 – 2008, 2011, 2015, 2016, 2017, 2018, 2019, and 2020; DBEDT 2020a). 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 (NASF), DLNR, and the State of Hawaiʻi Data Book (DBEDT 2020b). 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, 2016, 2018, and 2019 from the DLNR (2011, 2015, 2016, 2017, 2018, 2019, and 2020). 1998 data were used as a proxy for 1990, 2002 data were used as a proxy for 2005 and 2007, and 2016 data were used as a proxy for 2017.

Managed forestland area data were obtained from the State of Hawaiʻi Data Book (DBEDT 2020b). 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 Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019. Unmanaged forests are not included in this analysis per IPCC guidelines because the majority of anthropogenic GHG emissions occur 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 2017 inventory report, the calculation of forested natural areas was updated to better reflect data from the State of Hawaiʻi Data Book. The resulting changes in historical emissions estimates are presented in Table 5-18.

Table 5-18: Change in Emissions from Forest Fires Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.01	0.04	0.02	0.01
This Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.01	0.04	0.02	0.01
Percent Change	-0.6%	-0.6%	-1.7%	-0.7%	-0.7%	-0.7%

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 Hawaiʻi. However, emission estimates from prescribed fires in Hawaiʻi that are published by EPA's National Emission Inventory (NEI) program indicate that emissions from prescribed fires in Hawaiʻi were 1.92 MMT CO_2 Eq. in 2014 and 0.08 MMT CO_2 Eq. in 2017.[48] The NEI additionally does not report any emissions from wildfires in Hawaiʻi during these years. Given that prescribed fires are not common in Hawaiʻi 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.)

To estimate uncertainty associated with emissions from forest fires, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on USFS (2019a), IPCC (2006), and expert judgment. The following parameters contributed the most to the quantified uncertainty estimates: (1) reported forest area burned, (2) Hawaiʻi private forested area in conservation district, and (3) land under wildland fire protection.

The results of the quantitative uncertainty analysis are summarized in Table 5-19. Emissions from forest fires were estimated to be between 0.03 and 0.05 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 28 percent below and 31 percent above the emission estimate of 0.04 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.04	0.03	0.05	-28%	+31%

[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 2019, landfilled yard trimmings sequestered 0.05 MMT CO_2 Eq., accounting for 1.9 percent of carbon sinks. Table 5-20 summarizes

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

changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.06)	(0.05)

Note: Parentheses indicate negative values or sequestration.

Methodology

Estimates of the carbon sequestration in landfilled yard trimmings and food scraps for Hawaiʻi 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 2022c) 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 2022c), were used to calculate the national-level estimates. Hawaiʻi population data were obtained from the State of Hawaiʻi Data Book (DBEDT 2022a).

Changes in Estimates since the Previous Inventory Report

Relative to the 2017 inventory report, the State of Hawaiʻi population estimates were updated in the 2020 Hawaiʻi Data Book. The resulting changes in historical sink estimates from landfilled yard trimmings and food scraps are presented in Table 5-21.

Table 5-21: Change in Sinks from Landfilled Yard Trimmings and Food Scraps Relative to the 2017 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
This Inventory Report (MMT CO_2 Eq.)	(0.12)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)
Percent Change	0.0%	+	+	0.2%	+	0.1%

+ Does not exceed 0.05 percent.
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 Hawaiʻi is consistent with national estimates. The methodology does not consider Hawaiʻi-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 2005).

In addition, there are uncertainties associated with scaling U.S. sequestration to Hawaiʻi 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) the proportion of carbon stored permanently in food scraps, (2) 2018 yard trimming generation, (3) and 2017 yard trimming generation.

The results of the quantitative uncertainty analysis are summarized in Table 5-22. Sinks from landfilled yard trimmings and food scraps were estimated to be between -0.08 and -0.03 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 75 percent below and 48 percent above the sink estimate of -0.05 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(0.05)	(0.08)	(0.03)	+75%	-48%

[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 Hawaiʻi represented approximately five percent of Hawaiʻi's total area in 1990 and six percent of Hawaiʻi's total area in 2010 (U.S. Census Bureau 1990a and 2012; DBEDT 2018). In 2019, urban trees sequestered 0.63 MMT CO_2 Eq., accounting for 24.4 percent of carbon sinks. The upward trend in sequestration from urban trees from 2010 to 2019 is a result of the increased size of urban areas as well as an increase in urban tree density in all counties except Hawaiʻi. Table 5-23 and Table 5-24 below summarize carbon flux from urban trees, and the urban area in square kilometers, respectively in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2 Flux	(0.51)	(0.66)	(0.64)	(0.58)	(0.60)	(0.60)	(0.61)	(0.62)	(0.63)

Notes: Parentheses indicate negative values or sequestration.

Table 5-24: Statewide Urban Area (sq.km)

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
Urban Area	757.0	969.4	988.9	1,018.2	1,089.4	1,105.3	1,121.4	1,137.8	1,154.4

Methodology

Carbon flux from urban trees was calculated using a methodology consistent with the U.S. Inventory (EPA 2022a) 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 – 2020 U.S. Inventory provides state-level carbon sequestration rates from trees in *Settlements Remaining Settlements*, a land-use category that includes urban areas (EPA 2022a). Using the Hawaiʻi-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 Hawaiʻi.[49] State-level urban area estimates were adapted from the U.S. Census Bureau (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 Bureau (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 – 2019.

Nowak and Greenfield (2012) developed a study to determine percent tree cover by state. According to Nowak (2012), 39.9 percent of urban areas in Hawaiʻi were covered by trees circa 2005. With an estimate of total urban tree cover for Hawaiʻi, the Hawaiʻi-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

No changes were made to emissions from urban trees since the 2017 inventory report.

Uncertainties

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

- The methodology used to estimate urban area in 2015, 2016, 2017, 2018, and 2019 is based on USGS projections of area that are specific to Hawaiʻi 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 Hawaiʻi 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.

[49] 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).

To estimate uncertainty associated with sinks from urban trees, uncertainties associated with all input variables were assessed. Uncertainty was estimated quantitatively around each input variable based on Nowak et al. (2005, 2012, 2018a, and 2018b), Selmants et al. (2017), U.S. Census (2012), EPA (2021a), 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 Hawaiʻi, (2) Hawaiʻi tree cover, and (3) 2010 urban area in Honolulu. The quantified uncertainty estimated for net carbon sequestration per area of urban tree cover in Hawaiʻi contributed the vast majority to the quantified uncertainty estimates. The remaining input variables contributed relatively evenly to the overall uncertainty of the sink estimate.

The results of the quantitative uncertainty analysis are summarized in Table 5-25. Sinks from urban trees were estimated to be between -0.88 and -0.39 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 -0.63 MMT CO_2 Eq.

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

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(0.63)	(0.88)	(0.39)	+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)

Hawaiʻi 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 to discriminate between anthropogenic and non-anthropogenic sources and sinks because the majority of anthropogenic GHG emissions and sinks occur on managed land.[50] In 2019, forests and shrubland sequestered 1.91 MMT CO_2 Eq., accounting for 73.7 percent of carbon sinks. Table 5-26 summarizes carbon flux from forests and shrubland in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

[50] 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.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CO_2	(1.79)	(1.86)	(1.89)	(1.95)	(2.07)	(2.04)	(2.02)	(1.91)	(1.91)

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 Hawaiʻi forests. Unmanaged forests are not included in this analysis per IPCC guidelines. This method requires forestland acreage data as well as annual net C sequestration per unit area. The Gain Loss method calculates annual increase in carbon stocks using the following equation:

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

where,

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

Managed forestland acreage data were obtained from the State of Hawaiʻi Data Book (DBEDT 2020a). 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 Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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's Coastal Change Analysis Program (NOAA-CCAP) land cover study in 2000 and the USGS assessment of land cover in 2014 (NOAA-CCAP 2000; Selmants et al. 2017).

According to NOAA-CCAP, roughly half of Hawaiʻi'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 Hawaiʻi 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 – 2019. For 2005, 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 Hawaiʻi were obtained from USGS for 2011 through 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/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 rate across the entire timeseries was used.

Changes in Estimates since the Previous Inventory Report

Relative to the 2017 inventory report, the calculation of forested natural areas was updated to better reflect data from the State of Hawaiʻi Data Book. The resulting changes in historical estimates of carbon sequestration from forests are presented in Table 5-27.

Table 5-27: Change in Sinks from Forest Carbon Relative to the 2017 Inventory Report

Emission Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	(1.80)	(1.90)	(1.98)	(2.08)	(2.06)	(2.03)
This Inventory Report (MMT CO_2 Eq.)	(1.79)	(1.89)	(1.95)	(2.07)	(2.04)	(2.02)
Percent Change	0.5%	0.7%	1.7%	0.7%	0.7%	0.3%

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) Hawaiʻi private forested area in conservation district, and (3) total forest area.

The results of the quantitative uncertainty analysis are summarized in Table 5-28. Sinks from forest carbon were estimated to be between -2.28 and -1.58 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 19 percent below and 17 percent above the sink estimate of -1.91 MMT CO_2 Eq.

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

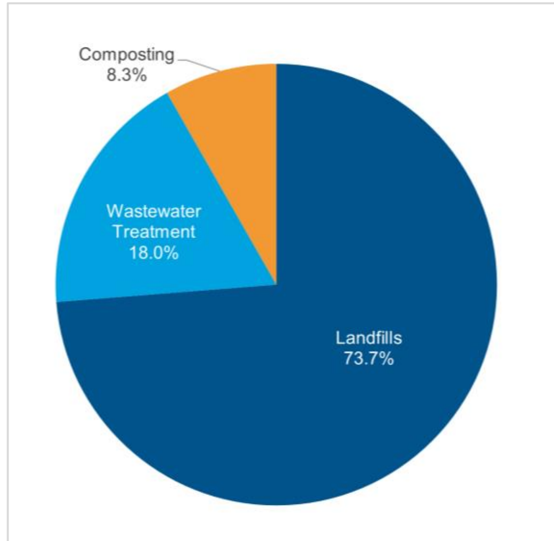
2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
(1.91)	(2.28)	(1.58)	+19%	-17%

[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 the Hawaiʻi, 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).[51] Emissions from the incineration of waste are reported under the Energy sector, consistent with the U.S. Inventory, since the incineration of waste generally occurs at facilities where energy is recovered.

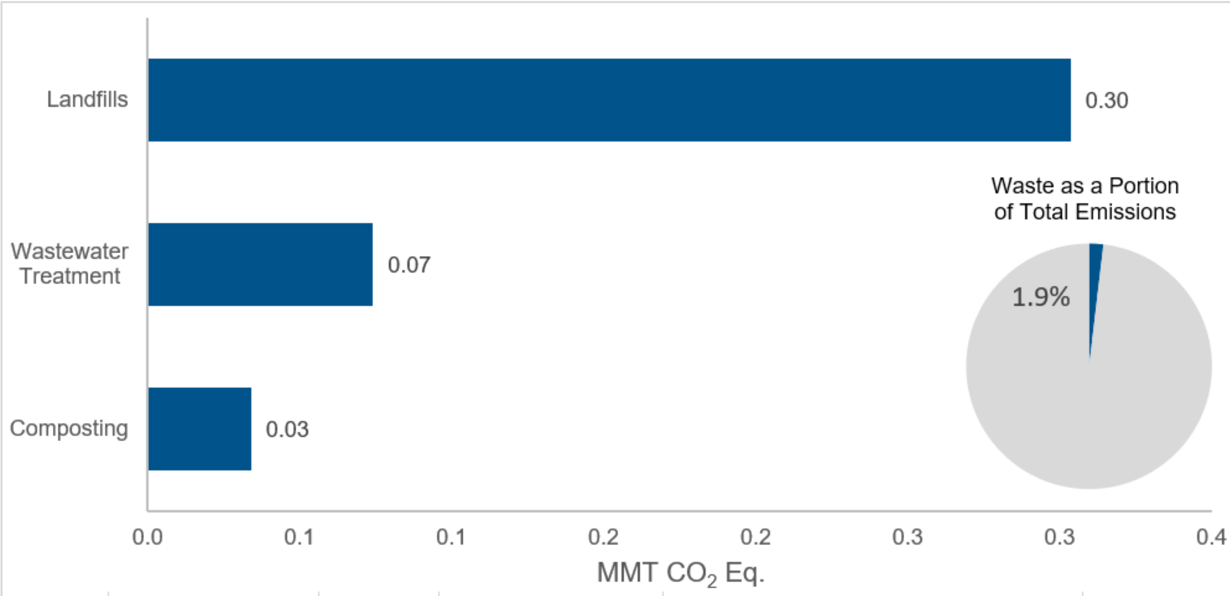
Figure 6-1: 2019 Waste Emissions by Source



In 2019, emissions from the Waste sector were 0.41 MMT CO_2 Eq., accounting for 1.9 percent of total Hawaiʻi emissions. Emissions from landfills accounted for the largest share of Waste sector emissions (73.7 percent), followed by emissions from wastewater treatment (18.0 percent) and composting (8.3 percent). Figure 6-1 and Figure 6-2 show emissions from the Waste sector by source for 2019.

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

Figure 6-2: 2019 Waste Emissions by Source (MMT CO_2 Eq.)



Emissions from the Waste sector have decreased since their 1990 peak and in 2019 were lower by 55.9 percent relative to 1990. 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 1990 and 2019 as a result of an increase in the volume of landfill gas recovered for flaring. Figure 6-3 below shows Waste sector emissions by source category for each inventory year. Emissions by source and year are also summarized in Table 6-1.

Figure 6-3: Waste Sector Emissions by Source and Year

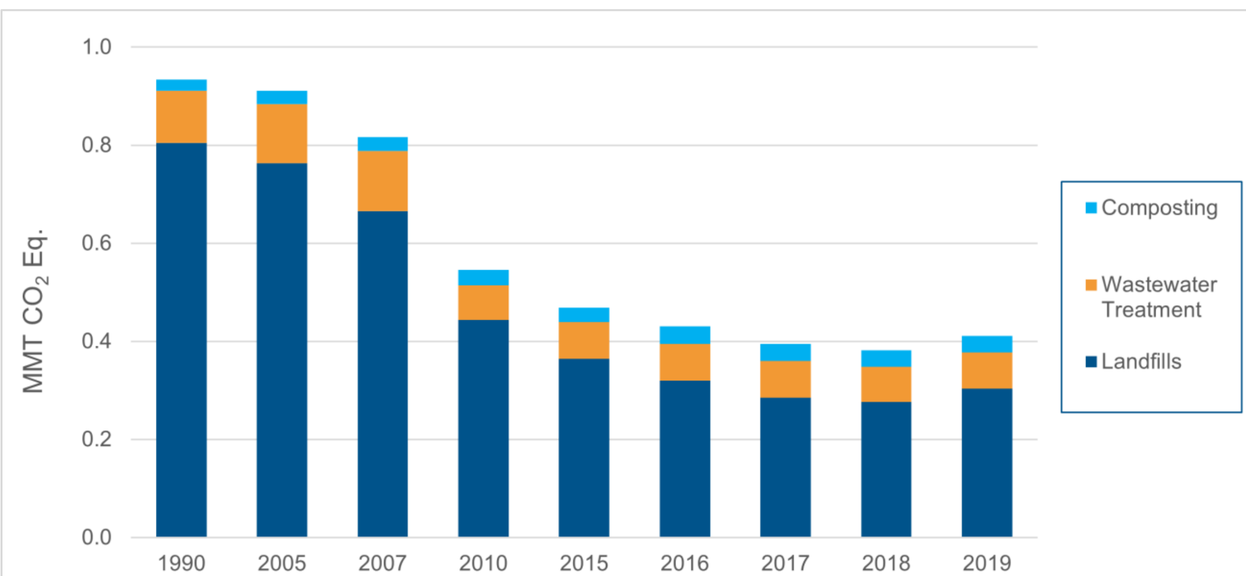


Table 6-1: GHG Emissions from the Waste Sector by Source (MMT CO_2 Eq.)

Source	1990	2005	2007	2010	2015	2016	2017	2018	2019
Landfills	0.81	0.76	0.67	0.44	0.36	0.32	0.29	0.28	0.30
Composting	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03
Wastewater Treatment	0.11	0.12	0.12	0.07	0.07	0.07	0.07	0.07	0.07
Total	**0.93**	**0.91**	**0.82**	**0.55**	**0.47**	**0.43**	**0.40**	**0.38**	**0.41**

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. Activity data and emission factors used in the analysis are summarized in Appendix F and Appendix G, 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 2022a). Consistent with IPCC (2006), biogenic CO_2 from landfills is not reported under the Waste sector. In 2019, CH_4 emissions from landfills in Hawaiʻi were 0.30 MMT CO_2 Eq., accounting for 73.7 percent of Waste sector emissions. Emissions from landfills have decreased since their 1990 peak and in 2019 were lower by roughly 62.3 percent relative to 1990. This trend is attributed to a relative increase in the volume of landfill gas recovered for flaring in Hawaiʻi. Table 6-2 summarizes CH_4 emissions from landfills in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.81	0.76	0.67	0.44	0.36	0.32	0.29	0.28	0.30

Methodology

Consistent with the methodology used for the U.S. Inventory (EPA 2022a), potential MSW landfill emissions were calculated using a combination of reported emissions data from EPA's Greenhouse Gas Reporting Program (GHGRP) (EPA 2022b), waste in place data provided by EPA's LMOP (EPA 2022g), and annual amounts of waste landfilled in Hawaiʻi. Data on the tons of waste landfilled per year in Hawaiʻi for 1995 through 2020 were provided by the Hawaiʻi Department of Health (DOH), Solid Waste Branch (Hawaiʻi DOH 2022a 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 Hawaiʻi from EPA's State Inventory Tool – Municipal Solid Waste Module (EPA 2022c).

For the years 2010 to 2019, direct measurements of CH_4 emissions were obtained from EPA's GHGRP database, using Equation HH-8 for MSW landfills and Equation TT-6 for Hawaiʻi's one industrial landfill

(EPA 2022b). GHGRP emissions are considered an IPCC Tier 3 approach (IPCC 2006) that consider flared and captured CH_4 from the landfill's operations, hours of operation of capturing technology, and the collection efficiency of the system. Since only landfills that surpass 25,000 MT CO_2 Eq. of emissions annually are required to report to GHGRP, a scaling factor was applied to each county's emissions to account for the landfills that fall under the GHGRP reporting threshold. The scaling factor is based on the difference between the amount of waste disposed at GHGRP reporting landfills and the total amount of waste at the county level for each year, calculated using LMOP's waste in place data and annual tipping amounts from Hawai‘i DOH.

Annual reporting requirements to EPA's GHGRP for applicable landfills began in 2010. Therefore, reported CH_4 generation obtained from GHGRP were back-casted to the years 1990, 2005, and 2007 and the total amount of flared CH_4 for each year was subtracted. Emissions from the Waimanalo Gulch landfill in Kapolei were excluded from the 1990 estimate because the landfill began operation in 1989. Emissions in the first year are assumed to be zero, as it typically takes one year for anaerobic conditions to be established and methane-producing bacteria to start decomposing waste (EPA 2022i).

Equation HH-8 for MSW landfills as described by GHGRP is as follows:

$$E = \left(\frac{R}{CE * f_{Rec}} - R\right) * (1 - OX) + R * \left(1 - (DE * f_{Dest})\right)$$

where,

E = amount of CH_4 emitted

R = quantity of recovered CH_4 from GHGRP equation HH-4 (metric tons)

CE = collection efficiency estimated at landfill

f_{Rec} = fraction of hours the recovery system was operating

OX = oxidation factor

DE = destruction efficiency

f_{Dest} = fraction of hours the destruction device was operating

Equation TT-6 for industrial landfills as described by GHGRP is as follows:

$$MG = G_{CH4} * (1 - OX)$$

where,

MG = amount of CH_4 generated, adjusted for oxidation

G_{CH4} = modeled methane generation from GHGRP Equation TT-1

OX = oxidation factor (default of 0.1)

Changes in Estimates since the Previous Inventory Report

The 2017 inventory report applied the First Order Decay (FOD) model to estimate emissions prior to 2010 and utilized data from GHGRP on landfill operation and gas collection systems to estimate emissions for years after 2010. To improve upon this estimate, this inventory report incorporated CH_4 emissions reported to EPA's GHGRP for years after 2010, and then applied a back-casting method based on GHGRP-reported data for years prior to 2010, resulting in lower emission estimates across the time series. This inventory report also incorporated CH_4 emissions from Hawai'i's industrial landfill based on data reported to GHGRP. The resulting changes in historical emission estimates are presented in Table 6-3.

Table 6-3: Change in Emissions from Landfills Relative to the 2017 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.65	0.92	0.87	0.75	0.69	0.73
This Inventory Report (MMT CO_2 Eq.)	0.81	0.67	0.44	0.36	0.32	0.29
Percent Change	24.7%	-27.3%	-48.9%	-51.4%	-53.8%	-60.9%

Uncertainties

Due to the change in methodology for calculating landfill methane emissions directly from EPA's GHGRP, uncertainty bounds are considerably smaller in this report compared to the previous iteration. To estimate uncertainty associated with emissions from landfills, uncertainties for several quantities were assessed, including: (1) landfill methane emissions from GHGRP, (2) landfill waste-in-place data from EPA's LMOP, (3) methane generation potential, (4) methane generation rate constant, (5) Hawai'i state population, and (6) 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 for MSW landfills: (1) reported methane emissions from the South Hilo landfill, (2) Maui county's population, and (3) reported methane emissions from the Central Maui landfill. Since Hawai'i only has one industrial landfill and methane emissions are taken directly from the GHGRP report, this parameter was the only one that contributed to the uncertainty estimate for industrial landfills.

The results of the quantitative uncertainty analysis are summarized in Table 6-4 for MSW landfills and Table 6-5 for industrial landfills. Emissions from MSW landfills were estimated to be between 0.25 and 0.27 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately three percent below and four percent above the emission estimate of 0.26 MMT CO_2 Eq. Emissions from industrial landfills were estimated to be between 0.04 and 0.05 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately five percent below and five percent above the emission estimate of 0.05 MMT CO_2 Eq.

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

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.26	0.25	0.27	-3%	+4%

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

Table 6-5: Quantitative Uncertainty Estimates for Emissions from Industrial Landfills

2019 Emissions Estimate ($MMT\ CO_2$ Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	($MMT\ CO_2$ Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.05	0.04	0.05	-5%	+5%

[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 of 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 2022a). In 2019, emissions from composting in Hawaiʻi were 0.03 MMT CO_2 Eq., accounting for 8.3 percent of Waste sector emissions. Relative to 1990, emissions from composting in 2019 were higher by 48.9 percent. This trend is attributed to increases in quantities of composted materials. Table 6-6 summarizes emissions from composting in Hawaiʻi for 1990, 2005, 2007, 2010, and 2015 – 2019.

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
N_2O	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
Total	**0.02**	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.03**	**0.03**	**0.03**

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 and by county were provided by Hawai'i's Department of Health (Hawai'i DOH 2022a). The emission factors for composting were obtained from IPCC (2006). It was assumed that CH_4 recovery did not occur at composting operations in Hawai'i.

Changes in Estimates since the Previous Inventory Report

This inventory report incorporated tons of waste composted from Hawai'i DOH, whereas the previous inventory estimated the tons of waste composted based on population and a U.S.-specific compost generation per capita. The resulting changes in historical emission estimates are presented in Table 6-7.

Table 6-7: Change in Emissions from Composting Relative to the 2017 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	+	0.02	0.01	0.02	0.02	0.02
This Inventory Report (MMT CO_2 Eq.)	0.02	0.03	0.03	0.03	0.04	0.03
Percent Change	602.5%	78.1%	111.3%	67.3%	108.4%	94.7%

+ Does not exceed 0.05.

Uncertainties

Due to a change in methodology to incorporate Hawai'i specific information regarding composting as opposed to taking a U.S. national average, uncertainty bounds in composting are lower than those in the previous report.

To estimate uncertainty associated with emissions from composting, uncertainties for the following were assessed: (1) CH_4 emission factor, (2) N_2O emission factor, (3) waste composted by county, and (4) Hawai'i population data. Uncertainty was estimated quantitatively around each input variable based on expert judgment, IPCC (2006), and EPA (2022a). The following parameters contributed the most to the quantified uncertainty estimates: (1) CH_4 emission factor, (2) N_2O emission factor, and (3) Honolulu county composting tonnage amount.

The results of the quantitative uncertainty analysis are summarized in Table 6-8. Emissions from composting were estimated to be between 0.02 and 0.06 MMT CO_2 Eq. at the 95 percent confidence level. This confidence level indicates a range of approximately 51 percent below and 64 percent above the emission estimate of 0.03 MMT CO_2 Eq.

Table 6-8: Quantitative Uncertainty Estimates for Emissions from Composting

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.03	0.02	0.06	-51%	+64%

[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 2022a). 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 Hawai‘i, serving most of the state's population. The remaining wastewater is treated at on-site wastewater systems. In 2019, emissions from wastewater treatment in Hawai‘i were 0.07 MMT CO_2 Eq., accounting for 18.0 percent of Waste sector emissions. Relative to 1990, emissions from wastewater treatment in 2019 were lower by 29.8 percent. Table 6-9 summarizes emissions from wastewater treatment in Hawai‘i for 1990, 2005, 2007, 2010, and 2015 – 2019.

Table 6-9: Emissions from Wastewater Treatment by Gas (MMT CO_2 Eq.)

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CH_4	0.07	0.08	0.08	0.03	0.03	0.03	0.03	0.02	0.03
N_2O	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
Total	**0.11**	**0.12**	**0.12**	**0.07**	**0.07**	**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 2022a) and EPA's State Inventory Tools – Wastewater Module (EPA 2022c). Wastewater emissions from municipal wastewater treatment, septic tank treatment, and wastewater biosolids were quantified using data on population, septic tank use, biochemical oxygen demand (BOD) production and flow rate at wastewater treatment plans, and biosolids fertilizer use practices.

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

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

where,

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

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

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

where,

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

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

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

where,

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

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

Data on National Pollutant Discharge Elimination System (NPDES) and non-NPDES wastewater treatment plants, including flow rate and BOD_5, were provided by Hawaiʻi DOH, Wastewater Branch (Pruder 2008, Hawaiʻi DOH 2017, Hawaiʻi DOH 2018, and Hawaiʻi DOH 2022a, 2022b, 2022c, 2022d) or obtained from EPA's Enforcement and Compliance History Online (ECHO) Database (EPA 2022j). Where sufficient data were available, it was used to characterize BOD_5 for a given island and inventory year. When sufficient data were not available, data for a particular WWTP were either proxied to the most recent year with data, or to the Hawaiʻi default BOD_5 value from the 1997 inventory of 0.1356 due to it being the best available data that is Hawaiʻi-specific and sourced from the Hawaiʻi State Department of Health (DBEDT and DOH 1997). Specifically, because of incomplete historical data, the Hawaiʻi default BOD_5 value from the 1997 inventory was used across all counties for the 1990, 2005, and 2007 inventory years.

Population data from the State of Hawaiʻi Data Book (DBEDT 2022a), 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 the full timeseries comprehensive data on the number of households on septic systems were unavailable. Therefore, annually variable data on the percentage of the population using centralized wastewater treatment facilities from the U.S. GHG Inventory were used to estimate the percent of Hawaiʻi's population using septic systems for all inventory years (EPA 2022a). Emission factors were obtained from EPA's State Inventory Tool (EPA 2022c).

Changes in Estimates since the Previous Inventory Report

For the 2017 inventory report, data on the number of households using a septic system in each county from 1990 and 2007 were utilized. Due to a lack of data availability the percentage of each county's population using a septic system was estimated using 2007 data as a proxy. For this inventory, the percentage of the U.S. population that uses septic systems in each inventory year was used as a proxy to estimate the portion of the population in the state of Hawaiʻi using septic systems.

In addition, this inventory updated historical emission estimates by incorporating newly obtained flow rates and BOD_5 for NPDES WWTPs, from Hawaiʻi DOH Wastewater Branch and from EPA's ECHO Database, respectively.

The resulting changes in historical emission estimates are presented in Table 6-10.

Table 6-10: Change in Emissions from Wastewater Treatment Relative to the 2017 Inventory Report

Sink Estimates	1990	2007	2010	2015	2016	2017
2017 Inventory Report (MMT CO_2 Eq.)	0.10	0.12	0.07	0.07	0.07	0.07
This Inventory Report (MMT CO_2 Eq.)	0.11	0.12	0.07	0.07	0.07	0.07
Percent Change	0.6%	2.1%	3.7%	3.8%	4.6%	1.7%

Uncertainties

Due to the lack of Hawaiʻi-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, so a U.S. country average was used in its place. For instances where BOD or flow rate data from 2019 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 six quantities were assessed: (1) wastewater treatment plan flow rates, (2) BOD_5 values, (3) direct N_2O emissions rate, (4) biosolid N_2O emission factor, (5) CH_4 emission factor, and (6) percentage of biosolids used as fertilizer. 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 6-11. 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 25 percent below and 28 percent above the emission estimate of 0.07 MMT CO_2 Eq.

Table 6-11: Quantitative Uncertainty Estimates for Emissions from Wastewater Treatment

2019 Emissions Estimate (MMT CO_2 Eq.)	Uncertainty Range Relative to Emissions Estimate[a]			
	(MMT CO_2 Eq.)		(percent)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
0.07	0.06	0.09	-25%	+28%

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

7. Emission Projections

This chapter presents projections for Hawaiʻi statewide and county-level GHG emissions and sinks for 2020,[52] 2025, 2030, 2035, 2040, and 2045. This chapter includes a summary of the baseline projection results and the methodology used to develop these projections. This chapter also includes scenario-based statewide GHG projections due to variations in (1) world oil prices, (2) renewable energy deployment, and (3) ground transportation technology adoption.

7.1. Methodology Overview

Methodology

Greenhouse gas emissions result from economic activities occurring within Hawaiʻi. These emissions are impacted by the overall level of economic activities, the types of energy and technologies used, and land use decisions, among other factors. 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.

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 for the years 2020, 2025, 2030, 2035, 2040, and 2045. Several sources (residential, commercial, and industrial energy use, domestic and international aviation, non-energy uses, composting and wastewater treatment) were projected based on either a long-range forecast for gross state/county product or future population (including visitor arrivals), using the 2019 statewide GHG inventory as a starting point. For several small sectors, sector-specific approaches were taken. For example, for electrical transmission and distribution, electricity sales forecasts were used to project GHG emissions. For 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. For GHG emitting sources for which there has been substantial federal and state policy intervention (energy industries, substitution of ozone depleting substances, and transportation), bottom-up approaches were used. Due to policies that affect these sources, projected economic activities are 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**[53], three major points of uncertainty were assessed by modeling six

[52] Some sector-specific data were available for 2020; in these cases, actual historical data were used to develop 2020 GHG emissions estimates. Details regarding data sources used are available in Appendix J.

[53] A modeled emissions baseline scenario estimates emissions assuming no additional action is taken during the projected years. Historic emissions are projected using observed trends and applied growth rates consistent with the inventory methodology.

alternative scenarios for statewide GHG emissions in 2020, 2025, 2030, 2035, 2040, and 2045, as described below.

- **Alternate Scenario 1A and 1B: World oil prices.** Shifts in fossil fuel prices will impact consumer use of different fuels and resulting GHG emissions. This scenario looks at both *high* (Alternate Scenario 1A) and *low* (Alternate Scenario 1B) future oil price pathways based on the U.S. Energy Information Administration's Annual Energy Outlook 2022 (EIA 2022b).
- **Alternate Scenario 2A and 2B: Renewable energy deployment.** Hawaiʻi 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, and moving forward, 40 percent by 2030, 70 percent by 2040, and 100 percent by 2045 (HRS §269-92). Similar to the baseline, Alternate Scenario 2A used the Hawaiian Electric Industries (HEI) most recent planning documents (Integrated Grid Plan, baseline scenario). Alternate Scenario 2A illustrates a more aggressive path for renewable energy deployment.[54] For Alternate Scenario 2B, renewable energy deployment is projected based on the rate of deployment since the RPS took effect in 2010. Compared to the proposed E3 with Grid Modernization Plan in HECO's Power Supply Improvement Plan (PSIP) (PUC 2016) renewable energy deployment has on average been delayed by 32 MW per year in Honolulu county, 10 MW per year in Maui county, and 21 MW per year in Hawaiʻi County.
- **Alternate Scenario 3A and 3B: Ground transportation technology adoption.** In 2017, Hawaiʻi'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. This scenario creates a *high electric vehicle (EV) adoption scenario* (Alternate Scenario 3A) and *a low EV adoption scenario* (Alternate Scenario 3B).

A detailed description of the methodologies used to project statewide GHG emissions by source and sink categories 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

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

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[54] Both the baseline and Alternate Scenario 2A start with integrated grid plan (IGP) scenario assumptions for Oʻahu, with key modifications. Most notably, due to the gap in assessed 2021 renewable energy generation with the plan, the scenarios assume a lag in renewable energy adoption per the plan by five years.

- **Inventory Estimates:** The projections were developed using the 2019 statewide GHG inventory as a starting point, the results of which can be found in section 2.2. Any uncertainties related to quality and availability of data used to develop the historical inventory estimates similarly apply to the emission projections.
- **Macroeconomy and Population Projections:** The COVID-19 pandemic created tremendous economic impacts, including uncertainty in projections around economic recovery and future growth. The DBEDT (2022a) short-term forecast was used for this analysis. The Hawaiʻi economy is projected to return to pre-pandemic activities by 2023 and, from there, the DBEDT long-term forecast is applied (DBEDT 2018). This includes assumptions for future population growth. Uncertainty in forecasting Hawaiʻi's economy and population is implicit in projecting Hawaiʻi's GHG emissions.
- **Future Technology:** Break-throughs in technology, for example in large-scale battery storage or direct carbon air capture, will change the available suite and relative cost-effectiveness of commercially available low carbon technologies.
- **Policy:** Elements of other recently adopted policies such as Act 15 of 2018, which focuses on increasing GHG sequestration in Hawaiʻi's agricultural and natural environment, and Act 16, Session Laws of Hawaiʻi 2018 (Act 16 of 2018), which establishes a framework for a carbon offset program, were not directly considered in this analysis.
- **Linear Projections:** Historical data were used as a basis for linear projections within the report. These projections relied on the assumption that future data will follow a trend consistent with the past. Confounding factors such as climate change, natural disasters, land use change limitations, and other events may cause future relationships to differ from historic patterns.

7.2. Projections Summary

Table 7-1 summarizes emission projections of statewide emissions (excluding sinks, including aviation) for 2020, 2025, 2030, 2035, 2040, and 2045 under the baseline and each alternate scenario. Under the baseline scenario, total GHG emissions are projected to be 18.44 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.) in 2025, 17.49 MMT CO_2 Eq. in 2030, and 13.88 MMT CO_2 Eq. in 2045.

Table 7-2 summarizes net emissions, which take into account carbon sinks and are relevant for tracking progress toward the 2030 GHG target pursuant to Act 238 of 2022, under the baseline and each alternate scenario. Net emissions in the baseline scenario are projected to be 15.94 MMT CO_2 Eq. in 2025, 15.03 MMT CO_2 Eq. in 2030, and 11.25 MMT CO_2 Eq. in 2045.

Table 7-3 summarizes net emissions, which include carbon sinks, exclude aviation, and are relevant for tracking the progress toward the 2020 GHG target pursuant to Act 234 of 2007. Results under the baseline and each alternate scenario are included. Emissions under the baseline scenario are projected to be 11.58 MMT CO_2 Eq. in 2020, 10.46 MMT CO_2 Eq. in 2025, 9.38 MMT CO_2 Eq. in 2030, and 5.36 MMT CO_2 Eq. in 2045.

Under the alternate scenarios, total GHG emissions are projected to range from 16.83 to 19.18 MMT CO_2 Eq. in 2025, 15.69 to 18.33 MMT CO_2 Eq. in 2030, and 12.31 to 15.11 MMT CO_2 Eq. in 2045. Net emissions are projected to range from 14.33 to 16.68 MMT CO_2 Eq. in 2025, 13.23 to 15.87 MMT CO_2 Eq. in 2030, and 9.69 to 12.49 MMT CO_2 Eq. in 2045. Net emissions excluding aviation are projected to range from 9.51 to 10.85 MMT CO_2 Eq. in 2025, 8.07 to 9.81 MMT CO_2 Eq. in 2030, and 4.50 to 6.60 MMT CO_2 Eq. in 2045. Emission projections under all alternate scenarios are equal to the baseline projections in 2020.

Table 7-1: Hawaiʻi GHG Emission Projections (Excluding Sinks, Including Aviation) by Scenario for 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO_2 Eq.)

Scenario	Total Emissions (Excluding Sinks, Including Aviation)[a]					
	2020	2025	2030	2035	2040	2045
Baseline Scenario	**17.24**	**18.44**	**17.49**	**16.52**	**14.61**	**13.88**
Alternate Scenario 1A	17.24	16.83	15.69	14.72	12.94	12.31
Alternate Scenario 1B	17.24	19.18	18.33	17.36	15.41	14.69
Alternate Scenario 2A	17.24	17.93	16.18	14.64	13.88	13.01
Alternate Scenario 2B	17.24	18.27	17.23	16.51	15.54	15.11
Alternate Scenario 3A	17.24	18.44	17.37	16.18	13.84	13.03
Alternate Scenario 3B	17.24	18.45	17.55	16.76	15.15	14.84

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

Table 7-2: Hawaiʻi Net GHG Emission Projections (Including Sinks and Aviation) by Scenario for 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO2 Eq.)

Scenario	Net Emissions (Including Sinks and Aviation)[a,b]					
	2020	2025	2030	2035	2040	2045
Baseline Scenario	**14.69**	**15.94**	**15.03**	**14.03**	**12.06**	**11.25**
Alternate Scenario 1A	14.69	14.33	13.23	12.23	10.39	9.69
Alternate Scenario 1B	14.69	16.68	15.87	14.87	12.86	12.06
Alternate Scenario 2A	14.69	15.43	13.72	12.15	11.33	10.39
Alternate Scenario 2B	14.69	15.77	14.76	14.02	12.99	12.49
Alternate Scenario 3A	14.69	15.93	14.90	13.69	11.29	10.40
Alternate Scenario 3B	14.69	15.95	15.08	14.27	12.59	12.22

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

[b] Domestic aviation emissions, which are reported under the Energy sector, are included in Hawaiʻi's GHG emission reduction goal for 2030 established in Act 238 of 2022.

Table 7-3: Hawai'i Net GHG Emission Projections (Including Sinks, Excluding Aviation) by Scenario for 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO2 Eq.)

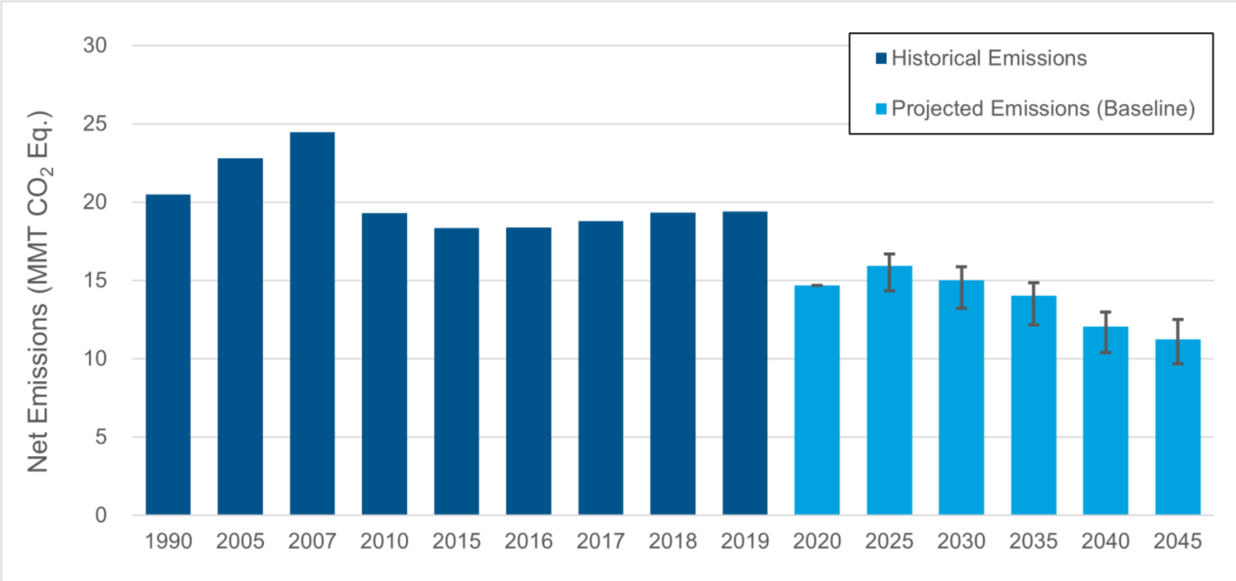
Scenario	Net Emissions (Including Sinks, Excluding Aviation)[a,c]					
	2020	2025	2030	2035	2040	2045
Baseline Scenario	**11.58**	**10.46**	**9.38**	**8.28**	**6.24**	**5.36**
Alternate Scenario 1A	11.58	9.51	8.35	7.28	5.38	4.60
Alternate Scenario 1B	11.58	10.85	9.81	8.66	6.55	5.65
Alternate Scenario 2A	11.58	9.96	8.07	6.40	5.51	4.50
Alternate Scenario 2B	11.58	10.30	9.11	8.27	7.17	6.60
Alternate Scenario 3A	11.58	10.46	9.26	7.94	5.47	4.51
Alternate Scenario 3B	11.58	10.47	9.43	8.52	6.77	6.33

[a] Emissions from International Bunker Fuels are not included in the totals, as per IPCC (2006) guidelines.
[c] Domestic aviation emissions, which are reported under the Energy sector, are excluded from Hawai'i's GHG emission reduction goal for 2020 established in Act 234 of 2007.

Relative to 2019, total emissions under the baseline scenario are projected to decrease by 16 percent by 2025, 21 percent by 2030, and 37 percent by 2045. Over the same period, net emissions are projected to decrease by 18 percent, 23 percent, and 42 percent, respectively, and net emissions excluding aviation are projected to decrease by 23 percent, 31 percent, and 61 percent, respectively. Under all scenarios, net emissions excluding aviation are projected to be less than the 1990 emissions level by 2020, where the decline in 2020 emissions can in part be attributed to the COVID-19 pandemic and lockdown restrictions.

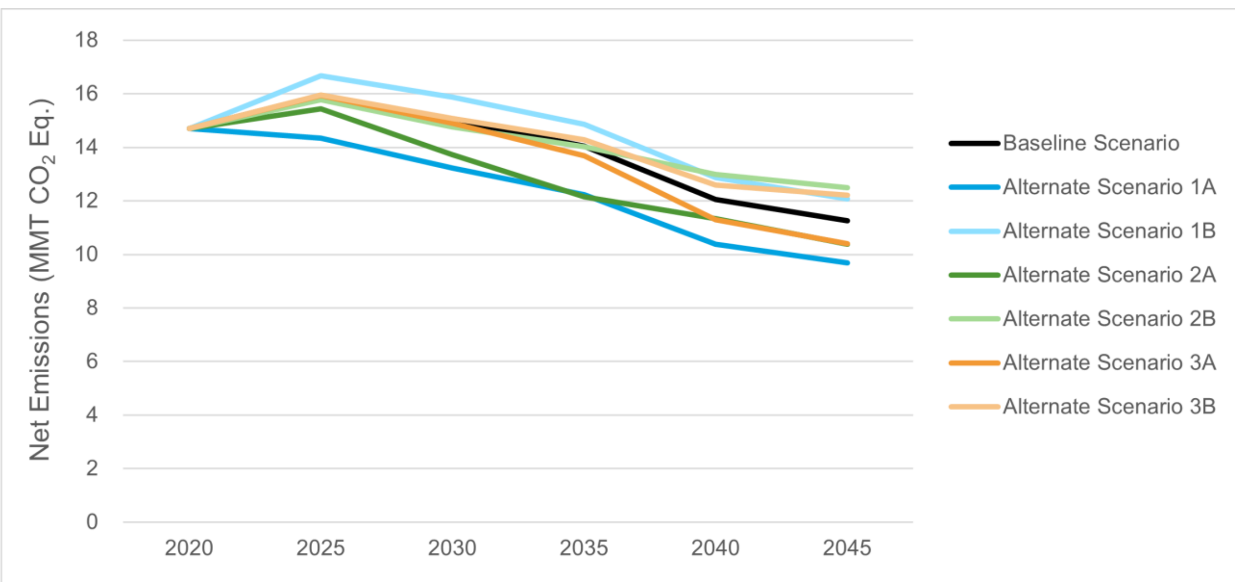
Figure 7-1 shows net GHG emissions for each historical and projected inventory year. This TSD document focuses on presenting net emissions in the State, including sinks, as these align with the official boundaries used for the State of Hawai'i's GHG emissions target for 2030 and 2045. A summary of the emission projections under each scenario is presented in Figure 7-2. Discussion of emission projections by sector is provided in the following sections.

Figure 7-1: Hawaiʻi Net GHG Emissions by Year (Including Sinks and 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. Emission estimates include aviation and sinks.

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



Note: Emission estimates include aviation and sinks.

7.3. Energy

For the Energy sector, projected emissions under both the baseline scenario and the alternate scenarios are presented.

Baseline Scenario

Under the baseline scenario, emissions from the Energy sector are projected to be 16.03 MMT CO_2 Eq. in 2025, 15.30 MMT CO_2 Eq. in 2030, and 12.16 MMT CO_2 Eq. in 2045, accounting for 86 percent, 87 percent, and 88 percent of total projected statewide emissions, respectively. Projected emissions under the baseline scenario by source for 2020, 2025, 2030, 2035, 2040, and 2045 are summarized in Table 7-4.

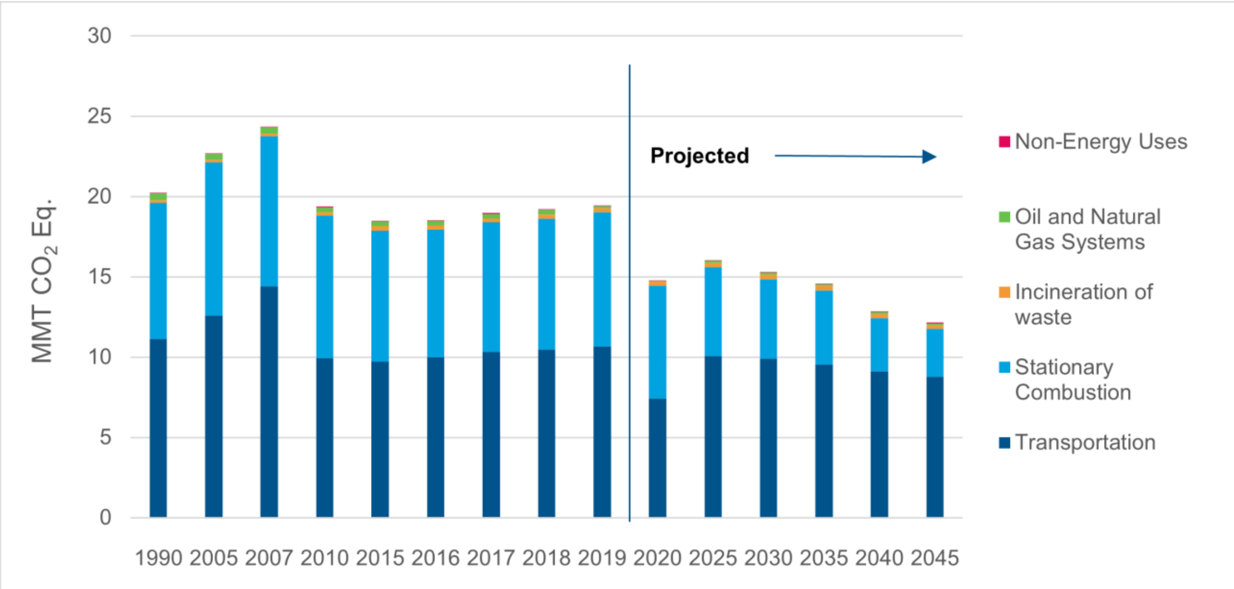
Table 7-4: GHG Emission Projections from the Energy Sector under the Baseline Scenario by Source (MMT CO_2 Eq.)

Source[a]	2020	2025	2030	2035	2040	2045
Stationary Combustion	**7.02**	**5.52**	**4.95**	**4.61**	**3.28**	**3.00**
Energy Industries[b]	6.04	4.45	3.81	3.42	2.02	1.67
Residential	0.06	0.06	0.05	0.05	0.05	0.05
Commercial	0.53	0.57	0.60	0.64	0.68	0.73
Industrial	0.40	0.44	0.48	0.51	0.53	0.56
Transportation	**7.41**	**10.07**	**9.91**	**9.53**	**9.13**	**8.77**
Ground	3.49	3.78	3.44	2.96	2.49	2.06
Domestic Marine[c]	0.65	0.65	0.65	0.65	0.65	0.65
Domestic Aviation	2.23	4.59	4.77	4.87	4.94	5.01
Military Aviation[d]	0.88	0.88	0.88	0.88	0.88	0.88
Military Non-Aviation[d]	0.16	0.16	0.16	0.16	0.16	0.16
Incineration of Waste	**0.27**	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**
Oil and Natural Gas Systems	**0.05**	**0.11**	**0.11**	**0.11**	**0.11**	**0.12**
Non-Energy Uses	**0.03**	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**
Total	**14.78**	**16.03**	**15.30**	**14.59**	**12.85**	**12.16**

[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 2019 emission estimates.
[d] Because decisions about military operations are generally external to Hawai'i's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2019 emission estimates.
Notes: Totals may not sum due to independent rounding. Emission totals include aviation emissions.

Relative to 2019, emissions from the Energy sector are projected to decrease by 18 percent by 2025, 21 percent by 2030, and 37 percent by 2045. This trend is 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 were estimated to decline substantially in 2020 due to pandemic-related decrease in airline travel. Though aviation emissions were estimated to rebound by 2025, transportation emission levels in 2030 and 2045 are expected to be seven percent and 18 percent lower, respectively, than 2019 due to increasing transportation fuel efficiency. Emissions from stationary combustion declines by 41 percent in 2030 and 64 percent in 2045 from 2019 levels due to an increase in the share of electricity generated from renewable sources. 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 (Including Aviation)



Note: Emission estimates include aviation emissions.

Alternate Scenarios

Under the alternate scenarios, emissions from the Energy sector are projected to range from 14.42 to 16.77 MMT CO_2 Eq. in 2025, 13.50 to 16.14 MMT CO_2 Eq. in 2030, 12.70 to 15.42 MMT CO_2 Eq. in 2035, 11.18 to 13.79 MMT CO_2 Eq. in 2040, and 10.59 to 13.40 MMT CO_2 Eq. in 2045. 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, 2030, 2035, 2040, and 2045 are summarized in Table 7-5 and graphically shown in Figure 7-4.

Table 7-5: GHG Emission Projections from the Energy Sector under the Alternate Scenarios by Source (MMT CO2 Eq.)

Source[a]	Alternate Scenario 1A					Alternate Scenario 1B					Alternate Scenario 2A				
	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045
Stationary Combustion	**5.12**	**4.56**	**4.23**	**2.92**	**2.63**	**5.67**	**5.05**	**4.66**	**3.29**	**3.02**	**5.03**	**3.65**	**2.75**	**2.57**	**2.16**
Energy Industries[b]	4.05	3.42	3.03	1.65	1.29	4.61	3.91	3.47	2.03	1.68	3.96	2.52	1.55	1.31	0.82
Residential	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05
Commercial	0.57	0.60	0.64	0.68	0.73	0.57	0.60	0.64	0.68	0.73	0.57	0.60	0.64	0.68	0.73
Industrial	0.44	0.48	0.51	0.53	0.56	0.44	0.48	0.51	0.53	0.56	0.44	0.48	0.51	0.53	0.56
Transportation	**8.88**	**8.52**	**8.13**	**7.84**	**7.60**	**10.65**	**10.64**	**10.30**	**9.91**	**9.55**	**10.07**	**9.91**	**9.53**	**9.13**	**8.77**
Ground	3.25	2.82	2.36	2.01	1.69	4.00	3.76	3.28	2.78	2.32	3.78	3.44	2.96	2.49	2.06
Domestic Marine[c]	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Domestic Aviation	3.94	4.00	4.07	4.13	4.21	4.95	5.18	5.33	5.43	5.53	4.59	4.77	4.87	4.94	5.01
Military Aviation[d]	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Military Non-Aviation[d]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Incineration of Waste	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**
Oil and Natural Gas Systems[e]	**0.09**	**0.09**	**0.09**	**0.10**	**0.10**	**0.11**	**0.12**	**0.12**	**0.13**	**0.13**	**0.09**	**0.09**	**0.09**	**0.10**	**0.10**
Non-Energy Uses	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**
Total	**14.42**	**13.50**	**12.79**	**11.18**	**10.59**	**16.77**	**16.14**	**15.42**	**13.65**	**12.97**	**15.52**	**13.99**	**12.70**	**12.12**	**11.29**

[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 2019 emission estimates.

[d] Because decisions about military operations are generally external to Hawai'i's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2019 emission estimates.

Notes: Totals may not sum due to independent rounding. Emission totals include aviation emissions.

Source[a]	Alternate Scenario 2B					Alternate Scenario 3A					Alternate Scenario 3B				
	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045	2025	2030	2035	2040	2045
Stationary Combustion	**5.36**	**4.68**	**4.60**	**4.22**	**4.24**	**5.53**	**5.04**	**4.88**	**3.46**	**3.14**	**5.52**	**4.91**	**4.57**	**3.21**	**2.92**
Energy Industries[b]	4.29	3.55	3.41	2.95	2.90	4.46	3.90	3.68	2.20	1.80	4.45	3.78	3.38	1.94	1.58
Residential	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05
Commercial	0.57	0.60	0.64	0.68	0.73	0.57	0.60	0.64	0.68	0.73	0.57	0.60	0.64	0.68	0.73
Industrial	0.44	0.48	0.51	0.53	0.56	0.44	0.48	0.51	0.53	0.56	0.44	0.48	0.51	0.53	0.56
Transportation	**10.07**	**9.91**	**9.53**	**9.13**	**8.77**	**10.06**	**9.70**	**8.92**	**8.18**	**7.79**	**10.07**	**9.99**	**9.80**	**9.73**	**9.82**
Ground	3.78	3.44	2.96	2.49	2.06	3.77	3.23	2.35	1.54	1.08	3.78	3.52	3.23	3.09	3.11
Domestic Marine[c]	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Domestic Aviation	4.59	4.77	4.87	4.94	5.01	4.59	4.77	4.87	4.94	5.01	4.59	4.77	4.87	4.94	5.01
Military Aviation[d]	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Military Non-Aviation[d]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Incineration of Waste	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**	**0.29**	**0.29**	**0.29**	**0.28**	**0.22**
Oil and Natural Gas Systems[e]	**0.11**	**0.11**	**0.11**	**0.11**	**0.12**	**0.11**	**0.11**	**0.11**	**0.11**	**0.12**	**0.11**	**0.12**	**0.12**	**0.13**	**0.13**
Non-Energy Uses	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**	**0.03**	**0.04**	**0.04**	**0.04**	**0.05**
Total	**15.86**	**15.03**	**14.58**	**13.79**	**13.40**	**16.01**	**15.17**	**14.23**	**12.08**	**11.29**	**16.04**	**15.35**	**14.83**	**13.39**	**13.13**

[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.

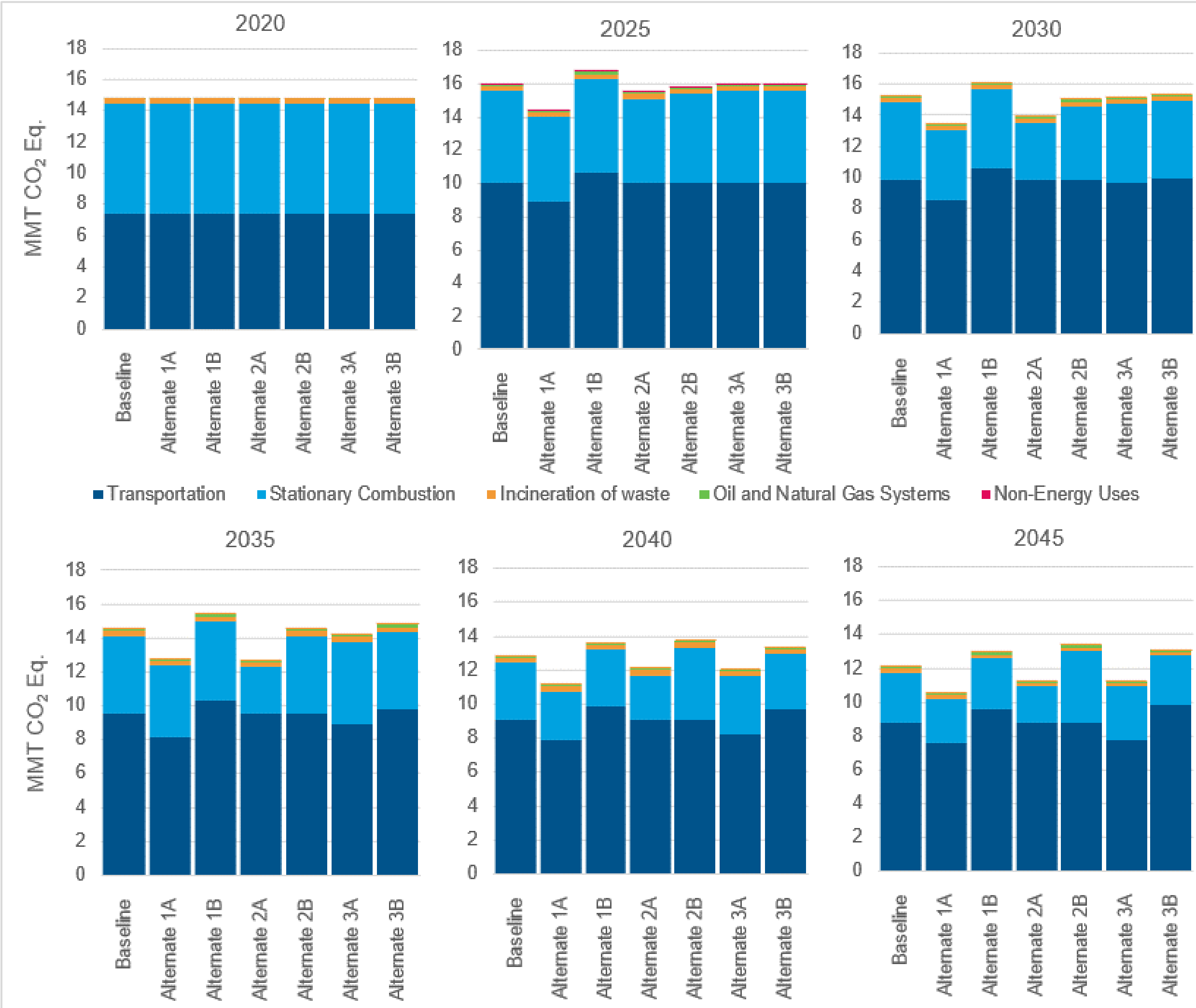
[b] Includes fuel combustion emissions from electric power plants and petroleum refineries.

[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 2019 emission estimates.

[d] Because decisions about military operations are generally external to Hawai'i's economy, future emissions from military are highly uncertain; these emissions are assumed to remain constant relative to 2019 emission estimates.

Notes: Totals may not sum due to independent rounding. Emission totals include aviation emissions.

Figure 7-4: GHG Projections from the Energy Sector under each Scenario (Including Aviation)



Note: Emission estimates include aviation emissions.

7.4. Industrial Processes and Product Use (IPPU)

Under the baseline scenario, emissions from the IPPU sector are projected to peak in 2025 at 0.77 MMT CO_2 Eq., and then drop steadily from there to 0.62 MMT CO_2 Eq. in 2030 and 0.25 MMT CO_2 Eq. in 2045.[55] These emissions account for four percent of total projected statewide emissions under the baseline scenario in 2025, four percent in 2030, and two percent in 2045. Projected emissions by source for 2020 through 2045 are summarized in Table 7-6.

Table 7-6: GHG Emission Projections from the IPPU Sector under the Baseline Scenario by Source (MMT CO_2 Eq.)

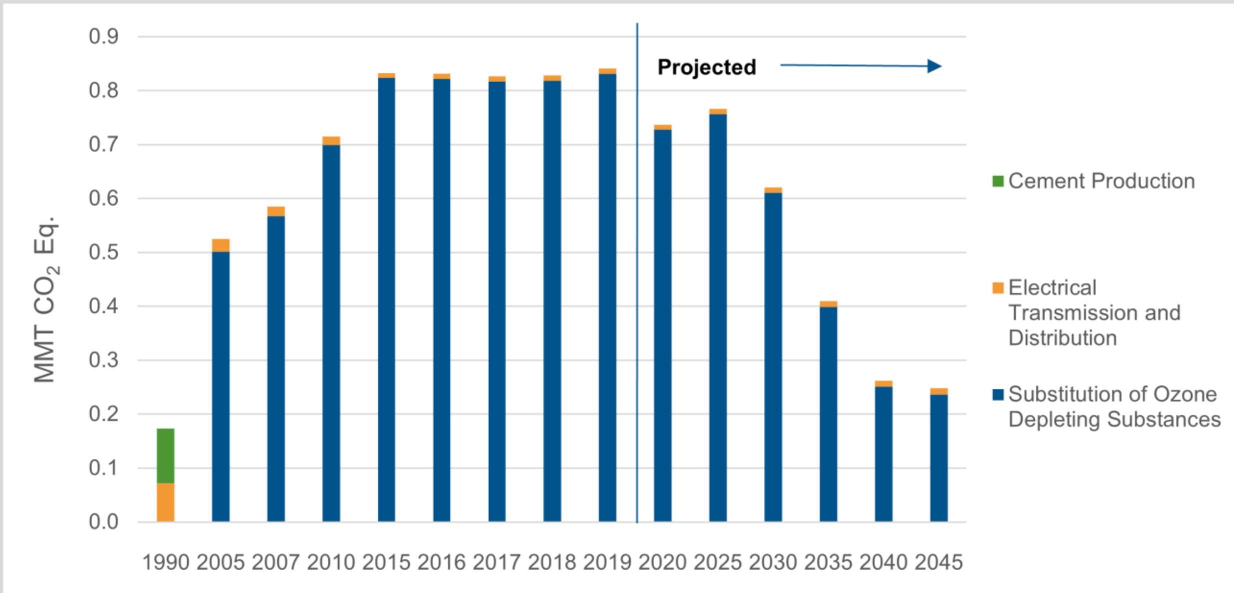
Source	2020	2025	2030	2035	2040	2045
Cement Production	NO	NO	NO	NO	NO	NO
Electrical Transmission and Distribution	0.01	0.01	0.01	0.01	0.01	0.01
Substitution of Ozone Depleting Substances	0.73	0.76	0.61	0.40	0.25	0.24
Total	**0.74**	**0.77**	**0.62**	**0.41**	**0.26**	**0.25**

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 2045. Relative to 2019, electrical transmission and distribution emissions by 2045 are projected to increase slightly though this increase represents emissions lower than 0.005 MMT CO_2 Eq. (or rounding error). Emissions from the substitution of ozone depleting substances are projected to decline due to the American Innovation and Manufacturing (AIM) Act, which was included in the 2021 Consolidated Appropriations Act (EPA 2022f). Emissions from cement production, which were zero in 2019, are projected to remain at zero through 2045. Figure 7-5 shows historical and projected emissions from the IPPU sector by source category for select years under the baseline scenario.

[55] Emissions from the IPPU sector are not expected to vary under the six alternative energy scenarios discussed in section7, thus only projections from the baseline scenario are discussed below.

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



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

Total emissions (excluding sinks) from the AFOLU sector are projected to be 1.22 MMT CO_2 Eq. in 2025, 1.14 MMT CO_2 Eq. in 2030, and 0.98 MMT CO_2 Eq. in 2045,[56] accounting for seven percent, seven percent, and seven percent of total Hawaiʻi emissions, respectively, under the baseline scenario. Carbon sinks are projected to be 2.50 MMT CO_2 Eq. in 2025, 2.46 MMT CO_2 Eq. in 2030, and 2.62 MMT CO_2 Eq. in 2045. Overall, the AFOLU sector is projected to result in a net increase in carbon sinks (i.e., net CO_2 removals) of 1.29 MMT CO_2 Eq. in 2025, 1.32 MMT CO_2 Eq. in 2030, and 1.64 MMT CO_2 Eq. in 2045. Projected emissions by source and sink category for 2020, 2025, 2030, 2035, 2040, and 2045 are summarized in Table 7-7.

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

Category	2020	2025	2030	2035	2040	2045
Agriculture	**0.44**	**0.43**	**0.42**	**0.42**	**0.41**	**0.41**
Enteric Fermentation	0.25	0.24	0.23	0.22	0.21	0.20
Manure Management	0.02	0.01	0.01	0.01	0.01	0.01
Agricultural Soil Management	0.18	0.18	0.19	0.19	0.19	0.20
Field Burning of Agricultural Residues	NO	NO	NO	NO	NO	NO
Urea Application	+	+	+	+	+	+

[56] Emissions from the AFOLU sector are not expected to vary under the six alternative energy scenarios discussed in section7, thus only projections from the baseline scenario are discussed below.

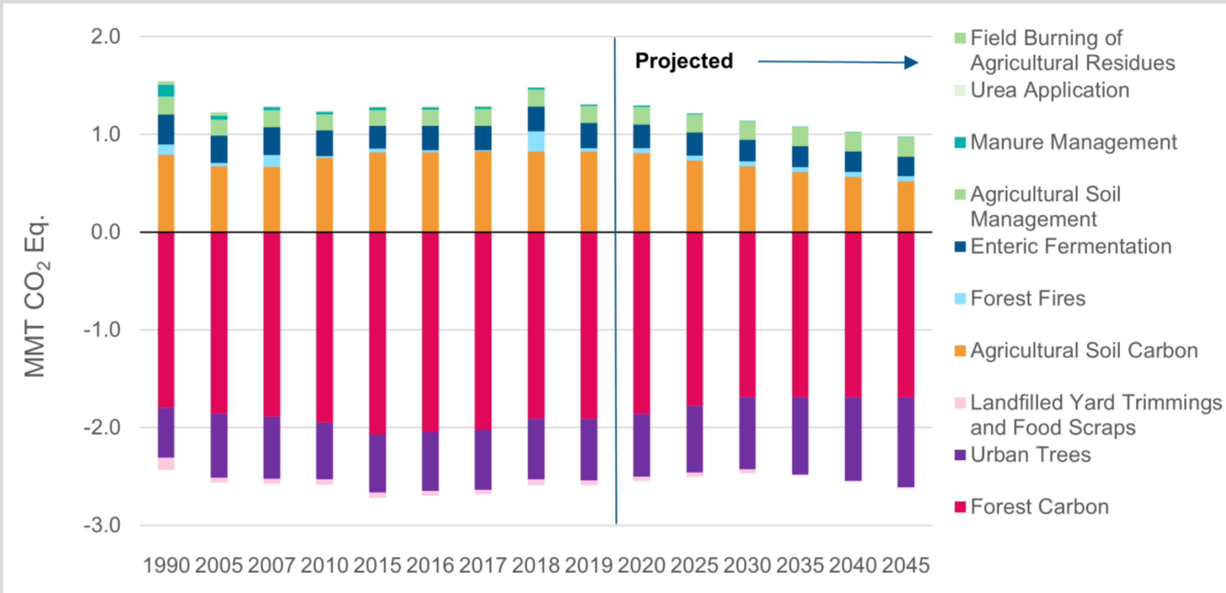
Category	2020	2025	2030	2035	2040	2045
Land Use, Land-Use Change, and Forestry	**(1.69)**	**(1.72)**	**(1.74)**	**(1.82)**	**(1.94)**	**(2.05)**
Agricultural Soil Carbon	0.81	0.74	0.67	0.62	0.57	0.52
Forest Fires	0.05	0.05	0.05	0.05	0.05	0.05
Landfilled Yard Trimmings and Food Scraps	(0.04)	(0.04)	(0.04)	(0.01)	(0.01)	(0.01)
Urban Trees	(0.64)	(0.69)	(0.74)	(0.80)	(0.86)	(0.92)
Forest Carbon	(1.86)	(1.77)	(1.68)	(1.69)	(1.69)	(1.69)
Total (Sources)	**1.30**	**1.22**	**1.14**	**1.08**	**1.03**	**0.98**
Total (Sinks)	**(2.54)**	**(2.50)**	**(2.46)**	**(2.49)**	**(2.55)**	**(2.62)**
Net Emissions	**(1.25)**	**(1.29)**	**(1.32)**	**(1.41)**	**(1.52)**	**(1.64)**

+ 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. Forest carbon is projected to sequester less carbon (i.e., become a smaller sink) from 2020-2030 and then increase slightly 2030-2045 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 from 2020-2030 and then increase 2030-2045, driven primarily by an increase in tons of landfilled food scraps. Emissions from enteric fermentation and manure management are projected to decrease and emissions from agricultural soil management are projected to increase based on the assumption that historical trends will continue. Emissions from field burning of agricultural residues are projected to be zero due to the closing of the last sugar mill in Hawaiʻi in 2018 while emissions from forest fires and urea application are projected to remain flat.

Overall, in 2020, 2025, and 2030, both the carbon sequestered from AFOLU sink categories and emissions from AFOLU sources are projected to decrease. For the years 2035, 2040, and 2045, emissions from AFOLU sources are projected to decline, but carbon sequestered from AFOLU sink categories is projected to increase. The growth in carbon sequestered from AFOLU sinks is driven by increased sequestration by Urban Trees; notably these projections are based on the assumption that urban area and carbon sequestration will increase linearly over the projected time series. Please see the Urban Trees methodology in section 5.9 for more detail. 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 under the Baseline Scenario



7.6. Waste

Emissions from the Waste sector are projected to be 0.43 MMT CO_2 Eq. in 2025, 0.43 MMT CO_2 Eq. in 2030, and 0.49 MMT CO_2 Eq. in 2045,[57] accounting for two percent, two percent, and four percent of total projected statewide emissions under the baseline scenario, respectively. Projected emissions by source for 2020, 2025, 2030, 2035, 2040, and 2045 are summarized in Table 7-8.

Table 7-8: GHG Emission Projections from the Waste Sector under the Baseline Scenario by Source (MMT CO_2 Eq.)

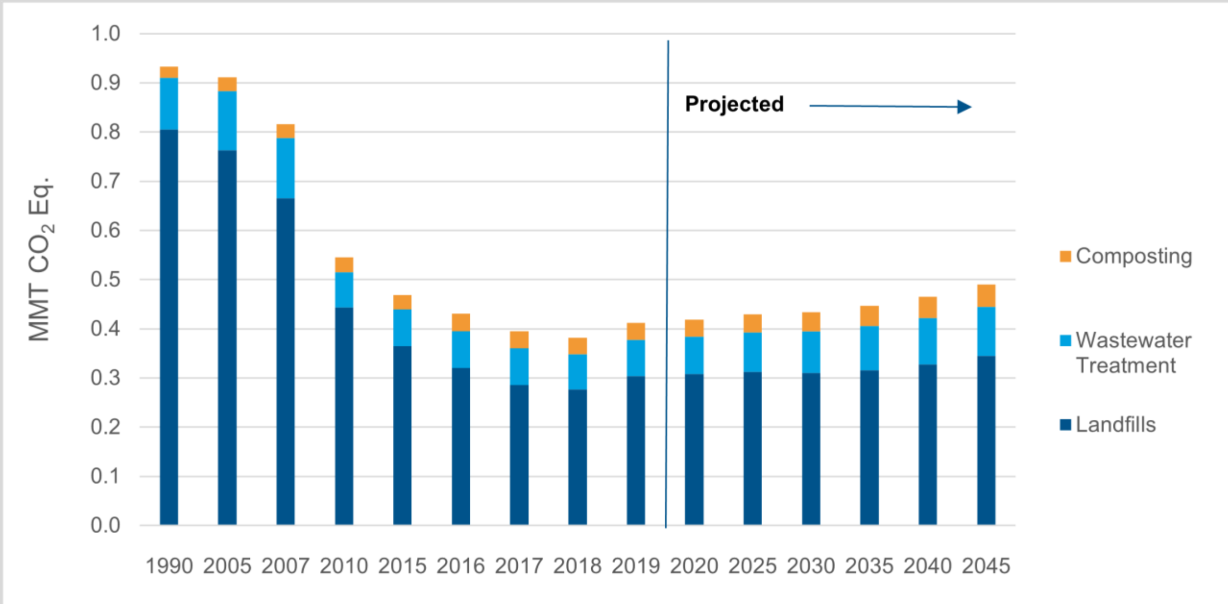
Source	2020	2025	2030	2035	2040	2045
Landfills	0.31	0.31	0.31	0.32	0.33	0.35
Composting	0.03	0.04	0.04	0.04	0.04	0.05
Wastewater Treatment	0.08	0.08	0.09	0.09	0.09	0.10
Total	**0.42**	**0.43**	**0.43**	**0.45**	**0.47**	**0.49**

Note: Totals may not sum due to independent rounding.

Relative to 2019, emissions from landfills, composting, and wastewater treatment are expected to increase slightly. Figure 7-7 shows historical and projected emissions from the waste sector by source category for select years.

[57] Emissions from the Waste sector are not expected to vary under the six alternative energy scenarios discussed in section7, thus only projections from the baseline scenario are discussed below.

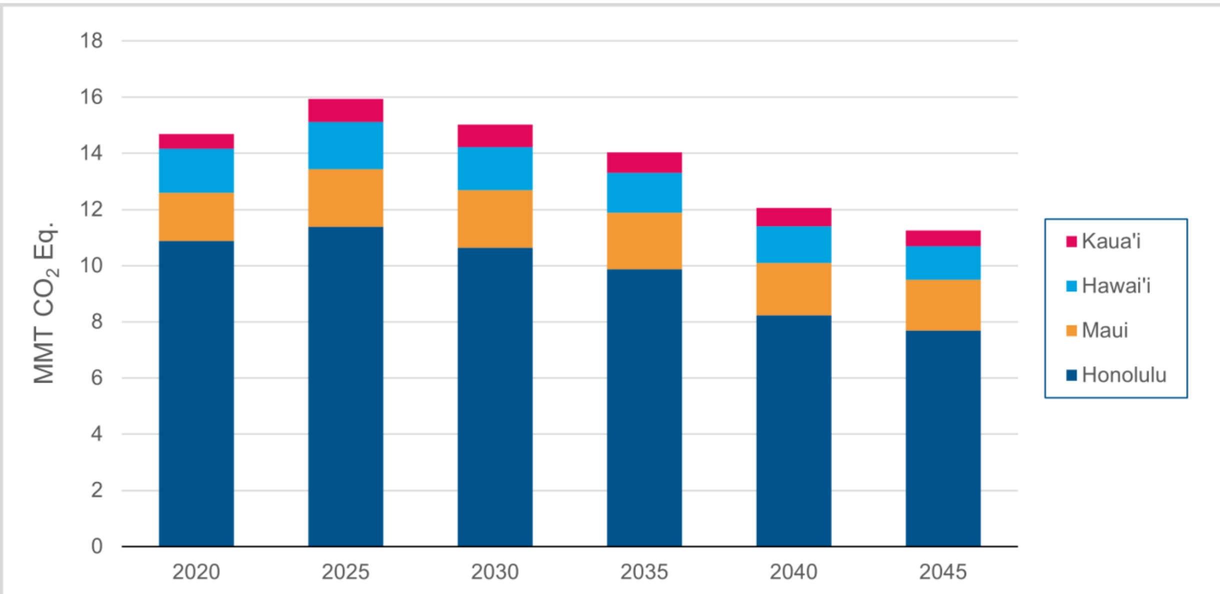
Figure 7-7: GHG Emissions and Projections from the Waste Sector under the Baseline Scenario



7.7. Emission Projections by County

This section summarizes emission projections by county under the baseline scenario. Consistent with the historical trend, Honolulu County is projected to account for the largest share of net GHG emissions in 2020, 2025, 2030, 2035, 2040, and 2045 followed by Maui County, Hawaiʻi County, and Kauaʻi County. Figure 7-8 shows net emission projections by county and year.

Figure 7-8: Projected Net GHG Emissions under the Baseline Scenario by County (2020, 2025, 2030, 2035, 2040, and 2045) (Including Sinks and Aviation)



Emissions from the Energy sector are projected to account for the largest portion of emissions from each county in 2020, 2025, 2030, 2035, 2040, and 2045. 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, 2030, 2035, 2040, and 2045 emission projections by sector for each county. Emission projections by sector and year for each county are summarized in Table 7-9.

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 Hawaiʻi'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 2019 county-level estimates.

Figure 7-9: Honolulu County GHG Emission Projections under the Baseline Scenario by Sector (2020, 2025, 2030, 2035, 2040, and 2045) (Including Sinks and Aviation)

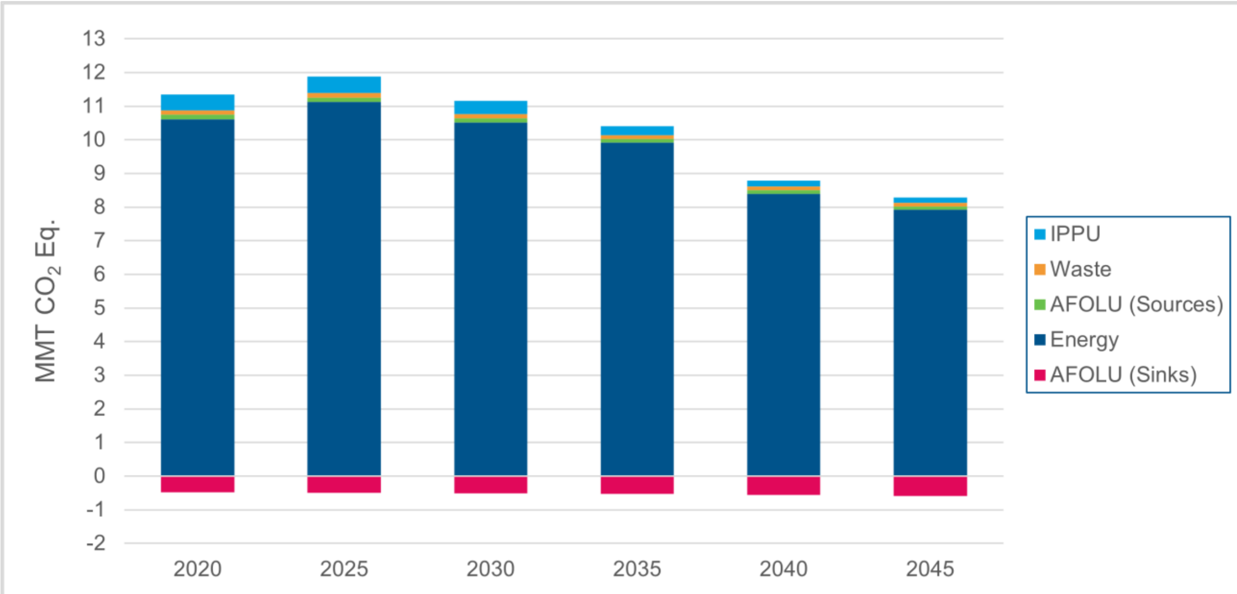


Figure 7-10: Hawaiʻi County GHG Emission Projections under the Baseline Scenario by Sector (2020, 2025, 2030, 2035, 2040, and 2045) Including Sinks and Aviation)

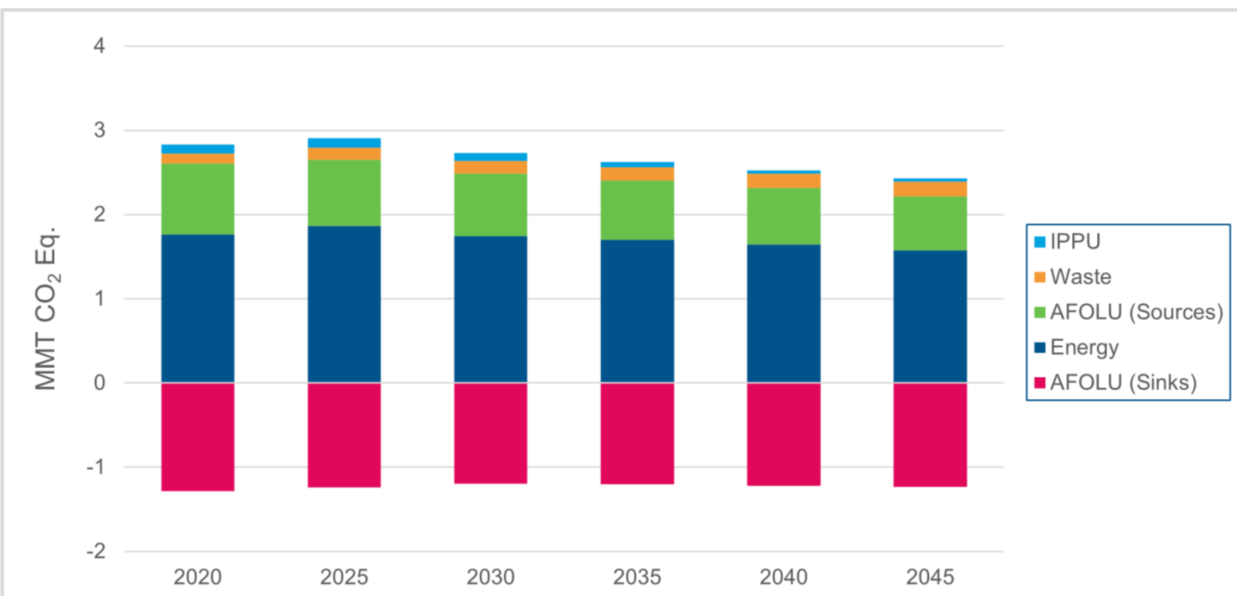


Figure 7-11: Maui County GHG Emission Projections under the Baseline Scenario by Sector (2020, 2025, 2030, 2035, 2040, and 2045) (Including Sinks and Aviation)

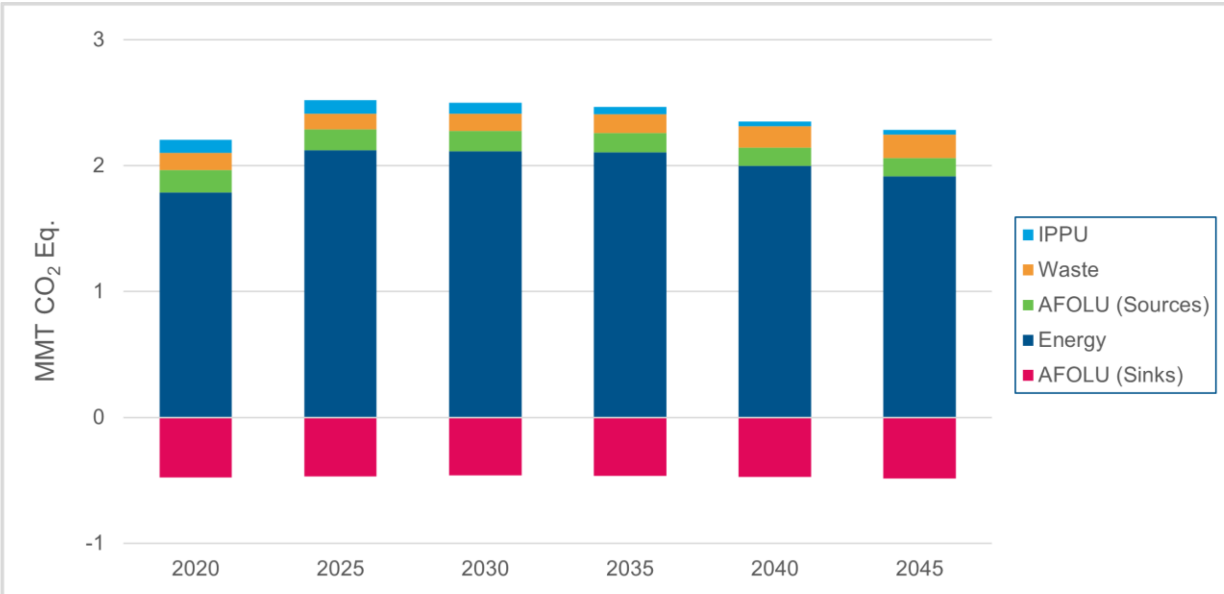


Figure 7-12: Kauaʻi County GHG Emission Projections under the Baseline Scenario by Sector (2020, 2025, 2030, 2035, 2040, and 2045) (Including Sinks and Aviation)

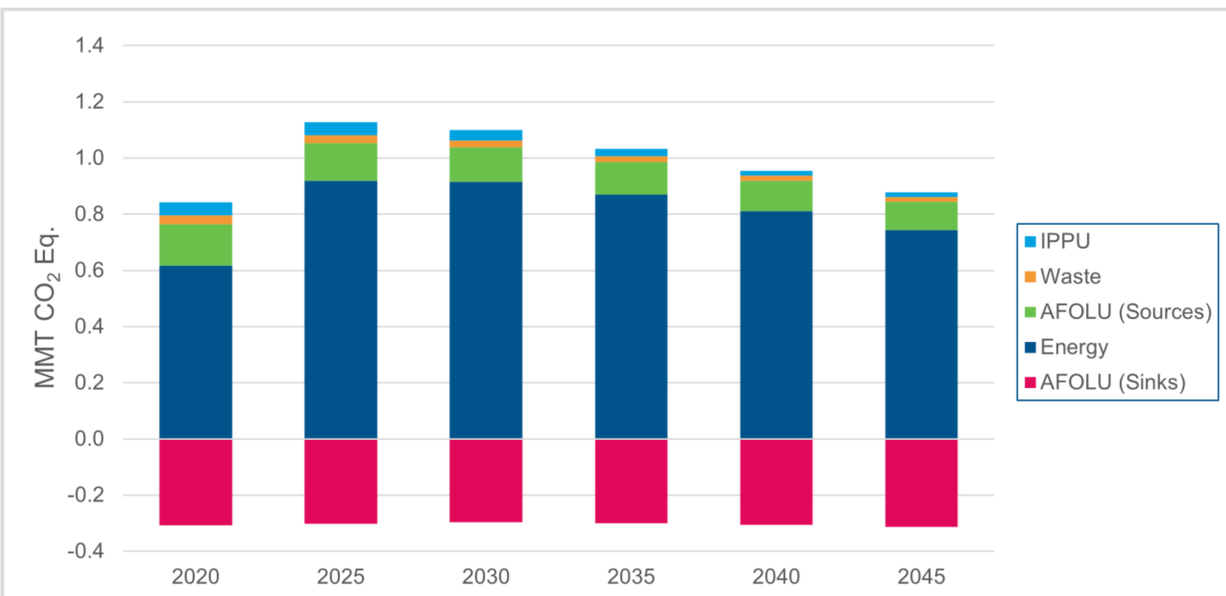


Table 7-9: Total and Net GHG Emission Projections under the Baseline Scenario by Sector and County for 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO_2 Eq.)

Sector	2020	2025	2030	2035	2040	2045
Honolulu County						
Energy	10.61	11.13	10.52	9.91	8.40	7.92
IPPU	0.48	0.50	0.40	0.26	0.16	0.15
AFOLU (Sources)	0.13	0.12	0.11	0.11	0.10	0.10
AFOLU (Sinks)	(0.48)	(0.49)	(0.51)	(0.52)	(0.55)	(0.59)
Waste	0.13	0.14	0.13	0.12	0.11	0.11
Total Emissions	**11.35**	**11.88**	**11.16**	**10.40**	**8.78**	**8.28**
Net Emissions	**10.88**	**11.39**	**10.65**	**9.88**	**8.23**	**7.70**
Hawaiʻi County						
Energy	1.76	1.86	1.75	1.70	1.65	1.58
IPPU	0.11	0.11	0.09	0.06	0.04	0.04
AFOLU (Sources)	0.84	0.79	0.74	0.70	0.67	0.64
AFOLU (Sinks)	(1.28)	(1.24)	(1.19)	(1.20)	(1.22)	(1.24)
Waste	0.12	0.14	0.15	0.16	0.17	0.18
Total Emissions	**2.83**	**2.90**	**2.73**	**2.62**	**2.52**	**2.43**
Net Emissions	**1.55**	**1.67**	**1.54**	**1.42**	**1.31**	**1.19**
Maui County						
Energy	1.79	2.12	2.12	2.10	2.00	1.92
IPPU	0.11	0.11	0.09	0.06	0.04	0.04
AFOLU (Sources)	0.18	0.17	0.16	0.15	0.15	0.14
AFOLU (Sinks)	(0.48)	(0.47)	(0.46)	(0.46)	(0.47)	(0.49)
Waste	0.13	0.12	0.13	0.15	0.17	0.19
Total Emissions	**2.21**	**2.52**	**2.50**	**2.47**	**2.35**	**2.28**
Net Emissions	**1.73**	**2.05**	**2.04**	**2.00**	**1.88**	**1.80**
Kauaʻi County						
Energy	0.62	0.92	0.91	0.87	0.81	0.74
IPPU	0.05	0.05	0.04	0.03	0.02	0.02
AFOLU (Sources)	0.15	0.13	0.12	0.12	0.11	0.10
AFOLU (Sinks)	(0.31)	(0.30)	(0.30)	(0.30)	(0.31)	(0.31)
Waste	0.03	0.03	0.02	0.02	0.02	0.02
Total Emissions	**0.84**	**1.13**	**1.10**	**1.03**	**0.95**	**0.88**
Net Emissions	**0.53**	**0.83**	**0.80**	**0.73**	**0.65**	**0.56**

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

8. GHG Reduction Goal Progress

The Hawaiʻi State Legislature has set three separate GHG targets for the state:

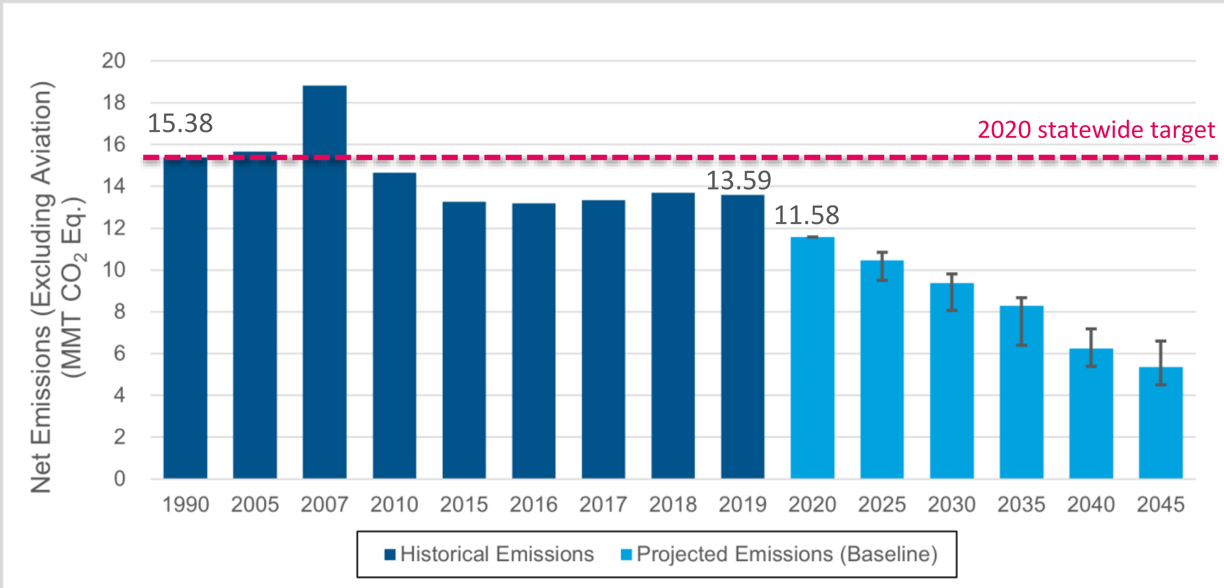
- **2020 target.** Act 234, Session Laws of Hawaiʻi 2007 (Act 234 of 2007) established a statewide GHG emissions limit at or below the statewide GHG emissions levels in 1990 to be achieved by January 1, 2020. While domestic aviation emissions are included in the inventory totals for the state of Hawaiʻi, **Act 234 of 2007 specifies that emissions from airplanes (i.e., domestic aviation and military aviation) shall not be included in this target.**[58]
- **2030 target.** Act 238, Session Laws of Hawaiʻi 2022 (Act 238 of 2022) established a goal for statewide GHG emissions to be at least 50 percent below 2005 levels by the year 2030, and that the **measurement of GHG emissions for the year 2005 include emissions from airplanes**.
- **2045 target.** Act 15, Session Law of Hawaiʻi 2018 (Act 15 of 2018), established a statewide carbon net-negative goal. Specifically, Act 15 of 2018 calls for **more atmospheric carbon and GHGs to be sequestered than emitted within the State as quickly as practicable, but no later than 2045.**

Figure 8-1 shows net emissions (excluding aviation) in Hawaiʻi for inventory years through 2019 as well as emission projections for 2020, 2025, 2030, 2035, 2040, and 2045. Figure 8-1 also shows the 2020 statewide target, which is equal to 1990 emission levels, pursuant to Act 234 of 2007. 1990 statewide emissions (excluding aviation) are estimated to be 15.38 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.[59]

Net emissions (excluding aviation) for 2020 are projected to be 11.58 MMT CO_2 Eq. in 2020. As such, **this report finds that, given existing policies, Hawaiʻi is currently expected to meet the 2020 statewide emissions target** set by Act 234 of 2007 (Figure 8-1).

[58] Emissions from international aviation, which are reported under the International Bunker Fuels source category, are also not included in Hawaiʻi's GHG target in accordance with IPCC (2006) guidelines for inventory development.
[59] When preparing GHG inventories, it is best practice to review GHG estimates for prior inventory years and revise them, as necessary, to take into account updated activity data and improved methodologies or emission factors that reflect advances in the field of GHG accounting.

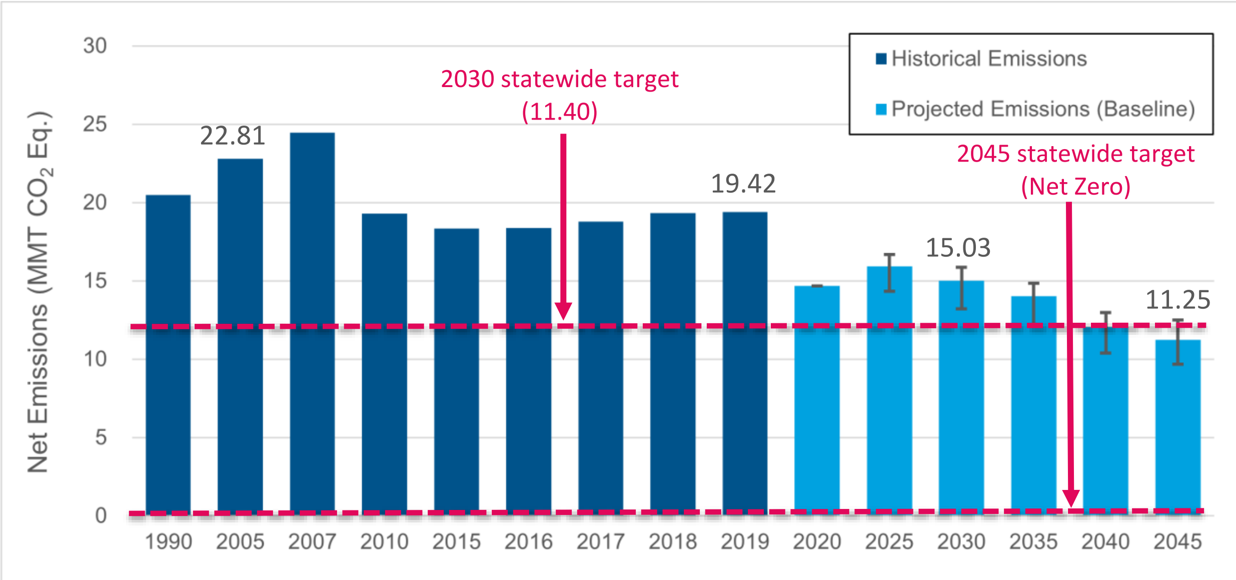
Figure 8-1: Hawai'i Net GHG Emissions Inventory Estimates and Projections (Including Sinks, Excluding Aviation)



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. Emission estimates include sinks but exclude aviation.

Figure 8-2 shows net emissions (including sinks and aviation) in Hawai'i for inventory years through 2019 as well as emission projections for 2020, 2025, 2030, 2035, 2040, and 2045. Figure 8-2 also shows the 2030 statewide target of 11.40 MMT CO_2 Eq., which is equal to 50 percent below 2005 emission levels, pursuant to Act 238 of 2022, and the 2045 carbon net-negative target pursuant to Act 15 of 2018. The target established by Act 238 of 2022 could change with future updates to the 2005 emission estimates, but it is not likely to change significantly. Net emissions (including sinks) for year 2030 are projected to be between 13.23 – 15.87 MMT CO_2 Eq. in 2030, and 9.69 – 12.49 MMT CO_2 Eq. in 2045. As such, **this report finds that Hawai'i is currently not on track to meet the 2030 or 2045 statewide emissions targets,** set by Act 238 of 2022 and Act 15 of 2018 respectively. Table 8-1 summarizes emissions in years 1990 and 2005, and projections between 2020 and 2045.

Figure 8-2: Hawaiʻi Net GHG Emissions By Year (Including Sinks and Aviation)



Note: Emission totals include sinks and aviation emissions.

Table 8-1: Hawaiʻi GHG Emissions for 1990 and 2005 and Projections by Sector under the Baseline Scenario for 2020, 2025, 2030, 2035, 2040, and 2045 (MMT CO2 Eq.)

Sector	1990	2005	2020	2025	2030	2035	2040	2045
Energy[a]	20.26	22.71	14.78	16.03	15.30	14.59	12.85	12.16
IPPU	0.17	0.53	0.74	0.77	0.62	0.41	0.26	0.25
AFOLU (Sources)	1.55	1.22	1.30	1.22	1.14	1.08	1.03	0.98
AFOLU (Sinks)	(2.43)	(2.56)	(2.54)	(2.50)	(2.46)	(2.49)	(2.55)	(2.62)
Waste	0.93	0.91	0.42	0.43	0.43	0.45	0.47	0.49
Total Emissions (Excluding Sinks)	**22.91**	**25.37**	**17.24**	**18.44**	**17.49**	**16.52**	**14.61**	**13.88**
Net Emissions (Including Sinks)	**20.48**	**22.81**	**14.69**	**15.94**	**15.03**	**14.03**	**12.06**	**11.25**
Aviation[b]	5.10	7.14	3.11	5.47	5.65	5.75	5.82	5.89
Net Emissions (Including Sinks, Excluding Aviation)[b]	**15.38**	**15.66**	**11.58**	**10.46**	**9.38**	**8.28**	**6.24**	**5.36**

[a] Emissions from International Bunker Fuels are not included in the totals, as per IPCC (2006) guidelines.
[b] Domestic aviation and military emissions, which are reported under the Energy sector, are excluded from Hawaiʻi's GHG emission reduction goal established in Act 234 of 2007.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

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Appendix A. IPCC Source and Sink Categories

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

Category Code and Name		Included in Inventory	Notes
Energy			
1A1	Fuel Combustion Activities	✓	Includes emissions from fuel combustion for electricity generation and petroleum refining.
1A2	Manufacturing Industries and Construction	✓	
1A3	Transport	✓	
1A4	Other Sectors	✓	
1A5	Non-Specified	✓	
1B1	Fugitive Emissions from Solid Fuels		NO: Solid fuels (e.g., coal) are not produced or processed in Hawaiʻi.
1B2	Oil and Natural Gas	✓	
1C	Carbon Dioxide Transport and Storage		NO: CO_2 is not transported or stored in Hawaiʻi.
IPPU			
2A1	Cement Production	✓	
2A2	Lime Production		NO: Activity is not applicable to Hawaiʻi.
2A3	Glass Production		NO: Activity is not applicable to Hawaiʻi.
2A4	Other Process Uses of Carbonates		NO: Activity is not applicable to Hawaiʻi.
2B	Chemical Industry		NO: Activity is not applicable to Hawaiʻi.
2C	Metal Industry		NO: Activity is not applicable to Hawaiʻi.
2D	Non-Energy Products from Fuels and Solvent Use	✓	IE: Included under the Energy sector.
2E	Electronics Industry		NO: Activity is not applicable to Hawaiʻi.
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 Hawaiʻi.

Category Code and Name		Included in Inventory	Notes
2G3	N_2O from Product Uses		NO: Activity is not applicable to Hawaiʻi.
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 Hawaiʻi.
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 Hawaiʻi.
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 Hawaiʻi.
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 Hawaiʻi.
4B	Biological Treatment of Solid Waste	✓	

Category Code and Name		Included in Inventory	Notes
4C	Incineration and Open Burning of Waste		In Hawaiʻi, incineration of MSW occurs at waste-to-energy facilities and thus emissions are accounted for under the Energy sector.
4D	Wastewater Treatment and Discharge	✓	

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

Appendix B. Updates to the Historical Emission Estimates Presented in the 2017 Inventory Report

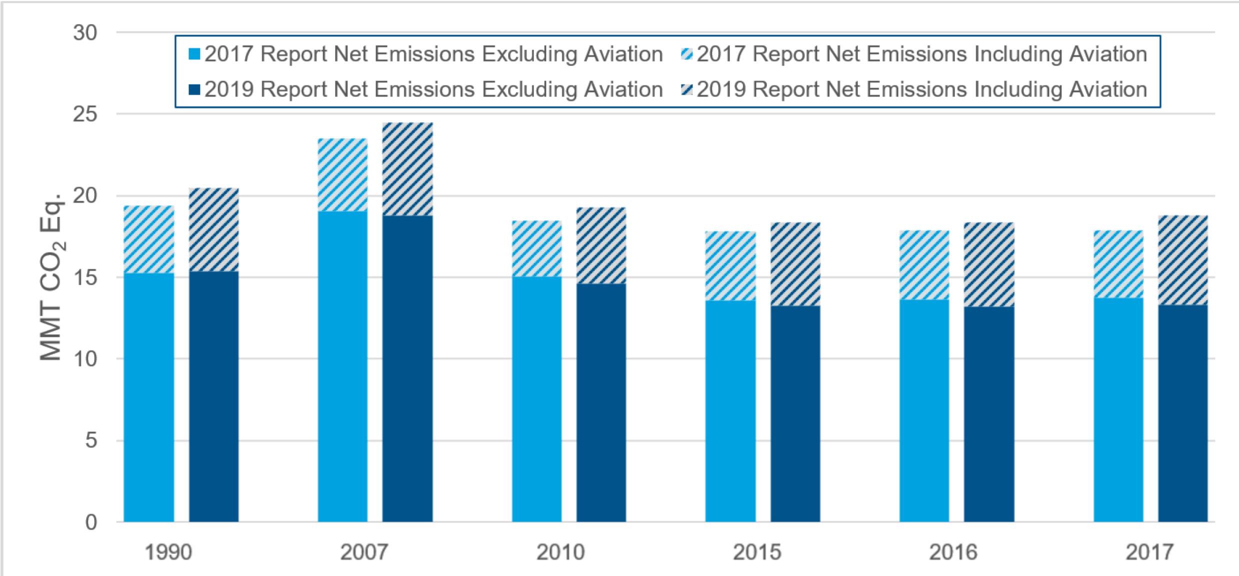
It is good practice to review historical emission estimates, and update any estimates, if warranted. The changes in emission estimates are largely due to methodological or data updates. In this report, the following updates were made in order of largest to smallest impact: (1) In the Energy Sector, the Domestic and Military Aviation and Aviation International Bunker Fuels category was updated to reflect revised fuel consumption estimates, (2) In the Waste sector, updates to incorporate CH_4 emissions from industrial landfills and application of a back-casting method based on GHGRP-reported data for landfills, (3) In the Waste sector, updates to incorporate new sources of Hawaiʻi-specific data (e.g., tons of waste composted), (4) In the AFOLU sector, the Nitrogen excretion (Nex) rates and weighted Methane Conversion Factors (MCFs) were updated to incorporate Hawaiʻi specific data for agricultural soil carbon, (5) In the AFOLU sector, updates to incorporate top-down estimates for cattle population data for Enteric Fermentation and Manure Management, (6) In AFOLU, updates to historical urea fertilizer consumption for Urea Application. Updates to the U.S. Inventory also resulted in some minor updates compared to the 2017 report for the sectors that utilize data from the U.S. Inventory, such as Agricultural Soil Carbon, Substitution of Ozone Depleting Substances (ODS), and Electric Transmission and Distribution.

Domestic and Military Aviation

The Energy Information Administration (EIA) State Energy Data System (SEDS) follows a new methodology to estimate state-level jet fuel consumption for 2010 onwards (EIA 2022a). This change impacts fuel consumption for domestic and military aviation, as well as aviation international bunker fuels. To maintain time series consistency, jet fuel consumption was back-casted for the years 1990 – 2009 using the overlap splicing technique as prescribed by IPCC 2006. This update is further detailed in the methodology discussion of section 3.2.

Relative to the 2017 inventory report (Hawaiʻi DOH 2021), total emissions presented in this inventory report increased by roughly 4.9 percent for 1990, 3.5 percent for 2007, 3.7 percent for 2010, 2.6 percent for 2015, 2.5 percent for 2016, and 4.5 percent for 2017. Net emissions including aviation increased by 5.6 percent for 1990, 4.0 percent for 2007, 4.4 percent for 2010, 3.1 percent for 2015, 2.9 percent for 2016, and 5.2 percent for 2017. Figure B-1 depicts the changes in net emissions including aviation between the 2017 and 2019 inventories. Net emissions excluding aviation, which is used to establish Hawaiʻi's statewide emissions target under Act 234 of 2007, increased by 0.7 percent for 1990, and decreased by 1.3 percent for 2007, 2.8 percent for 2010, 2.5 percent for 2015, and increased by 3.2 percent for 2016, and 3.2 percent for 2017.

Figure B-1: Net Emissions Comparison Between 2017 Report and 2019 Report



Updates that impacted emission estimates are discussed by source in this report. A summary of the change in emission estimates relative to the 2017 inventory report is provided below in Table B-1.

Table B-1: Change in Emissions Relative to the 2017 Inventory Report (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										
2017 Report	19.30	15.19	4.11	0.17	1.60	(2.44)	0.75	21.83	19.39	15.28
2019 Report	20.26	15.16	5.10	0.17	1.55	(2.43)	0.93	22.91	20.48	15.38
Difference	0.96	(0.03)	0.99	(+)	(0.05)	0.01	0.18	1.08	1.09	0.10
Percent Change	5.0%	-0.2%	24.1%	-0.1%	-3.4%	-0.3%	23.8%	4.9%	5.6%	0.7%
2007										
2017 Report	23.12	18.66	4.46	0.59	1.35	(2.58)	1.05	26.11	23.53	19.07
2019 Report	24.35	18.70	5.65	0.58	1.29	(2.57)	0.82	27.04	24.47	18.81
Difference	1.23	0.03	1.19	(+)	(0.06)	0.01	(0.23)	0.93	0.94	(0.26)
Percent Change	5.3%	0.2%	26.8%	-0.4%	-4.7%	-0.5%	-22.3%	3.5%	4.0%	-1.3%
2010										
2017 Report	18.15	14.75	3.40	0.71	1.28	(2.62)	0.95	21.10	18.48	15.08
2019 Report	19.38	14.74	4.64	0.71	1.24	(2.58)	0.55	21.88	19.29	14.65
Difference	1.23	(0.01)	1.24	(+)	(0.05)	0.03	(0.41)	0.78	0.82	(0.42)
Percent Change	6.8%	-0.1%	36.4%	0.4%	-3.5%	-1.2%	-42.6%	3.7%	4.4%	-2.8%
2015										
2017 Report	17.58	13.37	4.20	0.83	1.30	(2.73)	0.84	20.55	17.81	13.61
2019 Report	18.50	13.40	5.10	0.83	1.28	(2.72)	0.47	21.08	18.37	13.27
Difference	0.92	0.03	0.89	+	(0.02)	0.01	(0.37)	0.54	0.55	(0.34)
Percent Change	5.3%	0.2%	21.3%	0.3%	-1.4%	-0.5%	-44.2%	2.6%	3.1%	-2.5%

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)
2016										
2017 Report	17.66	13.44	4.22	0.83	1.29	(2.71)	0.78	20.56	17.86	13.64
2019 Report	18.52	13.34	5.18	0.83	1.29	(2.69)	0.43	21.07	18.37	13.19
Difference	0.86	(0.10)	0.96	(0.01)	(+)	0.01	(0.35)	0.50	0.52	(0.44)
Percent Change	4.9%	-0.7%	22.7%	-0.8%	-0.1%	-0.5%	-44.8%	2.4%	2.9%	-3.2%
2017										
2017 Report	17.64	13.54	4.10	0.83	1.26	(2.69)	0.82	20.56	17.87	13.77
2019 Report	18.97	13.51	5.47	0.82	1.28	(2.68)	0.40	21.47	18.79	13.33
Difference	1.33	(0.03)	1.36	(0.01)	0.02	0.01	(0.43)	0.92	0.92	(0.44)
Percent Change	7.6%	-0.2%	33.2%	-1.7%	1.8%	-0.3%	-51.9%	4.5%	5.2%	-3.2%

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

[a] positive percent change in this column 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 appendix summarizes proposed areas for improvement to the Hawaiʻi statewide greenhouse gas inventory for the next iteration of inventory development.

Energy

Area for Improvement #1

If data become available, naphtha and fuel gas consumption data for 2005 should be incorporated into stationary combustion emissions calculations.

Area for Improvement #2

All 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 Hawaiʻi statewide inventory. Currently SEDS does not report jet fuel kerosene consumption for stationary combustion separately, as this category is very small. Future research could be done to determine whether any jet fuel is consumed for this purpose and removed from transportation estimates. Alternative options for estimating military aviation fuel consumption across the relevant fuel types should be reviewed, as EIA no longer reports this data separately. Alternative options for estimating the fraction of transportation emissions that are from non-highway vehicles should be reviewed.

Area for Improvement #3

Review data sources and methodological options to further disaggregate data reported for the transportation source categories beyond the current end use sectors of ground, domestic marine, domestic aviation, military aviation, and military (non-aviation) transportation.

Area for Improvement #4

Follow up outreach to reporters can confirm whether data not reported to GHGRP needs to be corrected. Par West Refinery did not report any petroleum refinery emissions or hydrogen production to GHGRP in 2019.

Area for Improvement #5

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

Area for Improvement #6

The current inventory assumes that biogas generated at wastewater treatment plants (WWTP) in Hawaiʻi is not captured and converted to renewable natural gas (RNG). As of 2018, the Honouliuli Wastewater Treatment Plant produces renewable natural gas (RNG) that Hawaiʻi Gas captures and uses it for injection into their synthetic natural gas (SNG) distribution system (Hawaiʻi Free Press 2018). Therefore, RNG consumption in Hawaiʻi is expected to be included in the synthetic natural gas (SNG) consumption totals reported by EIA's Natural Gas Annual beginning in 2019. Future inventory reports should account for renewable natural gas that is combusted in Hawaiʻi.

IPPU

Area for Improvement #7

Data are available for SF_6 purchases and emissions for HECO from GHGRP, subpart DD for 2011 through 2020 (EPA 2021b). These data are not inclusive of HECO's subsidiaries, HELCO and MECO, or emissions from Kauaʻi Island Utility Cooperative (KIUC).[60] If data on SF_6 purchases for Hawaiian utilities and all subsidiaries were made available, the methodology could be revised to incorporate these data into future inventory analyses.

Area for Improvement #8

EIA's RECS provides data on the number of air conditioning units in the United States by both region and climate zone. Hawaiʻi falls within the Pacific region and the Hot and Humid climate zone. Data on household air conditioning saturation is available for 1993, 1997, 2001, 2005, 2009, 2015, and 2020; however, data disaggregated by climate zone is only available beginning with the 2009 reporting year.

If other metrics are identified that could be used to disaggregate national emissions, particularly for the air conditioning sub-category, which is also impacted by the local climate, the methodology could be revised to incorporate these metrics into future inventory analyses. For example, if available, information on the percentage of households with central or room air conditioning could be incorporated.

AFOLU

Area for Improvement #9

If updated data becomes available, updated and/or Hawaiʻi-specific emission factors for waste management systems (WMS) should be incorporated into future analyses. Additional research was

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[60] State of Hawaiʻi Public Utilities Commission: Regulated Electric Utilities. Available online at: https://puc.hawaii.gov/energy/

conducted to identify updated and/or Hawaiʻi-specific WMS emission factors, but no new information was identified that could be used to inform emission estimates from manure management.

Area for Improvement #10

Further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses. If crop residue factors are updated and/or better data become available, future analyses should update the factors accordingly. Additional research was also conducted on fertilizer consumption in Hawaiʻi and crop residue factors, but no new information was identified that could be used to inform emission estimates from agricultural soil management. Further research into the accuracy of calendar year fertilizer consumption patterns and updated crop residue factors may be considered in future analyses.

Area for Improvement #11

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

Area for Improvement #12

Further research into the accuracy of calendar year fertilizer consumption patterns may be considered in future analyses, as well as investigating new sources for urea consumption data. Additional research was conducted on urea consumption in Hawaiʻi, but no new information was identified that could be used to verify the accuracy of calendar year fertilizer consumption patterns.

Updated historical data was identified for urea application in 2015 and 2016 from the American Association of Plant Food Control Officials Commercial Fertilizers Reports; however, no new data was available for 2017, 2018, or 2019. Additional research was conducted to identify other sources of more recent urea consumption data, but no new information was identified that could be used to inform emission estimates from urea application.

Area for Improvement #13

Dr. Crow is actively conducting research to develop a soil carbon map for Hawaiʻi and new models are being explored to model GHG flux and soil carbon in Hawaiʻi. Outreach regarding this research will be conducted and further research into emission reductions from improved agricultural soil management practices may be considered in future analyses.

Area for Improvement #14

Further investigation into alternative sources for historical wildfire acres burned and prescribed fire acres burned may be considered in future analyses. To improve emission estimates from forest fires for Hawaiʻi, Michael Walker (DLNR) was contacted to ask about the availability of historical data on acres burned from wildland and prescribed fires. 1990 wildfire data exists, but are not currently accessible. DLNR does not maintain a record of prescribed burns in Hawaiʻi.

Incorporating 1990 wildfire data from DLNR into the 1990 inventory for Hawaiʻi once it becomes available is a potential future improvement identified.

Area for Improvement #15

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. 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 Hawaiʻi. 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 Hawaiʻi; therefore, emissions from prescribed fires are likely very small. However, the NEI indicates that emissions from prescribed fires in Hawaiʻi 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 Hawaiʻi.

Due to the inconsistency in methodology used to identify emissions for the NEI, a lack of data available for all inventory years, and expert guidance from Christian Giardina, this inventory continues to assume that emissions from prescribed fires in Hawaiʻi are negligible. Incorporating emissions from prescribed wildfires into the statewide inventory for Hawaiʻi if data becomes available was also identified as a potential improvement.

Area for Improvement #16

Further research into Hawaiʻi trends in diverting yard trimmings and food scraps from landfills, as well as yard trimmings and food scraps sequestration rates that incorporate Hawaiʻi's climate may be considered in future analyses. Additional research was conducted to identify Hawaiʻi-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.

Future improvement could include further research into Hawaiʻi trends in diverting yard trimmings and food scraps from landfills, as well as yard trimmings and food scraps sequestration rates that incorporate Hawaiʻi's climate may be considered in future analyses.

Area for Improvement #17

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 Hawaiʻi forests, improved forest management practices, and their emissions reduction potential may also be considered in future analyses.

The 2016 inventory report used carbon sequestration rates and land cover data by forest type for Hawaiʻi 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 in 2019 to confirm that the 2017 study contained the latest available information on Hawaiʻi land-cover and sequestration rates. Paul indicated at that time 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. Based on that new information provided by Paul Selmants (USGS), new yearly carbon sequestration rates for forest and shrubland were calculated and incorporated into the 2017 – 2019 inventory reports. Further improvements can include incorporating additional data on forest land cover if they become available as additional models are run.

Area for Improvement #18

Identify data and estimate emissions for source and sink categories that are currently not estimated due to a lack of data. The affected source categories include Land Converted to Forest Land, Wetlands, Land Converted to Settlements, Other Land, Biomass Burning in Grassland, Liming, and Harvested Wood Products. Research was conducted to identify additional data from sources and sinks that are not currently included in the Hawaiʻi 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.

Further improvements could include identifying data and estimating emissions for source and sink categories that are currently not estimated due to a lack of data.

Waste

Area for Improvement #19

Further assessment can be done to ensure the accuracy of the back-casting method used to estimate emissions from landfills for years prior to 2010, when GHGRP reporting requirements began. The current back-casting method assumes that CH_4 generation increases exponentially over time. Confirming waste in place data by Hawaiʻi DOH or landfills themselves to either replace or confirm LMOP data would lead to more accurate scaling factors to account for landfills under the GHGRP reporting threshold.

Area for Improvement #20

Future improvement could be made by incorporating flow rate and BOD_5 data for non-NPDES WWTPs for 2018 and 2019 and historical years in which no or little data were not available. Should state-specific data on total number of households on septic systems and/or share of households in Hawaiʻi on septic systems become available, it can be incorporated. Additionally, more recent data on the percentage of biosolids from WWTPs used as fertilizer can be used to improve estimates.

Appendix D. County Emissions Methodology

This appendix summarizes the methodology used to quantify Hawai'i'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, 2017, and 2019 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 2022b). GHGRP facility level emissions data were unavailable for the years 1990, 2005, and 2007. Emissions for the energy industries and industrial sectors for 1990, 2005, 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 2022b).

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 (2022a).

Transportation

Ground transportation emissions for 2005, 2007, 2010, 2015, 2016, 2017, and 2019 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 2022a). For 1990 ground transportation emissions, 1990 motor vehicle registration data were unavailable. Therefore, 2007 motor vehicle registration data were used to allocate 1990 ground transportation emission to each county.

Emissions from domestic marine, military aviation, and military non-aviation transportation were allocated solely to Honolulu based on available DBEDT data (DBEDT 2008a) which indicate that over 99 percent 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 2022).

Incineration of Waste

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

Oil and Natural Gas Systems

Hawaiʻi's two oil and natural gas facilities, Par West and Par East, 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, 2017, and 2019 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 2022b).

GHGRP facility level emissions data were unavailable for the years 1990, 2005, and 2007. Emissions for non-energy uses for 1990, 2005, 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 2022b).

IPPU

Cement Production

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

Electrical Transmission and Distribution

Emissions were calculated by apportioning U.S. emissions from this source to each island based on the ratio of the island's electricity sales to U.S. electricity sales. Estimates of national SF_6 emissions data were taken from the U.S. Inventory (EPA 2022a). National electricity sales data come from the EIA (2021). Hawaiʻi electricity sales data by island come from the State of Hawaiʻi Data Book (DBEDT 2022a). 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 2022a) to each county based on the ratio of the county's vehicle registrations from the State of Hawaiʻi Data Book (DBEDT 2022a) to U.S. vehicle registrations from the U.S. Department of Transportation, Federal Highway Administration (FHWA 2020). 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 2022a) 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, 2015, and 2020 RECS to each county based on population (EIA 2013; EIA 2018; EIA 2022d). For the remaining sub-categories, national emissions from the U.S. Inventory (EPA 2022a) were apportioned to each county based on the ratio of the county's population from DBEDT (2022a) to U.S. population from the U.S. Census Bureau (2021).

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 used to apportion state-level cattle population data from Steller (2020) to each county, 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 2017 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 used to apportion state-level cattle population data from Steller (2020) to each county, 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 2017 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 the 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. Sugarcane area and production was zeroed out in 2018 and onward due to the closure of the last sugarcane mill in Hawaiʻi. 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 2019 (or the most recent year available) was used. Emissions from county-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 Agricultural Land Use Maps (Hawaiʻi State Office of Planning 2015) for the year 1992 and the University of Hawaiʻi (2016 & 2022) for 2015 and 2020. Agricultural land use by county for the years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and years 2016, 2017, and 2019 were interpolated between 2015 and 2020. 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 used to apportion state-level cattle population data from Steller (2020) to each county, 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 2017 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 the years 1990 to 2007 were obtained directly from USDA NASS and for year 2017 from the USDA Census of Agriculture. 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. Sugarcane area and production was zeroed out in 2018 and onward due to the closure of the last sugarcane mill in Hawaiʻi. 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 Agricultural Land Use Maps (Hawaiʻi State Office of Planning 2015) for 1992 and the University of Hawaiʻi (2016 & 2022) for 2015 and 2020. Agricultural land use by county for the years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and years 2016, 2017, and 2019 were interpolated between 2015 and 2020. 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 Agricultural Land Use Maps (Hawaiʻi State Office of Planning 2015) for the year 1992 and the University of Hawaiʻi for year 2015 (2016) and year 2020 (2022). Agricultural land use by county for the years 1990 and 1991 were proxied to 1992, years 1993 through 2014 were interpolated, and years 2016 through 2019 were interpolated.

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 2022a, 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 2022a).

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 areas 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 Hawaiʻi-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 (2022a). County-level emissions estimates were then calculated as the sum of each island in the county. CO_2 sinks were calculated using Hawaiʻi-specific forest and shrubland sequestration rates (Selmants et al. 2017), as described in section 5.10.

Waste

Landfills

Landfill emissions were calculated for each county using the methodology described in section 6.1.

Composting

Composting emissions were calculated based on per capita rates of composting per year by county, which were provided by Hawaiʻi's Department of Health (Hawaiʻi DOH 2022a).

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 E. Hawai‘i Administrative Rule (HAR) Facility Data

Hawai‘i Administrative Rule (HAR) affected facilities refers to large existing stationary sources with potential GHG emissions at or above 100,000 tons per year.[61] These facilities are subject to an annual facility-wide GHG emissions cap of 16 percent below the facility's total 2010 baseline (or alternate approved baseline) GHG emission levels to be achieved by January 1, 2020. Based on data obtained from EPA's GHGRP (EPA 2022b), Table E-1 summarizes annual GHG emissions from HAR affected facilities for 2010 to 2019. Table E-2 summarizes projected GHG emissions for the HAR affected facilities for 2020, 2025, 2030, 2035, 2040, and 2045. The table also includes information on the facility-specific 2020 emissions cap and the calculated difference between the cap and reported emissions for 2020. These tables include stationary combustion emissions from electric power plants, petroleum refineries, and industrial facilities as well as fugitive emissions from petroleum refineries. Biogenic CO_2 emissions from HAR affected facilities are not presented, as these emissions are excluded from the annual facility-wide GHG emission cap.

HAR Facility Projections

Methodology: For the Hawaiian Electric power plants, data were taken directly from the 2019 inventory for HAR facilities and the PSIP E3 with Grid Modernization Plan (PUC 2016; DCCA 2017). Emissions for 2020 were taken directly from EPA Flight data for HAR facilities (EPA 2022h). Units that were identified to shutter within the PSIP were assumed to shutter (or switch to biofuels) on-schedule according to the PSIP. Emissions were then allocated to continuing units based on their 2020 relative contribution to emissions for HAR facilities and the total level of emissions from HAR facilities (consistent with the emissions described in Appendix J, Stationary Combustion, scaled for HAR facilities).

Uncertainties: Hawaiian Electric 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.[62] This combined emissions cap would allow each HAR facility to exceed the individual cap of 16 percent below 2010 baseline (or alternate approved baseline) GHG emission levels 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 E-2 could change. Moreover, there is uncertainty in whether the scheduled shuttering (or switching to biofuels) of units as stated in the PSIP will continue to be implemented as planned or amended

[61] Hawai‘i Administrative Rules, Chapter 11-60.1, available online at http://health.Hawaii.gov/cab/files/2014/07/HAR_11-60_1-typed.pdf, excludes municipal waste combustion operations and conditionally exempts municipal solid waste landfills.
[62] Administrative Record, Page 5, available online at https://health.hawaii.gov/cab/files/2020/07/0067-01-C-Admin-Record.pdf

Table E-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	2018	2019
AES Hawaiʻi, Inc.	Energy Industries (1A1ai)	1.53	1.68	1.82	1.69	1.77	1.64	1.93	1.47	1.29	1.31
Hāmākua Energy Partners	Energy Industries (1A1ai)	0.17	0.13	0.14	0.10	0.11	0.13	0.09	0.09	0.16	0.22
Hawaiian Commercial & Sugar Company[a]	Industrial (1A2)	0.14	0.13	0.12	0.15	0.14	0.12	0.04	+	+	NO
HELCO Kanoelehua Hill Generation Station	Energy Industries (1A1ai)	0.20	0.19	0.17	0.17	0.17	0.18	0.23	0.18	0.16	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	0.24	0.22
HELCO Shipman Generating Station[b]	Energy Industries (1A1ai)	NE	NE	NE	NO	NO	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	0.04	0.07
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.97	0.88	0.86	0.86	0.88	1.01	0.80	0.81	0.85	0.86
HECO Kahe Generating Station	Energy Industries (1A1ai)	2.52	2.63	2.41	2.22	2.13	2.02	2.03	2.01	2.00	1.87
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	NO	+	+	+	+	+	+	+	0.02	0.14
HECO Honolulu Generating Station[c]	Energy Industries (1A1ai)	0.12	0.10	0.05	0.06	+	NO	NO	NO	NO	NO
Hu Honua Bioenergy Pepeekeo Power Plant[d]	Energy Industries (1A1ai)	NO	NO	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	0.88	0.90
Kauaʻi 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	0.12	0.11
Kauaʻi 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	0.08	0.05
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.21	0.19	0.18	0.13	0.14	0.11	0.14	0.18	0.17	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	0.47	0.49
MECO Palaau Generating Station	Energy Industries (1A1ai)	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Par West Refinery[e]	Energy Industries (1A1ai)	0.34	0.35	0.34	0.30	0.32	0.33	0.31	0.31	0.34	0.21
	Oil and Natural Gas (1B2)	0.19	0.21	0.23	0.16	0.21	0.19	0.19	0.17	0.18	+
Par East Refinery[e]	Energy Industries (1A1ai)	0.44	0.45	0.41	0.26	0.43	0.44	0.43	0.47	0.48	0.48
	Oil and Natural Gas (1B2)	0.12	0.13	0.12	0.07	0.13	0.11	0.09	0.13	0.12	0.11

HAR Affected Facility	Inventory Sector (IPCC) Source Category	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Energy Industries Subtotal[f]		**8.58**	**8.72**	**8.35**	**7.81**	**7.87**	**7.81**	**7.74**	**7.32**	**7.31**	**7.29**
Industrial Subtotal[f]		**0.14**	**0.13**	**0.12**	**0.15**	**0.14**	**0.12**	**0.04**	**+**	**+**	**NO**
Oil and Natural Gas Subtotal		**0.32**	**0.34**	**0.34**	**0.24**	**0.34**	**0.30**	**0.29**	**0.30**	**0.30**	**0.11**
Total		**9.04**	**9.19**	**8.82**	**8.19**	**8.36**	**8.23**	**8.06**	**7.62**	**7.61**	**7.40**

[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.

[e] Par West Refinery was previously known as Island Energy Services Refinery and prior to that, as the Chevron Products Company Hawaiʻi Refinery; the Par East Refinery was previously known as the Refinery Kapolei which previously was known as the Hawaiʻi Independent Energy Petroleum Refinery. In 2018, the Island Energy Services refinery ceased refinery operations and converted to an import terminal (Mai 2018).

[f] Sector subtotals presented in this table, which are based on facility-level data, differ from the estimates by end-use sector presented in this report, which are adjusted to ensure consistency with how SEDS allocates 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 E-2: Projected HAR Affected Facility GHG Emissions (excluding biogenic CO_2 emissions) (MMT CO_2 Eq.)

HAR Affected Facility	Inventory Sector (IPCC Source Category)	2020[g]	2025	2030	2035	2040	2045	2020 Cap	Difference
AES Hawaiʻi, Inc.	Energy Industries (1A1ai)	1.19	NO	NO	NO	NO	NO	1.28	0.09
Hamakua Energy Partners	Energy Industries (1A1ai)	0.12	0.09	0.06	0.05	0.04	0.03	0.14	0.02
Hawaiian Commercial & Sugar Co.[a]	Industrial (1A2)	NO	NO	NO	NO	NO	NO	NA	NA
HELCO Kanoelehua Hill Generating Station	Energy Industries (1A1ai)	0.18	0.13	0.09	0.08	0.07	0.04	0.16	(0.02)
HELCO Keahole Generating Station	Energy Industries (1A1ai)	0.27	0.20	0.14	0.13	0.10	0.07	0.22	(0.05)
HELCO Shipman Generating Station[b]	Energy Industries (1A1ai)	NO	NO	NO	NO	NO	NO	NA	NA
HELCO Puna Generating Station	Energy Industries (1A1ai)	0.06	NO	NO	NO	NO	NO	0.03	(0.03)
HECO Waiau Generating Station	Energy Industries (1A1ai)	0.63	0.53	0.45	0.40	0.19	0.16	0.80	0.17
HECO Kahe Generating Station	Energy Industries (1A1ai)	1.89	1.59	1.34	1.20	0.56	0.47	2.00	0.11
HECO Campbell Industrial Park Generating Station	Energy Industries (1A1ai)	0.12	0.10	0.08	0.07	0.03	0.03	0.11	(0.01)
HECO Honolulu Generating Station[c]	Energy Industries (1A1ai)	NO	NO	NO	NO	NO	NO	NA	NA

HAR Affected Facility	Inventory Sector (IPCC Source Category)	2020[g]	2025	2030	2035	2040	2045	2020 Cap	Difference
Hu Honua Bioenergy, LLC Pepeekeo Power Plant[d]	Energy Industries (1A1ai)	NO	NO	NO	NO	NO	NO	NA	NA
Kalaeloa Cogeneration Plant	Energy Industries (1A1ai)	0.79	0.73	0.62	0.54	0.25	0.21	1.06	0.27
KIUC Kapaia Power Station	Energy Industries (1A1ai)	0.09	0.09	0.08	0.06	0.03	NO	0.14	0.05
KIUC Port Allen Generating Station	Energy Industries (1A1ai)	0.03	0.03	0.03	0.02	0.01	NO	0.09	0.06
MECO Kahului Generating Station	Energy Industries (1A1ai)	0.15	0.08	NO	NO	NO	NO	0.14	(0.01)
MECO Maalaea Generating Station	Energy Industries (1A1ai)	0.38	0.21	0.26	0.27	0.19	0.13	0.42	0.04
MECO Palaau Generating Station	Energy Industries (1A1ai)	0.02	NO	NO	NO	NO	NO	0.02	(0.00)
Par West Refinery[e]	Energy Industries (1A1b)	0.13	NO	NO	NO	NO	NO	0.29	0.16
	Oil and Natural Gas (1B2)	NO	NO	NO	NO	NO	NO	NA	NA
Par East Refinery[e]	Energy Industries (1A1b)	0.31	0.44	0.46	0.47	0.48	0.48	0.62	0.31
	Oil and Natural Gas (1B2)	0.05	0.11	0.11	0.11	0.11	0.12	NA	NA
Energy Industries Subtotal[f]		**6.36**	**4.50**	**3.86**	**3.46**	**2.04**	**1.68**	**7.52**	**1.16**
Industrial Subtotal[f]		**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**0.00**	**0.00**
Oil and Natural Gas Subtotal		**0.05**	**0.11**	**0.11**	**0.11**	**0.11**	**0.12**	**0.00**	**0.00**
Total		**6.41**	**4.61**	**3.97**	**3.57**	**2.16**	**1.80**	**7.52**	**1.16**

[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.

[e] The Par West Refinery was previously known as the Island Energy Services Refinery and prior to that, as the Chevron Products Company Hawaiʻi Refinery; the Par East Refinery was previously known as the Refinery Kapolei which was previously known as Hawaiʻi Independent Energy Petroleum Refinery. In 2018, the Island Energy Services refinery ceased refinery operations and converted to an import terminal (Mai 2018).

[f] 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 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.

[g] 2020 values are reported GHGRP data that is not included in the 2019 inventory.

+ 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 F. Activity Data

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

Energy

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

Sector/Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Residential									
Diesel Fuel	2	1	19	1	2	0	1	0	0
Propane	217	584	480	918	505	690	580	455	495
Natural Gas	605	535	528	529	562	560	558	568	548
Wood and Waste	0	32	172	367	14	10	32	32	32
Commercial									
Diesel Fuel	2,636	2,237	1,629	1,528	1,298	904	1,181	1,361	1,823
Motor Gasoline[a]	310	62	60	58	1,452	1,473	1,495	1,521	1,527
Propane	359	965	857	2,041	2,319	2,327	3,025	2,843	3,085
Residual Fuel	5,189	18	3	0	0	0	0	0	0
Natural Gas	2,379	455	1,904	1,848	1,874	2,339	2,385	2,502	2,483
Ethanol	0	1	2	3	111	112	115	117	119
Wood and Waste	0	3,553	2,350	2,945	3,185	3,734	3,553	3,553	3,553
Other Fuels[b]	1	0	0	0	0	0	0	0	0
Industrial[c]									
Coal	695	1,411	1,795	1,415	1,136	271	0	0	0
Diesel Fuel	4,222	2,977	2,606	1,882	1,851	939	1,789	1,515	2,191
Motor Gasoline[a]	701	676	1,216	684	1,335	1,320	1,329	1,373	1,374
Propane	53	48	198	191	33	39	217	408	105

Sector/Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Residual Fuel	10,942	4,912	2,690	2,834	1,876	2,565	3,233	2,797	2,487
Natural Gas	0	1,319	521	353	434	81	83	87	89
Ethanol	0	14	37	40	102	100	103	105	107
Wood and Waste	18,159	68	5,447	4,392	3,169	3,360	24	68	68
Other Fuels[b]	2,653	1,425	169	5,350	4,410	2,923	2,692	2,222	1,912
Energy Industries									
Coal	26	15,095	15,313	15,702	14,495	16,160	14,948	14,367	14,179
Diesel Fuel	9,747	15,035	13,377	12,971	12,297	11,726	12,053	12,407	13,344
Residual Fuel	77,780	71,070	71,832	65,157	54,987	53,197	52,777	52,790	52,678
Fuel Gas[d]	0	1,763	1,763	2,503	3,794	3,992	3,992	5,601	4,392
Biodiesel[e]	0	0	0	130	867	643	907	703	469
Wood and Waste	7,765	1,762	0	40	853	1,076	1,762	1,762	1,762
Other Fuels[b]	(2905)	100	573	241	(148)	67	605	231	1,060
Naphtha[f]	0	4,065	4,065	4,419	6,240	5,413	5,578	6,515	7,558

[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 F-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 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). Naphtha data were obtained from DBEDT (2008a) for 1990 and 2007 in Bbtu.

Note: Totals may not sum due to independent rounding.

Sources: EIA (2022a); EPA (2022a); EPA (2022b); DBEDT (2008a).

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

Mode/Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Aviation[a]									
Aviation Gasoline	1,375	224	206	188	47	35	50	109	158
Jet Fuel Kerosene[b]	70,406	103,698	80,796	67,057	78,891	80,535	85,820	87,071	88,738
Ground[a]									
Diesel Fuel[c]	9,674	13,757	16,096	10,412	10,511	8,785	8,384	9,204	7,970
Motor Gasoline[d]	39,916	55,034	55,301	47,059	49,072	49,902	49,515	48,297	48,173
Propane	49	57	48	21	11	10	0	0	0
Natural Gas	0	3	3	2	2	2	2	2	0
Ethanol	0	1,176	1,699	2,742	3,765	3,787	3,821	3,718	3,805
Biodiesel[e]	0	59	204	38	0	584	576	699	558
Marine[a]									
Diesel Fuel[c]	5,771	8,241	9,601	6,061	627	973	787	921	7,970
Motor Gasoline[d]	18	35	35	43	54	23	25	238	577
Residual Fuel[f]	15,897	7,049	28,069	6,756	4,394	5,091	7,215	6,443	8,299
Ethanol	0	0	0	3	4	1	1	1	1
Military Aviation									
Aviation Gasoline	0	0	0	+	+	+	+	+	+
Jet Fuel Kerosene[b]	1,969	14,102	10,987	9,119	11,043	10,952	11,671	11,841	12,068
Naphtha[g]	17,786	0	0	0	0	0	0	0	0
Military Non-Aviation									
Diesel Fuel[c]	4,929	205	10,428	6,738	669	2,202	2,632	4,199	2,181
Motor Gasoline	4,597	0	0	0	0	0	0	0	0
Residual Fuel[f]	806	0	0	0	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 F-3, Table F-5, and Table F-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 (2019).
[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 (2022a) 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 (2022a).
[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 2019).
[g] Military aviation naphtha consumption was obtained from direct communication with EIA (2019).
Note: Totals may not sum due to independent rounding.
Sources: EIA (2022a); EIA (2019); EIA (2021); DBEDT (2022a).

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

Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Industrial									
Coal	0.0%	1.0%	1.0%	1.1%	1.5%	1.6%	1.8%	1.6%	1.8%
Asphalt and Road Oil	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Propane	71.8%	80.1%	78.8%	86.5%	84.0%	82.4%	82.4%	89.3%	88.1%
Lubricants	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Diesel Fuel	0.6%	1.0%	1.5%	0.5%	0.6%	0.6%	0%	0.6%	0.6%
Transportation									
Lubricants	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: EPA (2022c).

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

Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Industrial									
Coal	3	14	19	15	17	4	0	0	0
Diesel Fuel	27	30	38	10	10	6	0	8	12
Propane	38	38	156	165	28	32	179	364	93
Other Fuels[a]	2,652	1,423	169	5,350	4,410	2,923	2,692	2,222	1,912
Aviation									
Other Fuels[a]	214	184	185	17	49	59	49	89	142
Ground Transportation									
Other Fuels[a]	187	161	162	368	375	336	318	261	212
Marine Transportation									
Other Fuels[a]	61	53	53	79	30	25	25	29	22

[a] Other fuels include asphalt and road oil, lubricants, and waxes.
Sources: EIA (2022a), EPA (2022c).

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

Aviation Miles	1990	2005	2007	2010	2015	2016	2017	2018	2019
International Gallons	7,475,210	9,914,439	9,960,882	9,557,257	16,322,531	17,115,139	18,070,399	18,427,350	18,472,057
Domestic Gallons	18,165,782	41,486,886	45,911,647	40,933,992	48,092,538	51,015,410	50,703,798	55,833,433	59,741,165
International Share	29.2%	19.3%	17.9%	18.9%	25.4%	25.4%	26.3%	24.8%	23.6%
Domestic Share	70.8%	80.7%	82.1%	81.1%	74.6%	74.6%	73.7%	75.2%	76.4%

Note: Consumption data are from flights originating in Hawaiʻi. Flights with a destination within Hawaiʻi or to the mainland U.S. are considered domestic while flights with an international destination are considered international.
Source: DOT (2020).

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

Mode/Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Aviation[a]									
Jet Fuel Kerosene	20,526	20,002	14,427	12,707	20,070	20,456	22,560	21,606	20,958
Marine[b]									
Diesel Fuel	944	1,263	251	2,398	1,084	461	1,191	2,095	1,095
Residual Fuel	465	9,190	425	2,826	247	323	405	590	435

[a] Calculated based on domestic and international flight mileage data from DOT (2020).

[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 Hawaiʻi consumption to total U.S. consumption in 2006 (the earliest year data is available for Hawaiʻi 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 (2022a), DOT (2020), DOC (2008), DOC (2018), DOC (2020) EPA (2022a).

IPPU

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

	1990	2005	2007	2010	2015	2016	2017	2018	2019
Clinker Production	195,044	0	0	0	0	0	0	0	0

Source: Wurlitzer (2008).

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

	1990	2005	2007	2010	2015	2016	2017	2018	2019
Hawaiʻi	8.3	10.5	10.6	10.0	9.4	9.3	9.1	9.1	9.2
U.S.	2,712.6	3,661.0	3,764.6	3,754.8	3,759.0	3,762.5	3,723.4	3,859.2	3,811.2

Sources: EIA (2022b) (U.S.); DBEDT (2022a) (Hawaiʻi).

Table F-9: Registered Vehicles by Year (thousands)

	1990	2005	2007	2010	2015	2016	2017	2018	2019
Hawaiʻi	870.7	1,091.3	1,103.8	1,086.2	1,193.9	1,194.7	1,213.1	1,219.6	1,232.9
U.S.	188,170.9	240,386.9	246,430.2	241,214.5	254,120.4	259,143.5	262,782.5	263,943.8	266,899.8

Sources: FHWA (2020) (U.S.); DBEDT (2022a) (Hawaiʻi).

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

Source	1990	2005	2007	2010	2015	2016	2017	2018	2019
Cars and Trucks A/C ODS Substitutes	0.00	69.27	71.18	68.06	46.34	43.30	40.14	38.46	36.74
Other A/C ODS Substitutes	0.01	10.20	15.00	25.16	39.21	41.60	43.39	45.45	48.35
Other ODS Substitutes	0.22	28.08	35.68	54.41	78.37	80.33	81.50	82.49	85.81
Electrical Transmission and Distribution	23.15	8.35	6.25	5.66	3.76	4.05	4.15	3.90	4.24

Source: EPA (2022a).

AFOLU

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

Animal Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Cattle	**198,815**	**157,781**	**159,339**	**149,123**	**128,863**	**136,226**	**138,150**	**139,528**	**139,667**
Dairy Cattle	**22,837**	**10,652**	**6,758**	**3,723**	**4,331**	**4,318**	**4,631**	**4,097**	**3,273**
Dairy Cows	11,000	5,700	3,800	1,800	2,200	2,200	2,400	2,000	1,500
Dairy Replacement Heifers	5,940	2,022	1,004	999	1,003	994	1,002	1,072	1,001
7-11 months	1,747	611	300	297	300	294	298	319	298
12-23 months	4,193	1,411	704	702	703	700	703	752	703
Dairy Calves	5,897	2,930	1,954	924	1,128	1,124	1,229	1,025	773

Animal Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Beef Cattle	**175,978**	**147,129**	**152,581**	**145,400**	**124,532**	**131,908**	**133,519**	**135,431**	**136,394**
Beef Cows	75,000	81,300	85,200	81,200	68,800	72,800	73,600	75,000	75,500
Beef Replacement Heifers	12,829	12,064	11,890	9,454	8,861	9,238	10,373	9,312	10,365
7-11 months	3,843	3,627	3,468	2,730	2,674	2,748	3,028	2,784	3,022
12-23 months	8,987	8,436	8,421	6,724	6,188	6,490	7,345	6,528	7,343
Other Beef Heifers	17,618	2,805	2,745	3,520	2,853	3,032	2,441	2,590	2,479
Heifer Stockers	12,955	2,588	2,505	3,104	2,590	2,747	2,110	2,173	2,098
Heifer Feedlot	4,663	217	240	416	263	284	331	416	381
Steers	26,455	3,866	4,305	4,730	4,839	5,317	5,488	5,868	5,585
Steer Stockers	17,299	3,480	3,865	3,976	4,313	4,739	4,827	5,080	4,879
Steer Feedlot	9,156	387	440	754	526	578	661	788	706
Beef Calves	39,076	42,094	43,441	41,495	35,178	37,521	37,616	38,662	38,465
Bulls	5,000	5,000	5,000	5,000	4,000	4,000	4,000	4,000	4,000
Sheep and Lambs	**22,526**	**21,389**	**22,376**	**22,103**	**25,077**	**26,129**	**27,181**	**26,709**	**27,276**
Goats	**3,348**	**7,647**	**9,169**	**11,465**	**14,933**	**15,579**	**16,225**	**17,030**	**17,727**
Swine	**36,000**	**19,000**	**15,000**	**12,500**	**9,000**	**10,000**	**8,000**	**9,000**	**11,000**
Horses and ponies	**3,770**	**5,761**	**6,547**	**5,687**	**4,774**	**4,661**	**4,548**	**4,204**	**4,017**
Chickens	**1,487,918**	**629,438**	**424,628**	**368,876**	**256,244**	**242,578**	**228,912**	**215,785**	**204,898**
Chickens (excluding broilers)	1,183,000	547,000	422,500	366,000	247,242	231,700	216,159	203,324	191,252
Broilers	304,918	82,438	2,128	2,876	9,002	10,877	12,753	12,460	13,646

Sources: (EPA 2022a) (cattle); (USDA 2022) (swine); USDA (1989, 1994, 2009, 2014, and 2019) [sheep, goats, horses, broilers, and chickens (for years 1990 – 2019)].

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

Crop Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Sugarcane for sugar	72,000	21,700	20,400	15,500	12,900	15,500	30	0	0
Pineapples	18,205	8,358	7,314	5,986	4,288	4,011	3,752	3,510	3,283
Sweet potatoes	193	296	297	648	878	877	876	1,032	1,081
Ginger root	300	122	80	64	115	136	157	143	153
Taro	462	548	535	503	489	492	495	480	477
Corn for grain	0	3,622	3,115	4,365	5,019	4,959	4,899	5,474	5,617
Seed production	900	3,680	4260	6,500	4,260	3,980	4,090	3,030	2,790

Sources: USDA (2018b) (sugarcane); USDA (1989, 1994, 2009, 2014, and 2019) (pineapples, sweet potatoes, ginger root, taro, and corn for grain); USDA (2004b, 2015, 2016, 2020a) (seed production).

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

Crop Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Sugarcane for sugar	6,538,000	1,753,000	1,493,000	1,195,000	1,139,000	1,336,000	435	0	0
Pineapples	607,322	257,945	225,952	185,246	133,037	124,513	116,536	109,070	102,082
Sweet potatoes	1,024	1,185	1,430	3,120	4,229	4,224	4,218	4,971	5,207
Ginger root	4,503	1,826	1,266	908	1,614	1,928	2,243	1,979	2,110
Taro	3,511	2,433	2,554	2,060	2,331	2,530	2,730	2,444	2,489
Corn for grain	0	4,376	3,497	7,567	12,880	13,747	14,614	16,134	17,209
Seed production	1,169	4,446	4,782	11,268	10,933	11,034	12,201	8,930	8,548

Sources: USDA (2018b) (sugarcane); USDA (1989, 1994, 2009, 2014, and 2019) (pineapples, sweet potatoes, ginger root, taro, and corn for grain); USDA (2004b, 2015, 2016, 2020a) (seed production).

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

Fertilizer Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Urea Fertilizer Consumption (short tons)	2,638	2,038	2,038	2,002	2,262	2,305	2,349	2,093	2,074
Synthetic Fertilizer Consumption (kg N)	16,218,014	12,550,066	12,550,066	12,324,312	13,953,712	14,227,325	14,500,939	14,477,552	15,048,166

Sources: TVA (1991 – 1994) (urea fertilizer); AAPFCO (1995 – 2019) (urea and synthetic fertilizer).

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

Area Burned	1990	2005	2007	2010	2015	2016	2017	2018	2019
Area Burned (Hectares)	8,172	10,721	11,975	3,856	2,264	7,335	3,115	12,380	6,807

Source: DLNR (1994 – 2008, 2011, 2015, 2016, 2017, 2018, 2019, and 2020).

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

Forest and Shrubland Area	1990	2005	2007	2010	2015	2016	2017	2018	2019
Forest and Shrubland Area (Hectares)	494,360	485,107	483,029	482,769	484,121	484,830	486,888	454,935	454,935

Source: DBEDT (2021).

Table F-17: Forest and Shrubland Area (percent)

Forest and Shrubland Area	1990	2005	2007	2010	2015	2016	2017	2018	2019
Forest	52.0%	58.5%	60.9%	64.5%	68.4%	68.4%	68.4%	68.4%	68.4%
Shrubland	48.0%	41.5%	39.1%	35.5%	31.6%	31.6%	31.6%	31.6%	31.6%

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

Table F-18: Hawai'i Landfilled Yard Trimmings and Food Scraps (thousand short tons, wet weight)

Material	1990	2005	2007	2010	2015	2016	2017	2018	2019
Landfilled Yard Trimmings	**126**	**48**	**45**	**55**	**53**	**47**	**42**	**52**	**45**
Grass	38	14	14	17	16	14	13	16	14
Leaves	51	19	18	22	21	19	17	21	18
Branches	37	14	13	16	16	14	13	15	13
Food Scraps	**85**	**115**	**119**	**136**	**149**	**150**	**150**	**259**	**191**

Source: EPA (2020).

Table F-19: Hawai'i Urban Area (km^2)

Hawai'i Urban Area	1990	2005	2007	2010	2015	2016	2017	2018	2019
Urban Area (km^2)	757.0	969.4	988.9	1,018.2	1,089.4	1,105.3	1,121.4	1,137.8	1,154.4

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

Waste

Table F-20: Quantity of MSW Landfilled (MT)

Year	Amount	Year	Amount	Year	Amount
1960	312,381	**1980**	837,840	**2000**	780,692
1961	336,277	**1981**	852,137	**2001**	817,079
1962	360,910	**1982**	868,330	**2002**	822,814
1963	372,098	**1983**	887,551	**2003**	814,567
1964	394,914	**1984**	903,600	**2004**	881,034
1965	410,684	**1985**	916,714	**2005**	994,112
1966	428,276	**1986**	930,154	**2006**	924,488
1967	450,956	**1987**	947,296	**2007**	803,274
1968	473,394	**1988**	960,756	**2008**	692,983

Year	Amount	Year	Amount	Year	Amount
1969	500,171	**1989**	976,832	**2009**	572,399
1970	530,921	**1990**	996,000	**2010**	546,656
1971	565,703	**1991**	702,000	**2011**	555,138
1972	598,176	**1992**	702,000	**2012**	517,978
1973	629,328	**1993**	980,000	**2013**	480,571
1974	656,404	**1994**	1,040,000	**2014**	500,888
1975	685,793	**1995**	827,142	**2015**	513,907
1976	716,076	**1996**	889,342	**2016**	536,847
1977	744,188	**1997**	851,153	**2017**	609,923
1978	772,606	**1998**	763,193	**2018**	628,535
1979	809,071	**1999**	759,442	**2019**	574,249

Sources: Hawaiʻi DOH (2022a); Otsu (2008); EPA (2022c).

Table F-21: Weight of Composted MSW (MT)

MSW Composted	1990	2005	2007	2010	2015	2016	2017	2018	2019
Hawaiʻi	22,564[a]	31,041	34,377	38,009	37,097	59,602	37,629	35,538	37,884
Maui	37,455[a]	50,067[a]	51,390[a]	52,705	46,637	46,255	51,112	46,087	51,157
Honolulu	60,190[a]	63,226	63,506[a]	75,163	65,233	90,465	98,608	100,745	86,412
Kauaʻi	12,812[a]	14,869[a]	15,565[a]	15,547	22,019	16,591	14,811	16,548	22,644

[a] Weight composted is calculated using a proxy to the nearest year with available data on per capita composting rate.
Source: Hawaiʻi DOH (2022a).

Table F-22: Per Capita Biological Oxygen Demand for Wastewater treatment (kg/person/day)

Island	1990	2005	2007	2010	2015	2016	2017	2018	2019
Hawaiʻi	0.0615	0.0615	0.0615	0.0059	0.0052	0.0054	0.0052	0.0045	0.0042
Kauaʻi	0.0615	0.0615	0.0615	0.0001	0.0002	0.0007	0.0007	0.0002	0.0002
Lānaʻi	0.0615	0.0615	0.0615	0.0615	0.0615	0.0164	0.0164	0.0138	0.0137

Island	1990	2005	2007	2010	2015	2016	2017	2018	2019
Maui	0.0615	0.0615	0.0615	0.0003	0.0003	0.0006	0.0006	0.0007	0.0006
Molokaʻi	0.0615	0.0615	0.0615	0.0615	0.0615	0.0008	0.0008	0.0010	0.0009
Niʻihau	0.0615	0.0615	0.0615	0.0615	0.0615	0.0615	0.0615	0.0615	0.0615
Oʻahu	0.0615	0.0615	0.0615	0.0289	0.0270	0.0269	0.0270	0.0232	0.0272

Sources: Pruder (2008), Hawaiʻi DOH (2017, 2018, 2022a, 2022b, 2022c, and 2022d).

Table F-23: Fraction of Population not on Septic (percent)

Country	1990	2005	2007	2010	2015	2016	2017	2018	2019
US	75.6%	78.8%	79.4%	79.9%	80.1%	81.1%	82.1%	82.9%	83.6%

Source: EPA (2022a).

Table F-24: Hawaiʻi Annual Protein Consumption (kg/person/year)

State	1990	2005	2007	2010	2015	2016	2017	2018	2019
Hawaiʻi	43.1	44.9	44.9	43.8	44.3	44.7	44.9	44.4	44.4

Source: EPA (2022a).

Appendix G. Emission Factors

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

Energy

Table G-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	2005	2007	2010	2015	2016	2017	2018	2019
Residential									
Diesel Fuel	44.47	44.91	44.64	44.62	44.58	44.56	44.56	44.58	44.58
Propane	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81
Natural Gas	31.88	31.88	31.88	31.92	31.81	31.81	31.81	31.81	31.81
Commercial									
Diesel Fuel	44.47	44.91	44.64	44.62	44.58	44.56	44.56	44.58	44.58
Motor Gasoline	42.81	42.59	43.14	42.75	42.44	42.46	42.51	42.48	42.48
Propane	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.88	31.88	31.88	31.92	31.81	31.81	31.81	31.81	31.81
Other Fuels									
Kerosene	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Industrial									
Coal	57.19	57.50	57.39	57.43	57.47	57.45	57.50	57.52	57.50
Diesel Fuel	44.47	44.91	44.64	44.62	44.58	44.56	44.56	44.58	44.58
Motor Gasoline	42.81	42.59	43.14	42.75	42.44	42.46	42.51	42.48	42.48
Propane	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.81	31.88
Other Fuels									
Asphalt and Road Oil	45.30	45.30	45.30	45.30	45.30	45.30	45.30	45.30	45.30
Kerosene	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Lubricants	44.53	44.53	44.53	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	43.64	43.64	43.64
Energy Industries									
Coal	57.19	57.50	57.39	57.43	57.47	57.45	57.50	57.52	57.50
Diesel Fuel	44.47	44.47	44.47	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	45.15	45.15	45.15

Sector/Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Fuel Gas	40.11	40.11	40.11	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	41.60	41.60	41.60
Motor Gasoline Blending Components	42.81	42.68	43.12	42.90	42.90	42.90	42.90	42.90	42.90
Unfinished Oils	44.42	44.78	44.71	44.78	44.78	44.78	44.78	44.78	44.78

Source: EPA (2022a).

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

Fuel Type/Sector	CH_4	N_2O
Coal		
Industrial	10	1.5
Energy Industries	1	1.5
Petroleum		
Residential	10	0.6
Commercial	10	0.6
Industrial	3	0.6
Energy Industries	3	0.6
Natural Gas		
Residential	5	0.1
Commercial	5	0.1
Industrial	1	0.1
Wood		
Residential	300	4
Commercial	300	4
Industrial	30	4
Energy Industries	30	4

Source: IPCC (2006).

Table G-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 G-2.
NA (emissions are Not Applicable).
Source: EPA (2022a).

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

Fuel Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Aviation Gasoline	41.58	41.58	41.58	41.58	41.58	41.58	41.58	41.58	41.58
Diesel Fuel	44.47	44.91	44.64	44.62	44.58	44.56	44.56	44.58	44.58
Jet Fuel Kerosene	42.77	43.43	43.43	43.43	43.43	43.43	43.43	43.43	43.43
Motor Gasoline	42.81	42.59	43.14	42.75	42.44	42.46	42.51	42.48	42.48
Propane	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81	37.81
Residual Fuel	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15
Natural Gas	31.88	31.88	31.88	31.92	31.81	31.81	31.81	31.81	31.81
Ethanol	41.16	41.16	41.16	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	33.49	33.49	33.49
Lubricants	44.53	44.53	44.53	44.53	44.53	44.53	44.53	44.53	44.53

Source: EPA (2022a).

Table G-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 / CARB LEV III	0.0045	0.0015
EPA Tier 2	0.0072	0.0048
CARB LEV II	0.0070	0.0043
CARB 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 / CARB LEV III	0.0065	0.0012
EPA Tier 2	0.0100	0.0025
CARB LEV II	0.0084	0.0057
CARB 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

Vehicle Type/Control Technology	CH_4	N_2O
Uncontrolled	0.2024	0.0220
Gasoline Heavy-Duty Vehicles		
EPA Tier 3 / CARB LEV III	0.0252	0.0136
EPA Tier 2	0.0297	0.0015
CARB LEV II	0.0391	0.0049
CARB 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	0.0009	0.0014
Moderate	0.0009	0.0014
Uncontrolled	0.0011	0.0017
Diesel Medium- and Heavy-Duty Trucks and Buses		
Aftertreatment	0.0095	0.0431
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 (2022a).

Table G-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	2005	2007	2010	2015	2016	2017	2018	2019
Ships and Boats									
Residual Fuel	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Aircraft									
Aviation Gasoline	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Industrial and Commercial Equipment									
Motor Gasoline	0.43	0.52	0.53	0.54	0.55	0.55	0.55	0.55	0.55
Diesel Fuel	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19

Source: EPA (2022a).

Table G-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	2005	2007	2010	2015	2016	2017	2018	2019
Ships and Boats									
Residual Fuel	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Aircraft									
Aviation Gasoline	2.64	2.64	2.64	2.64	2.64	2.64	2.64	2.64	2.64
Industrial and Commercial Equipment									
Motor Gasoline	0.76	0.91	0.94	0.97	0.99	0.99	0.99	0.98	0.98
Diesel Fuel	0.12	0.11	0.12	0.13	0.14	0.13	0.13	0.13	0.13

Source: EPA (2022a).

Table G-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 G-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 G-10: Clinker Production Emission Factors and Correction Factor by Year (Ton CO_2/Ton clinker produced)

	1990	2005	2007	2010	2015	2016	2017	2018	2019
Clinker Production Emission Factor	0.51	0.51	0.51	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	1.02	1.02	1.02

Source: IPCC (2006).

AFOLU

Table G-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	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	115.42	104.77	105.68	108.24	118.07	113.11	122.47	122.94	122.94
Dairy Replacements 7-11 months	47.94	44.59	46.24	45.92	45.64	45.62	45.58	45.54	45.51
Dairy Replacements 12-23 months	72.54	67.29	69.78	69.31	68.90	68.86	68.75	68.73	68.65
Other Dairy Heifers	60.24	55.94	58.01	57.62	57.27	57.24	57.39	57.48	57.48
Dairy Calves	11.54	11.74	12.23	12.16	12.20	12.17	12.18	12.18	12.27
Beef Cows	93.70	98.78	99.81	99.77	99.95	100.04	100.15	100.25	100.31
Beef Replacements 7-11 months	57.91	63.33	64.52	64.56	64.38	64.44	64.54	64.53	64.51
Beef Replacements 12-23 months	67.43	73.14	74.26	74.26	74.28	74.27	74.26	74.26	74.27
Heifer Stockers	36.36	33.32	36.63	31.20	37.19	35.19	36.36	36.64	34.11
Heifer Feedlot	33.15	31.48	34.49	29.01	36.67	34.55	35.16	35.03	31.97
Steer Stockers	34.10	32.85	35.81	30.85	36.74	34.07	34.79	35.32	33.32
Steer Feedlot	33.15	31.48	34.49	29.01	36.67	34.55	35.16	35.03	31.97
Beef Calves	11.57	11.35	11.29	11.27	11.31	11.30	11.30	11.30	11.32
Bulls	96.45	102.66	103.89	103.89	103.89	103.89	103.89	103.89	103.89

Source: EPA (2022a).

Table G-12: Typical Animal Mass (TAM) by Cattle Type and Year (kg)

Cattle Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	679.77	679.77	679.77	679.77	679.77	679.77	679.77	679.77	679.77
Dairy Replacement Heifers	407.72	405.70	406.35	406.87	406.38	407.23	406.51	407.51	407.51
Other Dairy Heifers	407.72	405.70	406.35	406.87	406.38	407.23	406.51	406.79	406.79
Dairy Calves	122.10	122.55	122.54	122.48	122.54	122.50	122.53	122.53	122.53
Beef Cows	553.34	601.37	610.89	610.89	610.89	610.89	610.89	610.89	610.89
Beef Replacement Heifers	371.54	398.60	405.73	406.33	403.81	404.53	405.54	405.54	405.54
Heifer Stockers	295.34	320.09	320.27	323.45	323.85	325.55	321.82	321.82	321.82
Heifer Feedlot	383.38	415.73	420.76	424.92	445.35	449.37	443.57	443.57	443.57
Steer Stockers	313.61	325.27	326.80	329.27	325.35	327.32	324.34	324.34	324.34
Steer Feedlot	418.46	441.81	449.66	451.89	470.22	474.89	470.55	470.55	470.55
Beef Calves	122.10	122.55	122.54	122.48	122.54	122.50	122.53	122.53	122.53
Bulls	830.00	902.06	916.34	916.34	916.34	916.34	916.34	916.34	916.34

Source: EPA (2022a).

Table G-13: Volatile Solids (VS) by Animal Type and Year (kg VS/1000 kg animal mass/day)

Cattle Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	7.81	7.63	8.05	8.26	9.42	8.69	9.42	9.46	4.43
Dairy Replacement Heifers	7.86	7.85	8.48	8.44	8.44	8.43	8.44	8.43	8.42
Other Dairy Heifers	7.86	7.85	8.48	8.44	8.44	8.43	8.44	8.43	8.42
Dairy Calves	6.41	7.38	7.59	7.70	7.70	7.70	7.70	7.70	7.70
Beef Cows	8.73	8.47	8.43	8.42	8.46	8.45	8.46	8.46	8.47
Beef Replacement Heifers	7.96	8.55	8.52	8.44	8.54	8.50	8.54	8.51	8.51
Heifer Stockers	10.01	10.64	10.79	10.60	10.76	10.56	10.76	10.72	10.72
Heifer Feedlot	5.72	4.43	4.37	4.36	4.26	4.24	4.26	4.24	4.24
Steer Stockers	9.20	9.42	9.35	9.28	9.46	9.37	9.46	9.45	9.46
Steer Feedlot	5.18	4.05	3.99	4.00	3.89	3.89	3.89	3.87	3.89
Beef Calves	6.41	7.38	7.59	7.70	7.70	7.70	7.70	7.70	7.70
Bulls	5.99	5.87	5.85	5.85	5.85	5.85	5.85	5.85	5.85
Sheep	9.20	8.57	8.39	8.30	8.30	8.30	8.30	8.30	8.30
Goats	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50	9.50
Horses	6.20	6.26	6.28	6.16	6.16	6.17	6.16	6.16	6.16
Chickens	10.00	7.27	6.49	6.10	6.10	6.10	6.10	6.10	6.10
Broilers	10.80	10.95	10.98	11.00	11.00	11.00	11.00	11.00	11.00

Cattle Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Swine Breeding	15.00	16.50	16.83	17.00	17.00	17.00	17.00	17.00	17.00
Swine < 50 lbs.	2.60	2.70	2.72	2.74	2.74	2.74	2.74	2.74	2.74
Swine 50 - 119 lbs.	8.80	8.80	8.80	8.80	8.80	8.80	8.80	8.80	8.80
Swine 120 - 179 lbs.	5.40	5.40	5.40	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	5.40	5.40	5.40

Source: EPA (2022a).

Table G-14: Nitrogen Excreted (Nex) Produced by Animal Type and Year (kg Nex per head per year)

Cattle Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	143.80	129.45	125.92	124.42	132.99	129.06	136.83	137.34	83.79
Dairy Replacement Heifers	79.10	94.10	96.10	99.10	104.10	105.10	106.10	107.10	108.10
Other Dairy Heifers	79.10	94.10	96.10	99.10	104.10	105.10	106.10	101.60	101.60
Dairy Calves	13.37	18.45	19.57	20.12	20.13	20.12	20.13	20.13	20.13
Beef Cows	52.54	55.75	58.97	58.95	59.00	59.03	59.05	59.08	59.10
Beef Replacement Heifers	33.60	38.84	41.18	40.75	40.81	40.85	41.28	41.02	40.99
Heifer Stockers	33.60	38.84	41.18	40.75	40.81	40.85	41.28	41.02	40.99
Heifer Feedlot	57.36	53.11	53.07	54.64	57.70	59.01	58.08	57.73	58.24
Steer Stockers	30.78	31.94	33.44	33.55	33.41	33.57	33.45	33.29	33.38
Steer Feedlot	59.86	54.29	54.57	56.13	58.66	60.09	59.34	58.90	59.63
Beef Calves	13.37	18.45	19.57	20.12	20.13	20.12	20.13	20.13	20.13
Bulls	61.14	65.08	68.53	68.53	68.53	68.53	68.53	68.53	68.53
Sheep	10.52	11.04	11.19	11.27	11.27	11.27	11.27	11.27	11.27
Goats	10.51	10.51	10.51	10.51	10.51	10.51	10.51	10.51	10.51
Horses	49.28	42.95	41.14	40.24	40.24	40.24	40.24	40.24	40.24
Chickens	0.55	0.68	0.71	0.72	0.72	0.72	0.72	0.72	0.72
Broilers	0.36	0.33	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Swine Breeding	16.98	15.22	14.83	14.63	14.63	14.63	14.63	14.63	14.63
Swine < 50 lbs	2.85	3.99	4.24	4.37	4.37	4.37	4.37	4.37	4.37
Swine 50 - 119 lbs	5.98	7.26	7.54	7.69	7.69	7.69	7.69	7.69	7.69
Swine 120 - 179 lbs	10.40	12.62	13.12	13.37	13.37	13.37	13.37	13.37	13.37
Swine > 180 lbs	13.91	16.89	17.56	17.89	17.89	17.89	17.89	17.89	17.89

Source: EPA (2022a).

Table G-15: Weighted Methane Conversion Factor (MCF) by Animal Type and Year

Animal Type	1990	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	61.9%	53.6%	52.5%	51.2%	49.9%	49.3%	49.5%	49.7%	50.5%
Dairy Replacement Heifers	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Other Dairy Heifers	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%	1.6%
Dairy Calves	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Beef Cows	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Beef Replacement Heifers	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Heifer Stockers	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Heifer Feedlot	2.2%	2.3%	2.3%	2.2%	2.3%	2.3%	2.3%	2.3%	2.3%
Steer Stockers	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Steer Feedlot	2.2%	2.3%	2.3%	2.2%	2.3%	2.3%	2.3%	2.3%	2.3%
Beef Calves	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.0%	0.5%	0.5%
Bulls	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Sheep	0.9%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%
Goats	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Swine	34.9%	47.2%	45.2%	42.0%	38.8%	38.2%	37.6%	37.7%	37.7%
Horses	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Chickens & Broilers	60.4%	20.4%	20.3%	20.3%	20.5%	20.3%	20.4%	20.5%	20.5%

Sources: EPA (2022a).

Table G-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	9.00	68.60
Goats	9.00	64.00
Swine	1.50	60.44
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 (2022a).
NA (Not Applicable).

Table G-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	0.17
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 (2022a)

Table G-18: Fraction Volatile Solids Distribution by Animal Type, Waste Management System (WMS), and Year

Animal Type	WMS	1990	2005	2007	2010	2015	2016	2017	2018	2019
Dairy Cows	Pasture	0.4%	7.1%	6.6%	5.8%	4.4%	4.2%	4.2%	4.2%	4.2%
Dairy Cows	Anaerobic Lagoon	67.7%	55.0%	54.8%	54.6%	54.2%	54.1%	54.1%	54.1%	54.1%
Dairy Cows	Liquid/Slurry	21.2%	12.5%	10.6%	7.8%	3.0%	2.1%	2.1%	2.1%	2.1%
Dairy Cows	Solid Storage	10.6%	18.8%	20.3%	22.4%	26.1%	26.8%	26.8%	26.8%	26.8%
Dairy Cows	Deep Pit	0.1%	4.9%	5.7%	7.0%	9.0%	9.4%	9.4%	9.4%	9.4%
Dairy Replacement Heifers	Liquid/Slurry	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Dairy Replacement Heifers	Dry Lot	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Other Dairy Heifers	Liquid/Slurry	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Other Dairy Heifers	Dry Lot	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Dairy Calves	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Beef Cows	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Beef Replacement Heifers	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Heifer Feedlot	Liquid/Slurry	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Heifer Feedlot	Dry Lot	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Heifer Stockers	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Steer Feedlot	Liquid/Slurry	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%
Steer Feedlot	Dry Lot	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Steer Stockers	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Animal Type	WMS	1990	2005	2007	2010	2015	2016	2017	2018	2019
Beef Calves	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Bull	Pasture	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Sheep	Pasture	54.9%	68.9%	68.9%	68.9%	68.9%	68.9%	68.9%	68.9%	68.9%
Sheep	Dry Lot	45.1%	31.1%	31.1%	31.1%	31.1%	31.1%	31.1%	31.1%	31.1%
Goats	Pasture	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%
Goats	Dry Lot	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Swine	Pasture	36.0%	27.3%	29.8%	34.5%	40.6%	41.5%	42.4%	42.4%	42.4%
Swine	Anaerobic Lagoon	13.5%	22.0%	21.3%	20.6%	18.4%	18.1%	17.7%	17.7%	17.7%
Swine	Liquid/Slurry	17.7%	23.3%	23.9%	23.7%	22.4%	22.2%	22.0%	22.0%	22.0%
Swine	Deep Pit	30.0%	19.5%	16.4%	12.8%	11.5%	11.3%	11.1%	11.1%	11.1%
Swine	Solid Storage	2.8%	0.9%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Horses	Pasture	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%	92.0%
Horses	Dry Lot	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Chickens	Anaerobic Lagoon	80.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
Chickens	Poultry without bedding	10.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Chickens	Solid Storage	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Source: EPA (2022a).

Table G-19: Urea Emission Factor

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

Source: IPCC (2006).

Table G-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	0.001

Source: IPCC (2006).

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

Source: IPCC (2006).

Table G-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 G-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 G-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 G-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 G-26: Ratio of Hawai'i Forest Land to Wildland (Dimensionless)

Factor	1990	2005	2007	2010	2015	2016	2017	2018	2019
Ratio of Hawai'i forestland to wildland	0.37	0.36	0.36	0.36	0.36	0.36	0.36	0.34	0.34

Source: National Association of State Foresters (NASF) (1998, 2002); DLNR (2011, 2015, 2016, 2017, 2018, 2019, and 2020).

Table G-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 G-28: Carbon Storage Factors for Landfilled Yard Trimmings and Food Scraps

Type of Waste	Content of Yard Trimmings (percent)	Moisture Content of Waste, MC_i (percent)	Proportion of Carbon Stored Permanently in Waste, CS_i (percent)	Initial Carbon Content of Waste, ICC_i (percent)	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 (2022c).
NA (Not Applicable).

Table G-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 (2022a).

Table G-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 G-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/Mg of refuse)	100
Methane Oxidation Rate (percent)	10%

Source: EPA (2022a).

Table G-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 G-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%
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 (2022c).

Appendix H. ODS Emissions

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 H-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. IPCC (2006) guidelines exclude the reporting of ODS emissions because they are controlled under the *Montreal Protocol* controls.

For informational purposes, ODS emissions were estimated for the state of Hawaiʻi. To estimate ODS emissions for Hawaiʻi, national ODS emissions were apportioned based on the ratio of Hawaiʻi population to U.S. population. Estimates of national ODS emissions (in kilotons (kt) by gas) were obtained from the U.S. Inventory (EPA 2022a). National population numbers were obtained from the U.S. Census Bureau (2021) while Hawaiʻi population data were obtained from the State of Hawaiʻi Data Book (DBEDT 2020b). Table H-2 summarizes ODS emissions in Hawaiʻi by gas for 1990, 2005, 2007, 2010, 2015 – 2019.[63]

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

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CFC-11	0.16	0.06	0.06	0.06	0.05	0.06	0.06	0.05	0.05
CFC-12	0.68	0.11	0.07	0.03	0.02	0.02	0.01	0.01	+
CFC-113	0.30	0.08	0.06	0.03	+	+	+	NO	NO
CFC-114	0.02	0.01	+	+	+	+	+	NO	NO

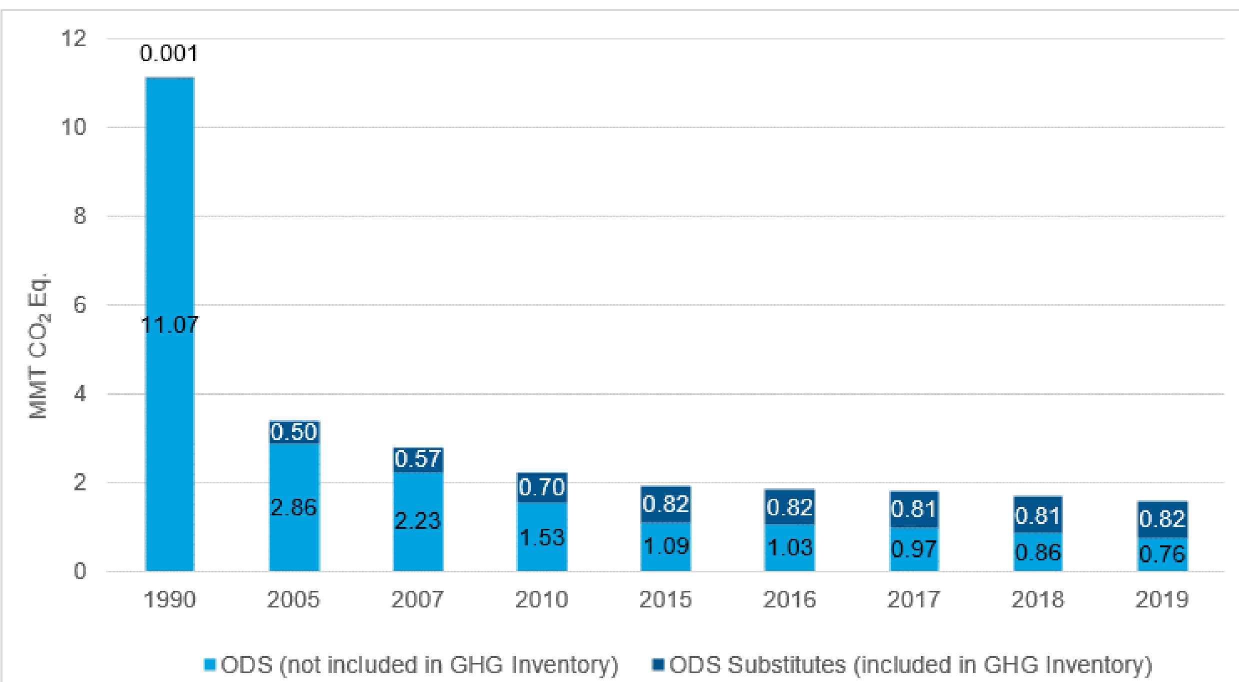
63 The methodology and data sources used to estimate ODS emissions in Hawaiʻi are consistent with the methodology and data sources used to estimate emissions from ODS substitutes.

Gas	1990	2005	2007	2010	2015	2016	2017	2018	2019
CFC-115	0.04	0.01	0.01	+	+	+	+	+	+
Carbon Tetrachloride	0.02	NO	NO	NO	NO	NO	NO	NO	NO
Methyl Chloroform	1.12	NO	NO	NO	NO	NO	NO	NO	NO
Halon 1211	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Halon 1301	0.01	+	+	+	+	+	+	+	+
HCFC-22	0.15	0.36	0.36	0.34	0.28	0.27	0.25	0.23	0.21
HCFC-123	NO	+	+	+	+	+	+	+	+
HCFC-124	NO	0.01	0.01	+	+	+	+	+	+
HCFC-141b	0.01	0.02	0.03	0.04	0.05	0.04	0.04	0.04	0.05
HCFC-142b	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
HCFC-225ca/cb	+	0.01	0.02	0.03	0.06	0.07	0.07	0.07	0.08
Total	**2.52**	**0.70**	**0.65**	**0.57**	**0.49**	**0.47**	**0.46**	**0.43**	**0.42**

+ Does not exceed 0.005 kt; NO (emissions are Not Occurring).
Source: EPA (2022a).

Emissions from ODS in Hawaiʻi have decreased significantly since 1990, following the implementation of the *Montreal Protocol*. Figure H-1 below presents combined emissions from ODS and ODS substitutes in Hawaiʻi. Combined emissions have similarly decreased between 1990 and 2019, even though emissions from ODS substitutes increased during the same period.

Figure H-1: Emissions from ODS and ODS Substitutes



Appendix I. Uncertainty

This appendix 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., 2019).

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 *2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) and 2006 IPCC Guidelines* (IPCC 2006). Under this method, GHG emissions (or sinks) for each source category are estimated by generating randomly-selected values according to the specified probability density function (PDF)[64] for each of the constituent input variables (e.g., activity data, emission factor) 10,000 times using @RISK, a commercially-available simulation software. The results of this methodology are presented as an overall emission (or sinks) PDF for each source category. The quantified uncertainties for each source category were then combined using Approach 2 to provide uncertainty estimates at the sector level as well as for the overall net and total emissions for the current inventory year.

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

Consistent with the U.S. Inventory, this inventory quantifies uncertainty for the current inventory year (i.e., 2019). 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 2019. 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 second time for the Hawaiʻi 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 *2019 Refinements to the 2006 IPCC Guidelines* (IPCC 2019) and *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 J. Emission Projections Methodology

This appendix summarizes the methodology used to project statewide emissions for 2020, 2025, 2030, 2035, 2040, and 2045 by source and sink category under both the baseline and alternate scenarios. Both baseline and alternate scenarios were based on key forecasts, including gross state/county product, visitor arrivals, future fossil fuel prices (residual oil, gasoline, diesel, and jet fuel), deployment of renewable energy technology, and uptake of electric vehicles in ground transportation. These forecasts are provided in Table J-1 below. This appendix also provides a discussion of key uncertainties and areas for improvement.

Macroeconomic and Fuel Price Forecasts

Table J-1: Gross County Product (Normalized to 2019=1)

Scenario	2020	2025	2030	2035	2040	2045
Hawaiʻi	0.89	1.03	1.17	1.33	1.50	1.68
Honolulu	0.89	1.03	1.12	1.22	1.33	1.43
Kauaʻi	0.89	1.03	1.15	1.29	1.44	1.62
Maui	0.89	1.03	1.17	1.32	1.48	1.67

The forecast for Gross County Product (GCP) was developed based on three sources. First, the relationship between GCP to Gross State Product (GSP) was determined based on the 2018 ratio for each county, as this was the most recent year for which both state-level and county-level metrics were available (DBEDT 2022b). Next, the DBEDT short-run forecast of GSP through 2025 was used, which included actual GSP for 2020 (DBEDT 2022c). Lastly, the DBEDT long-run forecast expected growth rate was applied through 2045 (DBEDT 2018). GCP was estimated using the ratio for each county. For simplicity, GCP and GSP are used interchangeably hereafter. The forecast for resident population was developed similarly to that of GSP. The DBEDT short-run forecast was used through 2025, and thereafter the long-run forecast (DBEDT 2022b and 2018). The ratio of statewide to county resident population was determined by actual 2021 population per county (DBEDT 2022c). The resident populations forecasts for each county, normalized to 2019, are provided in Table J-2 below.

Table J-2: Resident Population (Normalized to 2019=1)

Scenario	2020	2025	2030	2035	2040	2045
Hawaiʻi	1.00	1.02	1.08	1.14	1.19	1.25
Honolulu	1.00	0.98	1.00	1.01	1.02	1.02
Kauaʻi	1.00	1.00	1.04	1.08	1.12	1.16
Maui	1.00	1.00	1.04	1.09	1.13	1.16

The forecast for visitor arrivals similarly used the DBEDT short-run forecast through 2025, after which the DBEDT long-run forecast for visitor arrivals was applied. These forecasts are provided in Table J-3 below.

Table J-3: Visitor Arrivals by Air (Normalized to 2019=1)

Scenario	2020	2025	2030	2035	2040	2045
Hawaiʻi	0.26	1.01	1.08	1.16	1.23	1.30
Honolulu	0.26	1.01	1.04	1.08	1.10	1.14
Kauaʻi	0.26	1.01	1.06	1.12	1.17	1.22
Maui	0.26	1.01	1.07	1.13	1.19	1.25

The forecast for de facto population, shown in Table J-4 below, was based on both residents and visitors and returns to 2019 levels by 2025, after which the DBEDT long-run forecast for de facto population was applied.

Table J-4: De Facto Population (Normalized to 2019=1)

Scenario	2020	2025	2030	2035	2040	2045
Hawaiʻi	0.92	1.00	1.07	1.13	1.20	1.26
Honolulu	0.94	1.00	1.02	1.04	1.05	1.06
Kauaʻi	0.81	1.00	1.05	1.10	1.14	1.19
Maui	0.80	1.00	1.06	1.11	1.17	1.21

There were four fuel types for which the EIA Annual Energy Outlook (AEO) 2022 high and low fuel price forecasts (relative to the baseline) were used to determine outcomes in Scenarios 1A and 1B. These forecasts are given in Table J-5 below, where the baseline AEO (EIA 2022b) forecast was used to normalize the high and low price scenarios per fuel type.

Table J-5: Fuel Prices (Baseline=1)

Fuel Type	Scenario	2025	2030	2035	2040	2045
Residual Fuel Oil	High (1A)	1.70	1.71	1.68	1.70	1.70
	Low (1B)	0.48	0.42	0.57	0.54	0.47
Gasoline	High (1A)	1.54	1.51	1.46	1.43	1.42
	Low (1B)	0.78	0.74	0.75	0.73	0.71
Diesel	High (1A)	1.50	1.53	1.50	1.51	1.50
	Low (1B)	0.75	0.73	0.74	0.70	0.67
Jet Fuel	High (1A)	1.38	1.38	1.34	1.37	1.38
	Low (1B)	0.60	0.60	0.61	0.58	0.56

Energy

Stationary Combustion

Baseline Scenario Methodology

Emissions from stationary combustion were projected based on the macroeconomic forecast as well as utility-specific electricity demand forecasts and renewable energy deployment per county. For the residential, commercial, and industrial sectors, statewide emissions were assumed to grow at the rate of forecasted gross state product. For the energy industries sector, emissions were projected for the petroleum refinery[65] and each of the two electric utilities in Hawaiʻi: Hawaiian Electric, which serves Oʻahu, Hawaiʻi Island, and Maui County; and the Kauaʻi Island Utility Cooperative (KIUC), which serves the island of Kauaʻi.

For the petroleum refinery, emissions were projected out from 2019 based on the projected growth in aviation emissions (see the transportation section below for details on the method used to project aviation emissions).

For all counties, electric sector emissions in 2020 were based on facility emissions reported to the US EPA Greenhouse Gas Reporting Program (EPA 2022h). KIUC electricity demand was based on annual average historical growth in overall demand (Rockwell, personal communication, August 2022) and the electricity demand increase that was estimated to come from electric vehicles (EVs) in each year (see Ground Transportation, below). Renewable energy deployment was assumed to meet KIUCs goal of 70 percent renewables by 2030 (Rockwell, personal communication, August 2022) and the State RPS target of 100 percent by 2045 as amended by Act 240, Session Laws of Hawaiʻi 2022 (Act 240 of 2022). Emissions from fossil fuels were calculated based on 2020 average heat rates for diesel reported in EIA form 923 (EIA 2020) and 2022 emission factors from EPA (EPA 2022d).

For the service area under Hawaiian Electric, emissions projections for 2020, 2025, 2030, 2035, 2040, and 2045 were developed based on the utility's preliminary Integrated Grid Plan (IGP) and Power Supply Improvement Plan (PSIP) (PUC 2016; Hawaiian Electric 2021). The IGP underlying forecast assumptions provided a projection for future electricity demand as well as several pathways for renewable energy deployment. Overall, the Hawaiian Electric utility expected a twenty percent increase in net sales from 2019-2045. The IGP "land constrained" scenario served as the starting point for assumed expansion of renewable generation for Oʻahu. The PSIP was used for Maui and Hawaiʻi counties (PUC 2016).[66] Two key adjustments were made. First, future renewable energy generation was scaled to historic renewable generation in 2021 by taking the difference in expected geenration stated in the PSIP and actual generation reported in the companies report to the PUC for the year 2021. The PSIP is used for comparison for all service areas, as HECO's IGP forecast starts in the year 2027. Second, due to the more

[65] In 2018, Par Hawaiʻi Inc. acquired Island Energy Services, LLC., which had recently ceased refinery operations and converted to an import terminal (Mai 2018).
[66] Within the "grid modernization" scenario.

than 40 precent increase in assumed underlying demand between 2027 and 2045, and because renewable energy generation in Honolulu County in 2021 is substantially lower than what was planned (at 26 percent), the baseline assumed that renewable energy deployment for Oʻahu continued this lag by taking the prior five year period within the IGP "land constrained" scenario.[67] Maui and Hawaiʻi island were assumed to reach 100 percent renewables energy generation in 2045.

Annual GHG emissions from the electric sector, by county, were then estimated as follows:

$$E_{c,t} = \sum_f (D_{f,c,t} \times HR_{f,c,t} \times EF_f)$$

where,

$E_{c,t}$ = Emissions of GHGs for year *t* (MMT CO_2 Eq.) and county *c*

$D_{f,c,t}$ = Demand (GWh) for each type of fossil fuel fired generation *f* (diesel, LSFO, etc.) in county *c* in year *t*

$HR_{f,c,t}$ = Weighted average heat rate for fossil fuel fired generation *f in county* c within the PSIP or KIUC production plan for year *t*

EF_f = GHG CO_2 Eq. emission factor for fuel in county *c* for year *t* (Mt CO_2 Eq. per MMBtu)

As the level of renewable energy deployment increases, the level of demand for fossil fuel-based generation decreases and subsequently change the electric sector emissions.

Alternate Scenario 1A and 1B

Future energy prices, especially oil prices, are one of the greatest sources of uncertainty that will affect future GHG emissions. Hawaiʻi's demand for refined petroleum products depends on the price of refined petroleum products, which depends directly on world crude oil prices. Prices could fluctuate due to market forces external to Hawaiʻi as well as state or national policy regarding GHG pricing.[68]

To understand the potential effect of oil prices on Hawaiʻi's future emissions from the electric sector, the study team considered both a *high* (Alternate Scenario 1A) and *low* (Alternate Scenario 1B) future oil price pathway based on the EIA's Annual Energy Outlook (AEO) 2022 for refined petroleum products (EIA 2022b). As shown, in Table J-5 under the *high* oil price forecast, the price of oil was expected to be roughly 70 percent greater than in the baseline case in all years, while in the low oil price forecast, the price of residual fuel oil was expected to be roughly half the price of the baseline case in 2025 and 40 percent of the baseline case in 2045.[69]

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[67] Compliance within the RPS statute after 2030 is potentially less strict, as there are a number of stated reasons that the 70 and 100 percent targets could not be met; for example, if it is not cost-effective or economically beneficial (HRS §269-92).

[68] An economy-wide carbon pricing scheme would also affect the price of coal and natural gas, which is not accounted for as part of this analysis. Given that coal phased out in 2022 and natural gas currently represents a small portion of total fuel consumption in Hawaiʻi, the impact of a carbon-pricing scheme on future coal and natural gas emissions is expected to be small.

[69] For context, a $25/MT CO_2 Eq. tax equates to approximately an additional $10/bbl of crude oil.

To estimate the percent change in electricity demand as a result of higher and lower residual oil prices, the underlying electricity demand which was met with fossil generation in the baseline case was multiplied by the percentage change in price for each scenario and each year as well as the price elasticity of demand. Based on recent literature, electricity demand is relatively inelastic, meaning that a one percent increase in price is expected to result in much less than a one percent decrease in consumption (Coffman et al. 2016). For this analysis, an elasticity parameter equal to -0.1 was selected based on the Electric Power Research Institute (2010). This means that a one percent increase in electricity price results in a 0.1 percent decrease in electricity demand. This elasticity parameter was similar to findings published by Nakajima and Hamori (2010), Paul et al. (2009), and Metcalf (2008). Using this parameter, the change in demand for fossil fuel-based electricity under each scenario was calculated based on the following equation:

$$DS_{f,c,t} = D_{f,c,t} \times \left(1 + \%\Delta EP_{t,s} \times \sigma\right)$$

where,

$DS_{f,c,t}$	= Demand (GWh) for each type of fossil fuel generation in Scenario 1A or 1B
$D_{f,c,t}$	= Baseline demand (GWh) for each type of fossil fuel fired generation in county *c* in year *t*
$\%\Delta EP_{t,s}$	= The percentage change from the baseline in electricity price in year *t* under scenario *s*
σ	= Price elasticity of demand for electricity

This new demand for fossil fuel generation was then used to determine GHG emissions.

Alternate Scenario 2A and 2B

There is considerable uncertainty associated with the energy technologies that will ultimately be used to meet future electricity demand. For the purposes of this alternate scenario, two additional renewable energy deployment pathways were considered. Scenario 2A assumed that renewable energy deployment largely follows the IGP “baseline” scenario presented in the Honolulu and Maui County Grid Needs Assessment report, with several modifications (Hawaiian Electric 2022b and 2022a). Because annual generation was not presented by source in the Hawaiʻi Island Grid Needs Assessment Report, the county of Hawaiʻi was assumed to follow renewable energy deployment as described in the PSIP (similar to the baseline). Maui and Hawaiʻi island were assumed to follow the utility‘s plan starting in 2025 and reach 100 percent renewables by 2045. Oʻahu was assumed to lag five years behind the IGP “baseline” throughout the projection period, reaching 95 percent renewables in 2045. This is similar to the baseline using the IGP “land constrained” scenario; however, the IGP “baseline” is considerably more aggressive in its assumptions about the rate of reneweble energy adoption. Kauaʻi‘s renewable energy deployment pathway did not change from the baseline.

Scenario 2B assumed that delays in grid-scale renewable energy deployment follow the average annual capacity (MW) delay that has occurred between 2016 and 2022 for the Hawaiian Electric service area. The average annual delay was estimated by taking the difference between proposed renewable energy capacity buildouts in the PSIP (PUC 2016) and completed projects as listed in the State Energy Office‘s renewable energy project directory (HSEO 2022). Delays in renewable energy projects can occur for a number of reasons – from concerns about siting to changes in prices due to changes in the global market for supplies.

Alternate Scenario 3A and 3B

The level of adoption of EVs and other electrification of transportation will affect electricity demand and therefore GHG emissions within the electric sector. This alternate scenario accounted for electric sector GHG emissions from two alternative electric vehicle adoption pathways, as described below in the Transportation section. The electric sector demand forecasts (by county) were adjusted to account for the difference in the penetration of EVs from the baseline.

County-level Projections

For the commercial and industrial economic sectors, county emissions were based on the allocation of county emissions for 2019 from section 2.6, and assumed to grow with the rate of GCP, taking into account sector-specific efficiency gains (EIA 2022b). The residential sector is assumed to grow with the rate of population, also taking into account expected household efficiency gains (EIA 2022b). Emissions for energy industries were calculated using the bottom-up methodology described in section 3.1, Stationary Combustion.

Uncertainties and Areas for Improvement

As highlighted by the alternate scenarios described above, there is uncertainty associated with fluctating electricity demand due to changes in world oil prices and the future build out of renewable energy capacity. Additional uncertainties exist in the future of renewable energy technology costs, particularly due to inflation and supply chain constraints, further land use constraints, and the viability of the remaining refinery. This analysis also did not account for future policies or programs that could impact fuel consumption by the Residential, Commercial, and Industrial sectors.

Transportation

Baseline Scenario 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. For domestic marine and military-related transportation, emissions were assumed to remain constant in the future relative to 2019 due to a lack of available data and inconsistencies in the historical emissions trends. For non-military air transportation, emissions were based on future expectations of visitor arrivals and gross state product. 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

LDVs represent statewide usage of on-road gasoline consumption, which comprise 85 percent of 2019 emissions in ground transportation.[70] An LDV turnover model was used to forecast the consumption of gasoline and its associated emissions from passenger cars and trucks – which included cars, light trucks, minivans, and sports utility vehicles. Vehicle turnover models estimate the rate at which older vehicles retire and new ones enter the road. The LDV model was calibrated to 2019 and tracks the miles, fuel efficiency, and fuel use of the existing stock of vehicles as well as all post-2019 vintages. Major changes to GHG emissions result from changing assumptions about the adoption of EVs and fuel prices.

To forecast future emissions from LDVs, the properties of the 2019 stock of vehicles first needed to be defined. This was particularly important to calculate the fleet's VMT by internal combustion engine vehicles (ICEVs) and EVs, as well as the average fuel efficiency of each. DBEDT (2021) and the FHWA (2022) provided data on the total number of LDVs by county and the average VMT per LDV by county; however, ICEVs and EVs were not distinguished. To compute the number of ICEVs, the number of EVs was subtracted from the total number of LDVs. The number of EVs on the road by county were based on both 2019 EV sales and registrations (DBEDT 2020c). Using FHWA (2022) for VMT per vehicle by county and assuming that average travel by EVs and ICEVs is the same, the total VMT by each vehicle type was computed as follows:

$$ICEV_{VMT\,c,2019} = ICEV_{LDV\,c,2019} \times VMTperVeh_{c,2019}$$

where,

$ICEV_{VMT\,c,2019}$	= The distance (miles) driven by ICEVs by county *c* in 2019
$ICEV_{LDV\,c,2019}$	= The number of ICEVs by county *c* in 2019
$VMTperVeh_{c,2019}$	= the distance (miles) driven per vehicle by county *c* in 2019

Next, as the inventory represents gasoline consumption but not ethanol that is used by vehicles, an adjustment was made to account for the Federal Renewable Fuel Standard such that blended gasoline contains 10 percent ethanol. The fuel efficiency of ICEVs was then given as follows:

$$ICEV_{FE\,c,2019} = ICEV_{VMT\,c,2019} \div \left(\frac{Gasoline_{c,2019}}{(1 - shE)}\right)$$

where,

$ICEV_{FE\,c,2019}$	= Fuel efficiency of the stock of ICEVs by county *c* in 2019
$Gasoline_{c,2019}$	= Petroleum gasoline (E0) consumption in county *c* in 2019
shE	= Share of ethanol in gasoline pool (10 percent)

To forecast future LDV GHG emissions, the 2019 calibration was projected into the future based on the assumptions about the following additional elements:

[70] It is assumed that all gasoline in Hawaiʻi is used by LDVs.

- A forecast for LDV VMT. For Honolulu, this forecast accounted for the proposed impact of the Honolulu rail transit project.
- An assumption of the relative contribution to the overall change in VMT from the change in VMT per vehicle or the change in the number of vehicles.
- Assumptions about new vehicle characteristics such as fuel efficiency, and the rate of additional EV adoption.
- Lastly, new vehicles enter the fleet based on assumptions on the scrappage rate of vehicles by vintage.

Future LDV VMT

To estimate future LDV VMT, an Ordinary Least Squares regression between historical county level de facto population (DBEDT 2022c) and county VMT, from 1979 to 2020, was estimated. Using the state's most current long range-forecast for the growth rate of defacto population to the year 2045 (DBEDT 2018), total future VMT for passenger cars and trucks was projected to 2045 for each county using the following equation:

$$VMT_{c,t} = Intercept\ (c) + Slope\ (c)\ \times DefactoP_{c,t}$$

where,

$VMT_{c,t}$	= Total county level VMT from all LDVs in year
$Itercept\ (c)$	= Intercept term in the least squares fit by county
$Slope\ (c)$	= Slope term in the least squares fit by county
$DefactoPc,_{t}$	= Forecast for defacto population by county in year *t*

The resulting value for VMT served as an effective demand for travel. For Honolulu, this demand could also be satisified by future rail trips. To isolate future energy used for LDVs, the LDV VMT was adjusted such that future VMT met through rail transit was subtracted. The Honolulu Area Rapid Transit (HART) initially estimated the maximum VMT that could be displaced from passenger cars and trucks, once the rail is fully operational and running at full capacity, to be 566 million miles (HART 2010). However, given the planned truncated service to the system (HART 2019), this was adjusted downward. Using HART (2019) estimates for expected passenger trips and making assumptions for peak and off-peak utilization, a new estimate for VMT reduction was made, reaching 456 million miles in 2045. To adjust LDV VMT, VMT services provided by LDVs was given by the following:

$$LDV\_VMT_{c,t} = VMT_{c,t} - VMTDispbyRail_{c,t}$$

where,

$LDV\_VMT_{c,t}$	= Adjusted (Honolulu) total county level VMT from all LDVs in year *t*
$VMTDispbyRail_{c,t}$	= VMT displaced by rail for Honolulu, zero for all other counties

VMT per LDV

The next step was to further define LDV VMT per vehicle, which was determined based on the number of vehicles and the average VMT per vehicle. Assuming that this was weighted equally, the VMT per LDV was given by the following:

$$VMTperLDV_{c,t} = (1 + 0.5\ \times VMTGrow_{c,t}) \times VMTperLDV_{c,t-1}$$

where,

$VMTperLDV_{c,t}$ = Average VMT per Vehicle (miles) in county *c* in year *t*

$VMTGrow_{c,t}$ = Annual growth in VMT in county *c* in year *t*

$VMTperLDV_{c,t-1}$ = Average VMT per Vehicle (miles) in county *c* in year *t-1*

Composition of the Vehicle Fleet

The LDV turnover model introduced new vehicles and retired older vehicles based on the assumed survival rate for cars and trucks by vehicle age (EPA 2016c). Vehicle sales by type in the current year was the difference between the total number of vehicles by type in the current year less the total number of vehicles in the previous year that remain on the road in the current year. The following standard vehicle turnover equation was used to compute the number of vehicles of each vintage, except the current year vintage.

$$Veh_{c,type,v,t} = (1 - Decay_{age}) \times New_{c,type,v,t-1}$$

where,

v = all vintages except the current year vintage

type = ICEV car, ICEV truck, EV car, or EV truck, for all post-2019 vintages

$Veh_{c,type,v,t}$ = Existing vehicles on the road in county *c*, by *type*, vintage *v*, and year *t*

$Decay_{age}$ = One year decay rate of vehicles of age (*t*-*v*)

The total number of vehicles was estimated by the ratio of total VMT and average VMT per vehicle. The number of new vehicles was the difference between the total number of all vehicles and the total number of existing vehicles:

$$NewVeh_{c,t} = TtlVeh_{c,t} - \Sigma_{type,v} Veh_{c,type,v,t}$$

for *v*=2019, ..., *t*-1

where,

$NewVeh_{c,t}$ = New vehicles in county *c* and year *t*

$TtlVeh_{c,t}$ = Total vehicles in county *c* and year *t*

New vehicles were then disaggregated into the four *types* of LDVs, first by splitting EVs and ICEVs. The share of new vehicles that are EVs came from HECO's IGP (Hawaiian Electric 2021):

$$TtlNewEV_{c,t} = EVSh_{c,t} \times NewVeh_{c,t}$$

where,

$TtlNewEV_{c,t}$ = New EVs in county *c* and year *t*

$EVSh_{c,t}$ = Share of new vehicle sales that are EVs

The difference between total new vehicles and total new EVs gave total new ICEVs. Next, new EVs were split into those that were cars and trucks. The share of new vehicles that were cars was set equal to the share of 2019 vehicle sales that were cars. So, the number of new car sales that were ICEVs was the difference of total car sales of all types and sales of EV cars, which then left the number of new LDVs that were ICEV trucks as the remainder of new vehicle sales after accounting for all EV sales and ICEV cars.

Fuel Efficiency of New Passenger Cars and Trucks

After computing the VMT per vehicle and number of vehicles, the only parameter needed to compute energy consumed by LDVs and hence their associated GHG emissions was the fuel efficiency of these vehicles. The calibration of the benchmark year, 2019, provided the average fuel efficiency of the stock of vehicles in 2019. What remained to be computed was the fuel efficiency for all post-2019 vintages.

Fuel efficiency of new passenger cars and trucks was estimated using the U.S. Environmental Protection Agency's (EPA) corporate average fuel economy (CAFE) standards for cars and light trucks, recently updated and returned to Obama era figures (EPA 2022e). CAFE standards require light duty cars and trucks to have an EPA rated efficiency of 165 g CO_2 Eq./mile and 240 g CO_2 Eq./mile, respectively, by 2026. These standards can be met through a combination of improving vehicle efficiency and/or reducing emissions of hydrofluorocarbons (HFCs) from vehicle air conditioning. For this analysis, it was assumed based on Davis and Boundy (2019) that a portion of improvements was made through reductions in leakage of refrigerants from vehicle air conditioning systems. Specifically, this method of compliance meant that fleet average fuel economy standards in 2025 declined from 54.5 to 45.4 mpg (Lattanzio et al., 2018; Davis and Boundy 2019). These fleet average fuel efficiency standards translated into effective tailpipe fuel efficiency standards for light duty cars and trucks, respectively, of 60.9 and 40.7 mpg in 2026 (EPA 2022e). Because the EPA assumes small changes in the vehicle composition through 2029, the efficiency standard was 62.6 and 42.1 mpg, respectively, for light duty cars and trucks. This level of CAFE standard was assumed to remain constant from 2029 through 2045.

New vehicle fuel efficiency was adjusted to account for the difference between federal fuel standards and true on-road fuel efficiency as estimated by new car window labels. EPA estimated this difference to range from 20 to 25 percent (EPA 2014). It was assumed that the actual fuel efficiency of new vehicles would be 22.5 percent lower than the CAFE standards. This efficiency standard was an average across ICEVs and EVs.

To compute emissions from light duty ICEVs, the implied on-road fuel efficiency standard for ICEVs needed to be determined. Using the AEO (EIA 2022b) forecast for EV sales, the Electric Vehicle's Database (2022) for EV efficiency, and the overall fleet efficiency, the effective efficiency standard for new ICEVs over the model horizon was computed. The efficiency of the existing stock of EVs was taken as the average across all 2021 EVs (EIA 2022b). The 2045 value was taken to be the efficiency of the Lightyear 0 concept car (Electric Vehicle's Database 2022). The efficiency from 2021 to 2045 was assumed to increase exponentially between the 2021 and 2045 value.

In addition to EVs embedded in the fuel efficiency achieved through CAFE, the model assumed different EV adoption rates for each county. For the baseline, annual sales shares for EVs were based on HECO's IGP (Hawaiian Electric 2021). Since Kauaʻi is not a part of HECO's service territory, EV penetration in this county was assumed to mirror that of Maui. By 2045, the baseline forecast projected the share LDV sales to be EVs: 40, 52, 59, and 59 percent for Hawai‘i, Honolulu, Kaua‘i, and Maui counties, respectively.

Total Energy Consumption

With the number of ICEVs, EVs, VMT per vehicle, and fuel efficiency, the amount of gasoline and electricity used to power the fleet of LDVs throughout the model time horizon was calculated as follows:

$Gasoline_{c,t} = \Sigma_v(VMTperLDV_{c,t} \times (NewVeh_{c,type,v,t} \div FE_{type,v}))$ for type = ICEV car and ICEV truck

$Electricity_{c,t} = \Sigma_v(VMTperLDV_{c,t} \times (NewVeh_{c,type,v,t} \div FE_{type,v}))$ for type = EV car and EV truck

where,

$FE_{type,v}$	= Fuel efficiency of vehicles by type (in miles for ICEVs and miles per kWh for EVs)
$Gasoline_{c,t}$	= Blended gasoline consumption (E10) in county *c* and year *t*
$Electricity_{c,t}$	= Electricity demand in county *c* and year *t*

LDV GHG Emissions

Lastly, tailpipe GHG tailpipe emissions for ICEVs were computed as the product of the fossil gasoline (E0) consumed and GHG emissions factor for fossil gasoline plus the product of ethanol (E100) consumed and GHG emissions factor for ethanol.[71] GHG emissions from ICEVs were given by:

$$EmissionsICEV_{c,t} = Gasoline_{c,t} \times (1 - shE) \times EF\_Gasoline + Gasoline_{c,t} \times shE \times EF\_Ethanol$$

where,

$EmissionsICEV_{c,t}$	= Emissions (MMT CO_2 Eq.) in county *c* and year *t*
$EF\_Gasoline$	= Emissions factor for gasoline (MT CO_2 Eq./gal of gasoline)
$EF\_Ethanol$	= Emissions factor for ethanol (MT CO_2 Eq./gal of ethanol)

Total statewide emissions from gasoline for each year are the sum of emissions over all counties. GHG emissions resulting from the consumption of electricity used by both EVs and future rail transit were accounted for through emissions from power generation.[72]

Heavy Duty Vehicles

The existing stock of diesel-powered vehicles were categorized as HDVs, including buses, other HDVs, and medium HDVs (MHDVs). Other HDVs included large trucks and cranes. MHDVs included all diesel-powered vehicles that were not HDVs. This breakout was used because of the large difference among these vehicle types in their characteristics, usage, and forecasts for electrification.

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[71] Consistent with standard emissions accounting practices, the CO_2 emission factor for ethanol is assumed to be zero. CH_4 and N_2O emissions from biofuels are included in the overall CO2-equivalent GHG emission factor.
[72] Assuming that rail transit takes 15 MW to operate the entire line (Honore 2019) and its current planned level of service will be fully operational by 2035.

As with the forecast of GHG emissions for gasoline powered LDVs, the characteristics of HDVs into the future were identified using a fleet turnover model where 2019 diesel fuel consumption was used for data calibration. FHWA (2022) data were used to disaggregate the country totals into these vehicle types. To forecast future emissions from HDVs, the properties of the 2019 stock of HDVs needed to be defined, specifically, the three fleet's VMT, fuel use, and average fuel efficiency.

For buses, fuel use equaled the product of the number of buses, annual mileage per bus, and average fuel economy of buses. The FHWA provided data on the number of buses by county; DBEDT (2021) provided data on the annual mileage of buses on O'ahu, which was assumed to hold for the other counties; and the average fuel efficiency for the fleet of buses was taken to be 7.3 mpg (EPA 2016a). Thus, total fuel use for buses by county was given by the following:

$$HDV\_Fuel_{c,bus,2019} = HDV\_VMT_{c,bus,2019} / FE_{c,bus,2019}$$

where,

$HDV\_Fuel_{c,bus,2019}$	= Fuel consumed by buses in county in 2019 (millions of gallons of B5 diesel)
$HDV\_VMT_{c,bus,2019}$	= VMT for buses in county in 2019 (millions of miles)
$FE_{c,bus,2019}$	= Average fuel efficiency for buses in county in 2019 (mpg)

For MHDVs, fuel consumption was computed in a similar manner to buses. The number of these vehicles in the state is 17,900 (AFDC 2019). The number per county was assumed to equal the product of the state total and the county's share of all LDV vehicles. The annual mileage for these vehicles was given by FHWA, and the average fuel economy of these vehicles was taken to be 17.6 (FHWA 2022). Thus, total fuel use for these vehicles by county was given by the following:

$$HDV\_Fuel_{c,MHDV,2019} = HDV\_VMT_{c,MHDV,2019} / FE_{c,MHDV,2019}$$

where,

$HDV\_Fuel_{c,MHDV,2019}$	= Fuel consumed by MHDVs in county in 2019 (millions of gallons of B5 diesel)
$HDV\_VMT_{c,nHDV,2019}$	= VMT for MHDVs in county in 2019 (millions of miles)
$FE_{c,nHDV,2019}$	= Average fuel efficiency for MHDVs in county in 2019 (mpg)

Fuel consumption for all other diesel-powered vehicles (other HDVs) was then taken to be the remainder of diesel fuel used in ground transportation. That is, diesel fuel consumed by other HDVs equaled the total diesel used in ground transportation less the diesel used for buses and MHDVs. The VMT for other HDVs was set equal to the total fuel use times the average fuel efficiency of other HDVs. The average fuel efficiency was taken to be 6.0 mpg (FHWA 2022; based on the fuel economy for combination trucks).

$$HDV\_VMT_{c,HDV,2019} = HDV\_Fuel_{c,HDV,2019} \times FE_{c,HDV,2019}$$

where,

$HDV\_Fuel_{c,HDV,2019}$	= Fuel consumed by other HDVs (millions of gallons of B5 diesel) in county *c* in the year 2019
$HDV\_VMT_{c,HDV,2019}$	= VMT for other HDVs (millions of miles) in county *c* in the year 2019
$FE_{c,HDV,2019}$	= Average fuel efficiency for other HDVs (mpg) in county *c* in the year 2019

It was assumed that diesel used in ground transportation was comprised of five percent biodiesel and 95 percent petroleum diesel. Therefore, gallons of fossil diesel and biodiesel consumed equaled 95 and five percent of total diesel, respectively. Thus, GHG emissions from each vehicle type equaled 95 percent of the product of the amount of diesel consumed by each vehicle type and the emissions factor for fossil diesel plus 5 percent of the product of the amount of diesel consumed by each vehicle and emissions factor for biodiesel.[73]

To estimate future GHG emissions from HDVs, the 2019 calibration year was projected into the future based on the assumptions about the following additional elements:

- Forecasted VMT by type of vehicle.
- Change in fleet average fuel efficiency.
- The rate of electrification.

Specifically, future GHG emissions for each diesel vehicle type equaled the product of the diesel consumed by each vehicle type and the emissions factor for diesel. The level of diesel consumption was found by dividing VMT from diesel powered vehicles by the average fuel efficiency of these vehicles. Emissions associated with future electric buses, HDVs, and MHDVs were found in a similar manner where the average fuel efficiency was measured in miles per kWh and emissions factor depended on the generation mix in the county of interest.

VMT Forecast for HDVs

Unlike LDVs, where VMT was projected based on the historic relationship to de facto population, county level VMT from all types of diesel powered vehicles were assumed to grow at the rate of GCP.

$$HDV\_VMT_{c,tpe,t} = HDV\_VMT_{c,type,2019} \times GCP_{c,t}/GCP_{c,2019}$$

where,

$HDV\_VMT_{c,type,t}$	= Total VMT by HDVs by type and county in year t (millions of miles)
$HDV\_VMT_{c,type,2019}$	= Total VMT by HDVs by type and county in 2019 (millions of miles)
$GCP_{c,t}$	= Forecast for real gross county product in year t
$GCP_{c,2019}$	= Gross county product in 2019

[73] Consistent with standard emissions accounting practices, the CO_2 emission factor for ethanol is assumed to be zero. CH_4 and N_2O emissions from biofuels are included in the overall CO2-equivalent GHG emission factor.

$type$ = Bus, HDV, MHDV

The VMT for each vehicle type was divided into travel by diesel powered (ICEV) and electric powered (EV) vehicles. For buses, the share of VMT by electric vehicles was based on each county's projections for purchases of new buses that are electric. Based on a Federal grant, Hawai'i's and Maui's counties are planning to entirely electrify their bus fleets by 2035 (Maui Now 2022). Honolulu's was based on the City and County's Zero-Emission Fleet Transition Plan, which forecasted all buses to be electric by 2040 (City & County of Honolulu 2022). For Kaua'i, the transition to electric buses was based on personal communication (email) with the county's department of transportation services, which stated that they expect all buses to be electric by 2035.

For MHDVs, given this is a much slower vehicle class to transition to EVs, the share of new vehicle sales that are EVs was taken to equal the low penetration forecast for LDVs (see scenario 3B). Similarly, because of the challenges associated with electrifying large HDVs, the penetration of these vehicles was assumed to be even slower than the other categories of diesel vehicles. Electric HDVs are assumed to first appear in 2025 with one percent of new sales being electric and increasing by 0.5 percent per year through 2045.

VMT by diesel powered and electric vehicles was given by the following:

$$HDV\_ICE\_VMT_{c,type,t} = HDV\_VMT_{c,type,t} \times (1 - EV\_Share_{c,type,t})$$

$$HDV\_EV\_VMT_{c,type,t} = HDV\_VMT_{c,type,t} \times EV\_Share_{c,type,t}$$

where,

$HDV\_ICE\_VMT_{c,type,t}$ = HDV ICE VMT (millions of miles) by county *c* and *type* in year *t*

$HDV\_EV\_VMT_{c,type,t}$ = HDV EV VMT (millions of miles) by county *c* and *type* in year *t*

$EV\_Share_{c,type,t}$ = Share of travel by EVs (percent) by county *c* and *type* in year *t*

Fuel Efficiency and Fuel Consumption

The fleet average fuel efficiency of each type of ICEV HDV was based on the harmonic average fuel efficiency of the prior year's fleet and the fuel efficiency of new vehicles.

$$FE\_HDV\_ICEfleet_{c,type,t} = 1 \Big/ \left(\frac{1 - ShrVMT\_HDV\_ICEnew_{c,type,t}}{FE\_HDV\_ICEfleet_{c,type,t-1}} + \frac{ShrVMT\_HDV\_ICEnew_{c,type,t}}{FE\_HDV\_ICEnew_{c,type,t}} \right)$$

where,

$FE\_HDV\_ICEfleet_{c,type,t}$ = Fleet average HDV ICE fuel efficiency (mpg) by county *c* and *type* in year *t*

$ShrVMT\_HDV\_ICEnew_{c,type,t}$ = Share (percent) of miles driven by new ICE HDVs by county *c* and *type* in year *t*

$FE\_HDV\_ICEnew_{c,type,t}$ = Average fuel efficiency for new ICE HDVs (mpg) by county *c* and *type* in year *t*

A similar calculation was made for each type of fleet of HDVs that are EVs.

$$FE\_HDV\_EVfleet_{c,type,t} = 1 \Big/ \left(\frac{1 - ShrVMT\_HDV\_EVnew_{c,type,t}}{FE\_HDV\_EVfleet_{c,type,t-1}} + \frac{ShrVMT\_HDV\_EVnew_{c,type,t}}{FE\_HDV\_EVnew_{c,type,t}} \right)$$

where,

$FE\_HDV\_EVfleet_{c,type,t}$	= Fleet average EV fuel efficiency (mpg) by county *c* and *type* in year *t*
$ShrVMT\_HDV\_EVnew_{c,type,t}$	= Share (percent) of miles driven by new EV HDVs by county *c* and *type* in year *t*
$FE\_HDV\_EVnew_{c,type,t}$	= Average fuel efficiency (mpg) for new EV HDVs by county *c* and *type* in year *t*

The fuel efficiency for each fleet was solved recursively starting with the year 2020, so for each year the fuel economy for new vehicles and the share of the fleet that was comprised of new vehicles need to be determined. The improvement in fuel efficiency for buses over time was assumed to follow the EPA's Phase II standards (EPA 2016a), which imply about 10 percent improvement over 2016 efficiencies by 2025 or 8.9 mpg. From 2026 onward, fuel efficiency was forecasted to improve by the same absolute annual mpg fuel efficiency improvement from 2024 to 2025 of 0.15 mpg. The fuel efficiency of new types of other diesel (internal combustion) engines was assumed to increase over time in proportion with the increase in EPA's fuel efficiency standards for HDVs (EPA 2016a). Averaging across the different engine classes for HDVs yielded an average increase in fuel efficiency from 2016 to 2025 of about 11 percent, or 1.2 percent per year. This rate of annual improvement in fuel efficiency was assumed to persist through 2045. The rates of improvement in EV bus and EV HDV fuel efficiency followed the same rate of improvement as their ICEV counterparts. The fuel efficiency of new electric 2021 buses and new 2021 HDVs was assumed to be 3 times that of their diesel counterparts on a diesel gallon equivalent.[74]

The fuel efficiency for new ICEV MHDVs was assumed to match the EPA CAFE standards combined for cars and trucks through 2029. Fuel efficiency for ICEVs was assumed to remain constant after 2029 because of the increased penetration of electric vehicles, which eases compliance with the CAFE standards. The efficiency for the electric MHDVs was assumed to follow that of the LDVs.

As for the share of miles traveled by new vehicles, this analysis assumed that approximately nine percent of VMT for HDVs and MHDVs was undertaken by new vehicles of the respective type each year. This figure was derived from estimates of HDV VMT by model year as obtained from the U.S. Inventory (EPA 2022a).[75] For bus fleets, the model assumed four percent of travel by diesel powered buses was conducted by new buses. Note that the overall share of VMT by new buses was larger because more of the new buses were expected to be electric.

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[74] The ratio of three was taken from the GREET model's ratio of fuel efficiency of electric buses to that of diesel buses (2020).

[75] The share of miles driven by new vehicles was estimated based on new vehicle data for 2007 because 2007 is believed to be a representative year in terms of typical vehicle sales.

The share of travel by electric vehicles that was made by new HDV EVs was represented by the following equation:

$$HDV\_New\_EV\_VMT_{c,tpe,t0} = Shr\_VMT\_EV_{c,type,t0} \times HDV\_VMT_{c,type,t0}$$

$$HDV\_EV\_VMT_{c,tpe,t} = Shr\_VMT\_EV_{c,type,t} \times HDV\_VMT_{c,type,t}$$

$$HDV\_New\_EV\_VMT_{c,tpe,t} = HDV\_VMT\_EV_{c,type,t} - Sum(tt, HDV\_New\_EV\_VMT_{c,type,tt})$$

where,

$HDV\_New\_EV\_VMT_{c,tpe,t}$ = VMT covered by new EVs sold in county *c* and *type* in year *t*

$HDV\_EV\_VMT_{c,tpe,t}$ = Total VMT covered by EVs sold through year *t* by *type* and in county *c*

t0 = First year EVs appear in the fleet for the *type* (buses, other HDVs, and MHDVs) in county *c*

tt = *t0, … ,t-1*

The share of travel by new HDV EVs for a given *type* and county in year *t* is the ratio of the travel conducted by new EVs sold to the total travel conducted by EVs.

Knowing the VMT for each type of vehicle and its fleet average fuel efficiency, the fuel consumption by each type of HDV was computed as the ratio of VMT to fuel efficiency. The first equation computed the amount of diesel consumed, and the second equation computed the amount of electricity consumed:

$$Diesel_{c,type,t} = {HDV\_ICE\_VMT_{c,type,t}}\Big/{FE\_HDV\_ICEfleet_{c,type,t}}$$

where,

$Diesel_{c,type,t}$ = Consumption of B5 (gallons), which contains 95 percent fossil and five percent bio diesel, in county *c* by *type* and in year *t*

$$Electricity\_HDV_{c,type,t} = {HDV\_EV\_VMT_{c,type,t}}\Big/{FE\_HDV\_EleFleet_{c,type,t}}$$

where,

$Electricity\_HDV_{c,type,t}$= Electricity consumption (GWh) in county *c* by *type* and in year *t*

HDV GHG Emissions

Lastly, tailpipe GHG emissions for diesel powered vehicles were computed as the product of the fossil diesel consumed and GHG emissions factor for fossil diesel. Total statewide emissions for each year were the sum of emissions over all counties. It was assumed that the share of biodiesel in the diesel pool remained constant at 2019 levels of five percent over time.

$$HDV\_ICE\_Emissions_{c,type,t} = ((1 - ShrBiodiesel(t)) \times Diesel_{c,type,t} \times EF\_fDiesel) + (ShrBiodiesel(t) \times Diesel_{c,type,t} \times EF\_bDiesel)$$

where,

$HDV\_ICE\_Emissions_{c,type,t}$	= Emissions (MM MT CO_2 Eq.) from diesel HDVs in county *c* by *type* and in year *t*
$ShrBiodiesel_t$	= Share of biodiesel in the diesel pool (five percent)
$EF\_fDiesel$	= Emissions factor for fossil diesel (MT CO_2 Eq./gallon)
$EF\_bDiesel$	= Emissions factor for biodiesel (MT CO_2 Eq./gallon)

Total statewide emissions from transportation diesel for each year were the sum of emissions over all counties and vehicle types. GHG emissions resulting from the consumption of electricity used by HDV EVs were accounted for through emissions from power generation.

Motorcycles

Annual county level GHG emissions from motorcycles were calculated based on the average fuel efficiency of motorcycles and the total county level annual VMT for motorcycles. As with the forecast of GHG emissions for other ground transportation, 2019 was used for data calibration. Historic data for county level gasoline consumption and emissions associated with motorcycles were based on county level data on the number of motorcycles (DBEDT 2021), VMT per motorcycle (FHWA 2022), and the average fuel efficiency of motorcycles (FHWA 2022).

$$Mot\_VMT_{c,2019} = VMTperMot_{c,2019} \times NMot_{c,2019}$$

where,

$Mot\_VMT_{c,2019}$	= Motorcycle VMT in county *c* in the year 2019
$VMTperMot_{c,2019}$	= Average VMT per motorcycle in county *c* in the year 2019
$NMot_{c,2019}$	= Number of motorcycles in county *c* in the year 2019

Total VMT for motorcycles was assumed to grow at the same rate as total VMT for LDVs.

$$Mot\_VMT_{c.t} = VMT\_Growth\_Index_{c,t} \times VMT\_Mot_{c,2019}$$

where,

$Mot\_VMT_{c.t}$	= Motorcycle VMT in county *c* and year *t*
$VMT\_Growth\_Index_{c,t}$	= Growth rate of VMT, based on LDV VMT, in county *c* and year *t*
$VMT\_Mot_{c,t}$	= Motorcycle VMT in county *c* and the year 2019

Motorcycle gasoline consumption was calculated by dividing total VMT for motorcycles by their average annual fuel efficiency, which was assumed to be 44 mpg (FHWA 2022) (and assumed to remain constant over time).

$$Mot\_Gasoline_{c.t} = Mot\_FE \times VMT\_Mot_{c,t}$$

where,

$Mot\_Gasolinec_{c,t}$	= Motorcycle gasoline consumption (gallons) in county *c* and year *t*

Mot_FE = Fuel efficiency for motorcycles (mpg)

$VMT\_Mot_{c,t}$ = Motorcycle VMT in county *c* and year *t*

GHG emissions from motorcycles were then calculated by multiplying gasoline consumption by the GHG emissions factor for gasoline. As with gasoline consumed by LDVs, this analysis assumed that gasoline consumed was E10, which contains 10 percent ethanol by volume.

$$Mot\_Emissions_{c.t} = EF\_Gasoline \times (1 - shE) \times Mot\_Gasoline_{c.t}$$

where,

$Motorcycle\_Emissions_{c,t}$ = GHG emissions (MM MT CO_2 Eq.) from motorcycles in county *c* and year *t*

Statewide GHG emissions from motorcycles were aggregated from county emissions for each year.

Domestic Aviation

GHG emissions from domestic aviation include emissions from passenger and cargo travel between Hawaiʻi and other domestic locations (including within Hawaiʻi). Passenger travel represents both residents and visitors. The inventory convention for attributing air travel emissions is to assign half the emissions to the location of the flight's origin and the other half to the flight's destination.

To forecast emissions for domestic aviation, the characteristics in these three categories – visitors, residents, and cargo traveling to and from domestic locations needed to be calibrated. Total jet fuel consumption by county in 2019 was broken into these three categories based on data for visitor arrivals and cargo shipments. First, all air travel was disaggregated into passenger overseas travel, passenger interisland travel, and cargo. This followed the methods presented in the City & County of Honolulu Climate Action Plan, Technical Appendix, for domestic aviation (City & County of Honolulu 2021).

In brief, air travel was split between that used to move passengers and cargo based on a share parameter from data on the number of passengers and tons of cargo, where tons of cargo were converted to passengers based on the assumed constraints of a Boeing 767. Overseas and interisland travel were combined in such a way that accounts for the difference in energy used for the two different types of trips. To do so, it was then assumed that an overseas trip required five times the amount of energy than an interisland trip (see City & County of Honolulu 2021). Next, passenger travel was further disaggregated into visitor overseas travel, visitor within Hawaiʻi travel, and residential travel. The share of overseas visitor travel was estimated based on the ratio of visitor arrivals to Hawaiʻi to total arrivals to Hawaiʻi, at 86 percent (City & County of Honolulu 2021). Interisland travel was assumed to be split evenly between visitors and residents.

Visitor and residential travel, as well as cargo were further disaggregated into international and domestic sources. Based on City & County of Honolulu (2021), two-thirds of visitor travel were found to come from the US. The share of air cargo traveling between Hawaiʻi and US destinations was taken to equal the ration of domestic jet fuel consumption to the sum of domestic jet fuel and international bunker jet fuel consumption.

Last, these categories were combined to make the following categories that accounted for all domestic aviation:

- Domestic visitor travel = Overseas visitor travel from domestic locations + Interisland visitor travel
- Domestic Residential travel = Overseas residential travel from domestic locations + Interisland residential travel
- Cargo = Cargo flown between domestic locations + Interisland cargo shipments

Since residential travel and cargo were assumed to increase with each county's GCP, domestic air travel was divided into visitor air travel and everything else. Thus, the share of travel by visitors was given by the following:

$$VisShr = DomVisTravel_{2019} / (DomVisTravel_{2019} + DomCargo_{2019} + ResTravel_{2019})$$

where,

$DomVisTravel_{2019}$ = Total 2019 travel by visitors between Hawaiʻi and domestic locations (including Hawaiʻi) (miles)

$DomCargo_{2019}$ = Total 2019 travel by cargo between Hawaiʻi and domestic locations (including Hawaiʻi) (miles)

$DomResTravel_{2019}$ = Total 2019 travel by residents between Hawaiʻi and domestic locations (including Hawaiʻi) (miles)

With the base year, 2019, value for jet fuel consumed in domestic activities by county and the share of jet fuel due to visitors, the model then forecasted the jet fuel consumed by visitors and all other domestic sources. To forecast jet fuel consumption due to visitor travel, the value of county level emissions from jet fuel was used as a starting point. The base year value was then multiplied by the growth index in visitor travel and the share of 2019 jet fuel due to visitor travel. This product was then multiplied by an efficiency index for air travel to account for the increase in efficiency of air travel over time.[76] The growth in domestic visitor travel was based on DBEDT's short- and long-range county level forecasts for visitor arrivals.

$$JetFuel\_Visitors_{c,t} = VisNdx_{c,t} \times Eff_t \times VisShr \times JetFuel_{c,2019}$$

where,

$JetFuel\_Visitors_{c,t}$ = Jet fuel consumed by visitors traveling between domestic locations and county, c, in year t (gallons)

$VisNdx_{c,t}$ = Visitor index for county, c, in year t (2019 = 1)

Eff_t = Efficiency index for air travel in year t (2019 = 1)

The growth in resident travel and cargo was based on DBEDT's short- and long-range county level forecasts for GCP.

$$JetFuel\_Cargo\&Res_{c,t} = GCPNdx_{c,t} \times Eff_t \times (1 - VisShr) \times JetFuel_{c,2019}$$

[76] Efficiency index was based on EIA's AEO 2022 air travel efficiency metric.

where,

$JetFuel\_Cargo\&Res_{c,t}$ = Jet fuel consumed by residents and cargo traveling between domestic locations and county, c, in year t (gallons)

$GCPNdx_{c,t}$ = Gross product index for county, c, in year t (2019 = 1)

Emissions from domestic aviation were then calculated by multiplying total jet fuel consumption by ICF's emission factors.

$$DomAir\_Emissions_{c.t} = EF\_JetFuel \times (JetFuel_{Visitors_{c,t}} + JetFuel\_Cargo\&Res_{c,t})$$

where,

$DomAir\_Emissions_{c,t}$ = County level emissions from domestic air in year t (MM MT CO_2 Eq.)

$EF\_JetFuel$ = Emission's factor for jet fuel (MT CO_2 Eq./gallon)

Domestic Marine, Military Aviation, and Military Non-Aviation

Emission projections were not developed for domestic marine or military. Instead, future emissions were assumed to remain constant relative to 2019. For the domestic marine category, emissions were not projected due to inconsistencies in the historical emissions trends. Emissions from military operations were also not projected because decisions regarding the magnitude of activities are generally external to Hawai'i's economy. Therefore, growing emissions based on gross state product or other Hawai'i specific economic indicators was determined to be inappropriate. Further discussion of data uncertainties for these sources is provided in the section below.

Alternate Scenario 1A and 1B

To understand the potential effect of oil prices on Hawai'i's future emissions from the transportation sector, *high* (Alternate Scenario 1A) and *low* (Alternate Scenario 1B) future oil price pathway based on the EIA's Annual Energy Outlook (AEO) 2022 for gasoline, diesel and jet fuel were assessed.

Ground Transportation

Light Duty Vehicles

To estimate the impact of a price change on LDV fossil fuel demand, the percent change in gasoline price between each oil price scenario and the baseline case was multiplied by the price elasticity of demand for gasoline. This analysis assumed that the elasticity started at -0.24 in 2022 and linearly increased in magnitude to -0.47 in the long run in 2035 (Hössinger et al. 2017). The change in demand for LDV gasoline for each scenario was then calculated based on the following equation:

$$\%\Delta LDV_{t,c,s} = \sigma_t \times \%\Delta GP_{t,s}$$

where,

$\%\Delta LDV_{t,c,s}$ = The percent change in LDV gasoline demand in county *c* and year *t* and under scenario *s*

σ_t = The price elasticity of LDV gasoline demand in year *t*

$\%\Delta GP_{t,s}$ = The percent change in gasoline price in year *t* under scenario *s*

As a last step, the percent change in gasoline demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions accordingly.

Heavy Duty Vehicles

To estimate the sensitivity of HDV fuel demand to changing diesel prices, the same technique as that for LDVs was used. The percent change in diesel price between each oil price scenario and the baseline case was multiplied by the price elasticity of demand for diesel. Based on recent literature, this analysis assumed that the elasticity started at -0.07 in 2022 and linearly increased in magnitude to -0.27 in the long-run in 2035 (Dahl 2012; Washington Department of Commerce 2015). The change in demand for HDV diesel for each scenario was then calculated based on the following equation:

$$\%\Delta HDV_{t,c,s} = \sigma_t \times \%\Delta DP_{t,s}$$

where,

$\%\Delta HDV_{t,c,s}$	= The percent change in HDV diesel demand in county *c* and year *t* and under scenario *s*
σ_t	= The price elasticity of HDV diesel demand in year *t*
$\%\Delta DP_{t,s}$	= The percent change in diesel price in year *t* under scenario *s*

As a last step, the percent change in diesel demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions accordingly.

Domestic Aviation

To estimate the sensitivity of aviation fuel demand to changing fuel prices, the same methodology used to calculate the sensitivity of LDV and HDV fuel demand to changing fuel prices was applied to jet fuel. The percent change in the jet fuel price between each oil price scenario and the baseline case was multiplied by the price elasticity of demand for jet fuel for domestic aviation. Based on recent literature, this analysis assumed that the elasticity started at -0.19 in 2022 and linearly increased in magnitude to -0.24 in the long run in 2035 (Fukui 2017; Sobieralski 2012). The change in demand for HDV diesel for each scenario was then calculated based on the following equation:

$$\%Air_{t,c,s} = \sigma_t \times \%\Delta JFP_{t,s}$$

where,

$\%\Delta Air_{t,c,s}$	= The percent change in jet fuel demand in county *c* and year *t* under scenario *s*
σ_t	= The price elasticity of jet fuel demand in year *t*
$\%\Delta JFP_{t,s}$	= The percent change in jet fuel price in year *t* under scenario *s*

As a last step, the percent change in aviation fuel demand under each alternate scenario was multiplied by emissions estimated under the baseline scenario and then added to the baseline emission estimates to adjust emissions accordingly.

Alternate Scenario 3A and 3B

In addition to the uncertainties around oil prices caused by global events and macroeconomic forces, there is great uncertainty over the future penetration of EV. To quantify these uncertainties, alternate scenario 3A and 3B accounted for potential variations in the sale of EVs. Alternate Scenarios 3A and 3B assumed higher and lower sales of EVs, respectively, than the baseline scenario.

For Alternate Scenario 3A, the share of LDV sales that are EVs were assumed to match that of the California Air Resources Board's Advanced Clean Cars II (CARB 2022). This rule calls for all new sales of LDVs in California to be EVs from 2035 onward. Though Hawaiʻi does not have the same waiver to federal CAFE as does California, this scenario was nonetheless selected to illustrate GHG reduction potential from such an approach.

For Alternate Scenario 3B, the share of new LDV sales that are EVs were based on the growth rate of the EIA AEO (2022b) "Reference" scenario for national EV adoption. Since the EIA's forecast starts at a sales share below that of Hawaiʻi's, the ratio of Hawaiʻi's to EIA's EV sales share in 2021 was applied to the EIA forecast for all future years, leading to the low EV sales forecast for Hawaiʻi being about twice as great at the EIA's reference scenario.

County-level Projections

Projected statewide ground transportation and domestic aviation emissions were built from the bottom-up by first developing forecasts for the four counties. The starting emissions for each country are taken from ICF's county level inventories for 2019 emissions. Projected statewide emissions from domestic marine, military aviation, and military non-aviation transportation were allocated solely to Honolulu County, consistent with the 2019 inventory.

Uncertainties and Areas for Improvement

As highlighted by the alternate scenarios described above, there is uncertainty associated with fossil fuel prices and EV adoption. There is also uncertainty from other economic forces, changes in VMT, and biofuel usage. Though this study accounted for LDV VMT reduction from the Honolulu Rail Project, there is uncertainty in future ridership estimates and thus potentially offset LDV VMT.

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 2019, which did not align with the activities of the overall economy. For the military, the data similarly showed large year-to-year variability. Decisions regarding future military operations in Hawaiʻi are largely external to Hawaiʻi's economy.

Incineration of Waste

Methodology

Emissions from incineration of waste represent the waste-to-power plant operating on Oʻahu. Emissions from this facility for 2020 were taken from the EPA GHG FLIGHT data (EPA 2022h). Emissions for future years were assumed to grow based on the percentage change in generation from the PSIP (PUC 2016).

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 Hawaiʻi, is located on the island of Oʻahu.

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 East petroleum refinery were projected forward from 2019 based on projected growth in aviation emissions (see the transportation section above for details on the method used to project aviation emissions).[77] Fugitive emissions from gas distribution and transmission pipelines were assumed to remain constant relative to 2019 emissions.

County-level Projections

Projected statewide emissions from oil and natural gas systems were allocated to Honolulu County because Par East, the only operational refinery in Hawaiʻi, is located on the island of Oʻahu.

Uncertainties and Areas for Improvement

During the COVID-19 pandemic Par East 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 to the planned decline in demand for fossil fuel products is an area of uncertainty. The methodology used to project emissions from oil and natural gas systems was based on the assumption that at least one oil refinery will remain in operation. 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 were 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 2019 remains constant through 2045.

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[77] In 2018, Par Hawaiʻi Inc. acquired Island Energy Services, LLC., which had recently ceased refinery operations and converted to an import terminal (Mai 2018).

Uncertainties and Areas for Improvement

The methodology used to project emissions from non-energy uses was based on the observation that emissions from this sector correlate with economic activity. This analysis did not account for policies or programs that could impact fuel consumption for non-energy uses.

IPPU

Cement Production

Methodology

Consistent with the 2019 inventory, emissions from cement production in Hawaiʻi were projected to be zero through 2045.

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 2019 based on the electricity sales forecast for 2019-2045 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 7-6 show that emissions from this source remain constant across the time series even though they are projected to increase slightly.

County-level Projections

Projected county-level emissions from electrical transmission and distribution were calculated using the methodology described in section 4.2, Electrical Transmission and Distribution.

Uncertainties and Areas for Improvement

The methodology used to project electrical transmission and distribution emissions was based on the historical trend of emissions from this source being 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 (ODS) were assumed to depend on the implementation of the American Innovation and Manufacturing Act (AIM Act), the rate of turnover of existing air conditioning systems, and the share of new air conditioning systems that use hydrofluorocarbons (HFCs) and other ODS substitutes. The AIM Act directs the EPA to phase down production and consumption of HFCs in the US by 85 percent over the next 15 years. Specifically, related to our projection years, the effective targets were to achieve a reduction in production and consumption of HFCs by 40 percent by 2025, 70 percent by 2030, 80 percent by 2035, and 85 percent by 2040 and 2045 (EPA 2022f).

There were four steps to compute the emissions from ODS substitutes. First, the expected emissions from ODS substitutes, assuming that there is no policy in place to eliminate HFCs or other ODS substitute chemicals, is determined based on growing county level 2019 emissions by each county's GCP, accounting for the change in energy consumption intensity for the commercial sector (EIA 2022b).[78] This was given by the following equation:

$$TtlUnregE_{c,t} = TtlUnregE_{c,2019} \times GSPIndex_{c,t} \times Eff_t$$

where,

$TtlUnregE_{c,t}$	= Estimated ODS substitute emissions if unregulated in county *c* and year *t*
$TtlUnregE_{c,t}$	= ODS substitute emissions in county *c* and in the year 2019
$GSPIndex_{c,t}$	= Forecast for Gross State Product in county *c* and year *t*
Eff_t	= Energy efficiency improvements in year *t*

Estimated unregulated emissions were then shared between existing units (i.e., appliances and air conditioning systems) and the vintages of new units. Emissions from the latest vintage were computed by taking the difference between the estimated unregulated emissions and the sum of emissions from prior vintages:

$$NewODSE_{c,t} = TtlUnregE_{c,t} - \Sigma_v UnregVintageE_{v,c,t}$$

where,

$NewODSE_{c,t}$	= New emissions from ODS substitutes in county *c* and year *t*
$UnregVintageE_{v,c,t}$	= Emissions from prior vintages *v* in county *c* and year *t*

To reflect the retirement of each vintage, it was assumed that the emissions of pre-2024 vintages decayed by 1/15 and emissions from post-2023 sources decayed at a rate of five percent (based on the typical life of an air conditioning system) (DOE 2022). So, the equation above was solved recursively for emissions from new sources for a given year after computing the emissions from all prior year vintages as shown below:

$$UnregVintageE_{v,c,t} = \frac{14}{15} \times UnregVintageE_{v,c,t-1} \text{ , for } t<2024$$

$$UnregVintageE_{v,c,t} = 0.95 \times UnregVintageE_{v,c,t-1} \text{ , for } t>2023$$

[78] Commercial sector energy consumption intensity in thousand Btus per square foot.

Last, to find the emissions under the AIM Act (i.e., regulated emissions), the AIM Act's reduction schedule was applied to the values for unregulated emissions for each county:

$$ODSE_{c,t} = \Sigma_v UnregVintageE_{v,c,t} \times (1 - AIM_{t-v})$$

where,

$ODSE_{c,t}$	= Emissions from ODS substitutes in county *c* and year *t*
AIM_{t-v}	= AIM Act targets applied to new vintages

Statewide emissions from ODS substitutes were determined based on aggregating county level emissions.

County-level Projections

Projected statewide emissions from the substitution of ozone depleting substances were calculated using the methodology described in section 4.3, Substitution of Ozone Depleting Substances.

Uncertainties and Areas for Improvement

This analysis considered the implementation of the AIM Act; however, the level to which sources of GHG emissions from ODS substitutes will be reduced also depends on the continued use of existing appliances and air conditioning systems. There is uncertainty in the usable life of these goods, as well as any future policy that might speed up their retirement.

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 2019 emissions. Animal population data were projected based on the trends in data, as obtained from the U.S. Inventory (EPA 2022a), the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) (USDA 2020b), and the USDA Census of Agriculture (USDA 2009, 2014, and 2019). Animal population baselines varied to accurately capture historic trends by animal type. Swine population projections used a twenty-year baseline to capture the decline in swine husbandry. Alternatively, dairy cattle projections were based on five years of historic data to accurately capture the recent decline. Within beef cattle, steers and bulls were using different baselines years, twenty year and five-year baselines, respectively. This methodology was chosen to capture the significant drop in steer stockers between 1990 and 2005. Where necessary, animal population trends were set with a minimum value to ensure that projections remain greater than or equal to zero.

Annually variable enteric fermentation emission factors were projected using the ten-year average by cattle type from the U.S. Inventory (EPA 2022a). Emission factors for sheep, goats, horses, and swine, which come from IPCC (2006), were 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 state-level population data from the US Inventory and historical county-level population data from USDA for each animal type (EPA 2022a; USDA 2019, 2020b). Projected county-level emissions from enteric fermentation were then calculated based on the county-level population data using the methodology described in section 5.1, Enteric Fermentation.

Uncertainties and Areas for Improvement

The methodology used to project emissions from enteric fermentation was 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, with the latest data available from the 2017 Census of Agriculture (USDA 2019). The 2022 Census of Agriculture is currently underway, and results are expected to be released in 2024. Because data is not available for every year in the time series, historical estimates for these animals were interpolated between years up to 2017, the most recent year of reported data. Further research into the accuracy and drivers of historical trends may be considered in future analyses.

Manure Management

Methodology

Emissions from manure management were projected by projecting activity data and emission factors, and applying the same methodology used to estimate 2019 emissions. Animal population data were projected using the same methodology as the enteric fermentation sector. 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 were assumed to remain constant relative to 2019 values (EPA 2022a). 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 2022a). 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 2022a), 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 state-level population data from the US Inventory and historical county-level population data from USDA for each animal type (EPA 2022a; USDA 2019, 2020b). Projected county-level emissions from manure management were then calculated based on the county-level population data using the methodology described section 5.2, Manure Management.

Uncertainties and Areas for Improvement

The methodology used to project emissions from manure management was 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 chickens are reported every five years in the USDA Census of Agriculture. As a result, historical estimates for these animals were 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 2019 emissions. Animal population data were projected using the same methodology as the enteric fermentation and manure management sectors.

Sugarcane crop area and production were projected to be zero starting in 2018 due to the closing of the last sugar mill in Hawaiʻi (Honolulu Magazine 2016, USDA 2020a). For other crops, crop area and production data were projected based on the twenty-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, 2020a).

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 2022a). Synthetic fertilizer consumption was projected based on the five-year historical trend from 2010 to 2014 (AAPFCO 1995 – 2019) while commercial organic fertilizer consumption was assumed to remain at zero. Crop residue factors from IPCC (2006) were also assumed to remain constant.

County-level Projections

County-level animal population and crop data were estimated by disaggregating statewide animal population and crop acreage projections based on the breakout of the most recently available state-level data from the US Inventory and historical county-level data from USDA for each animal and crop type (EPA 2022a; USDA 2019, 2020b). Projected county-level emissions from agricultural soil management were then calculated using the methodology described in section 5.3, Agricultural Soil Management.

Uncertainties and Areas for Improvement

The methodology used to project emissions from agricultural soil management was 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 were interpolated between years up to 2017, the latest year of reported data. Historical fertilizer consumption data were also extrapolated out to 2019 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 was projected to be zero starting in 2018 due to the closing of the last sugar mill in Hawaiʻi (Honolulu Magazine 2016, USDA 2020a). Historically, sugarcane was the only major crop in Hawaiʻi whose residues were regularly burned (Hudson 2008). As a result, no emissions from field burning of agricultural residues were projected in 2020, 2025, 2030, 2035, 2040, and 2045.

Uncertainties and Areas for Improvement

It is uncertain whether sugarcane production will return to Hawaiʻi 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 Hawaiʻi 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 2019 emissions. Fertilizer consumption data were projected based on the five-year historical trend (AAPFCO 1995 – 2019).

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 and 2020, as obtained from the Hawaiʻi DOA (2016 and 2022). Projected county-level emissions from urea application were then calculated using the methodology described in section 5.5, Urea Application.

Uncertainties and Areas for Improvement

The methodology used to project urea application was 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, specifically as crop acreage changes. 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 2019 emission estimates for grassland and cropland, respectively, to obtain 2020, 2025, 2030, 2035, 2040, and 2045 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 Hawaiʻi DOA (2016 and 2022) for the year 2015 and year 2020.

Uncertainties and Areas for Improvement

The methodology used to project emissions from agricultural soil carbon in grassland and cropland was based on USGS projections of emissions and area that are specific to Hawaiʻi 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 were also based on the assumption that emissions from grassland and cropland will decrease at constant rates annually from 2011 to 2061. This methodology did not consider inter-annual variability in emissions from grassland or cropland.

In addition, the methodology assumed 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 Hawaiʻi Greenhouse Gas Sequestration Task Force established by Act 15 of 2018 will work to identify practices in agriculture to improve soil health, which may also reduce future emissions from cropland. Further research into emission 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 2019 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 2019 estimates of forest and shrubland area from the State of Hawaiʻi Data Book to obtain 2020, 2025, 2030, 2035, 2040, and 2045 estimates (DBEDT 2021).

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 for 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 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 was based on USGS projections of area that are specific to Hawaiʻi 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 were 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 Hawaiʻi may be considered in future analyses.

Landfilled Yard Trimmings and Food Scraps

Methodology

Carbon sequestration in landfilled yard trimmings and food scraps were estimated by projecting activity data, emission factors, and other inputs, and applying the same methodology used to estimate 2019 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 2022c). Hawaiʻi and U.S. population estimates were projected based on five-year growth rates in Hawaiʻi's population from the State of Hawaiʻi Data Book (DBEDT 2021) 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 2022c) 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 2020b).

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in landfilled yard trimmings and food scraps was based on the assumption that the amount of landfilled yard trimmings and food scraps in Hawaiʻi will follow a trend consistent with the past. The methodology did 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 Hawaiʻi 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 2019 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 2019 estimate of urban area to project 2020, 2025, 2030, 2035, 2040, and 2045 estimates. The estimated carbon sequestration rates for urban trees and the percent tree cover in urban areas in Hawaiʻi were assumed to remain constant with 2019 estimates (Nowak et al. 2012; Nowak 2018a and 2018b; EPA 2022a).

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, as derived using the methodology described in section 5.9, Urban Trees. Projected county-level carbon sinks from urban trees were then calculated using the methodology described in section 5.9, Urban Trees.

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in urban trees was based on USGS projections of area that are specific to Hawaiʻi 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 were also based on the assumption that urban area and carbon sequestration will increase linearly over the projected time series. This methodology did not consider potential changes in the rate of urbanization over time. Similarly, the current methodology did not consider potential changes in urban density that would be assumed as urban expansion becomes limited. 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 Hawaiʻi Greenhouse Gas Sequestration Task Force established by Act 15 of 2018 will work to identify opportunities to increase urban tree cover. 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 2019 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 2019 estimates of forest and shrubland area by county from the State of Hawaiʻi Data Book to obtain 2020, 2025, 2030, 2035, 2040, and 2045 estimates (DBEDT 2021).

Average net C sequestration rates by forest type in Hawaiʻi 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 Hawaiʻi 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 Hawaiʻi 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 in section 5.10, Forest Carbon.

Uncertainties and Areas for Improvement

The methodology used to project carbon sequestration in forests and shrubland was based on USGS projections of area that are specific to Hawaiʻi 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 Hawaiʻi may be considered in future analyses.

The projections similarly assumed that carbon sequestration will increase linearly with forest and shrubland area. This methodology did 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 Hawaiʻi forest ecosystems, which can impact sequestration rates (Selmants et al. 2017). In addition, the Hawaiʻi Greenhouse Gas Sequestration Task Force established by Act 15 of 2018 will work to identify practices to increase forest carbon and promote sequestration, which may increase future sequestration rates in forests. Further research into the age of Hawaiʻi forests, improved forest management practices, and their emissions reduction potential may be considered in future analyses.

Waste

Landfills

Methodology

As a starting point, emissions from landfills in 2020 were taken from EPA GHG FLIGHT data (EPA 2022h) and then scaled to match reported landfill tonnage as described for waste in the 2019 inventory. Taking this as a jumping off point, emissions for 2025, 2030, 2035, 2040 and 2045 were projected based on extrapolating trends in historical emissions between 1990 and 2020 into future years for each county then summed to obtained state-wide landfill emissions.

County-level Projections

Projected county-level emissions from landfills were calculated using the methodology described in section 6.1, Landfills.

Uncertainties and Areas for Improvement

This analysis was based on historical emissions trends and therefore did not account for waste diversion policies or programs that could impact future waste generation. Because a substantial portion of waste on Oʻahu is already diverted to waste-to-power, this is more relevant for the counties of Maui, Hawaiʻi and Kauaʻi. This analysis also did not 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 Hawaiian Electric's PSIP or IGP.

Composting

Methodology

For each county, emissions from composting were 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 in section 6.2, Composting.

Uncertainties and Areas for Improvement

The methodology used to project emissions from composting was based on the assumption that per capita composting tonnage will remain constant through 2045. This analysis did 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 were assumed to grow at the rate of population (DBEDT 2018).[79] 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 in section 6.3, Wastewater Treatment.

Uncertainties and Areas for Improvement

The methodology used to project emissions from wastewater treatment was 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.

[79] 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.

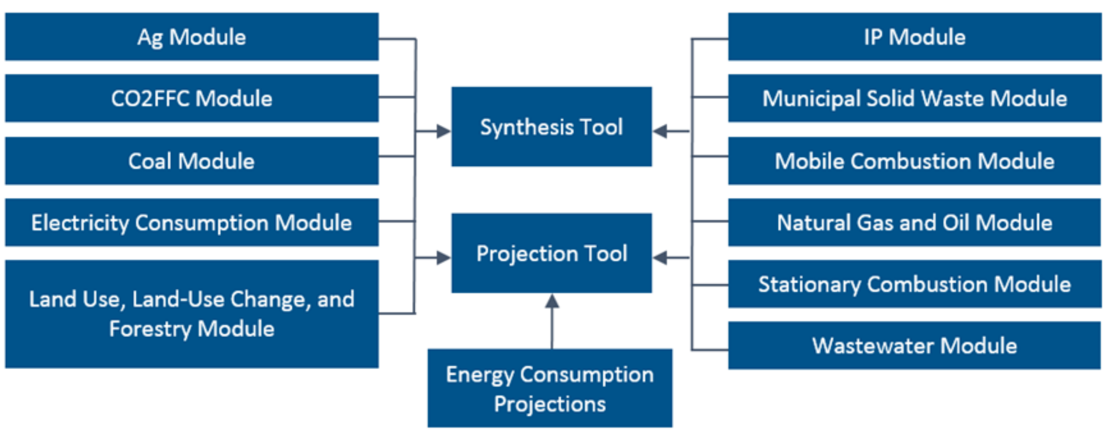
Appendix K. Comparison of Results with the State Inventory Tool and Projection Tool

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 Hawaiʻi, ICF ran the tool for Hawaiʻi using default values and compared the output against the 2019 inventory and inventory projections for 2020, 2025, 2030, and 2045, as developed by ICF and the

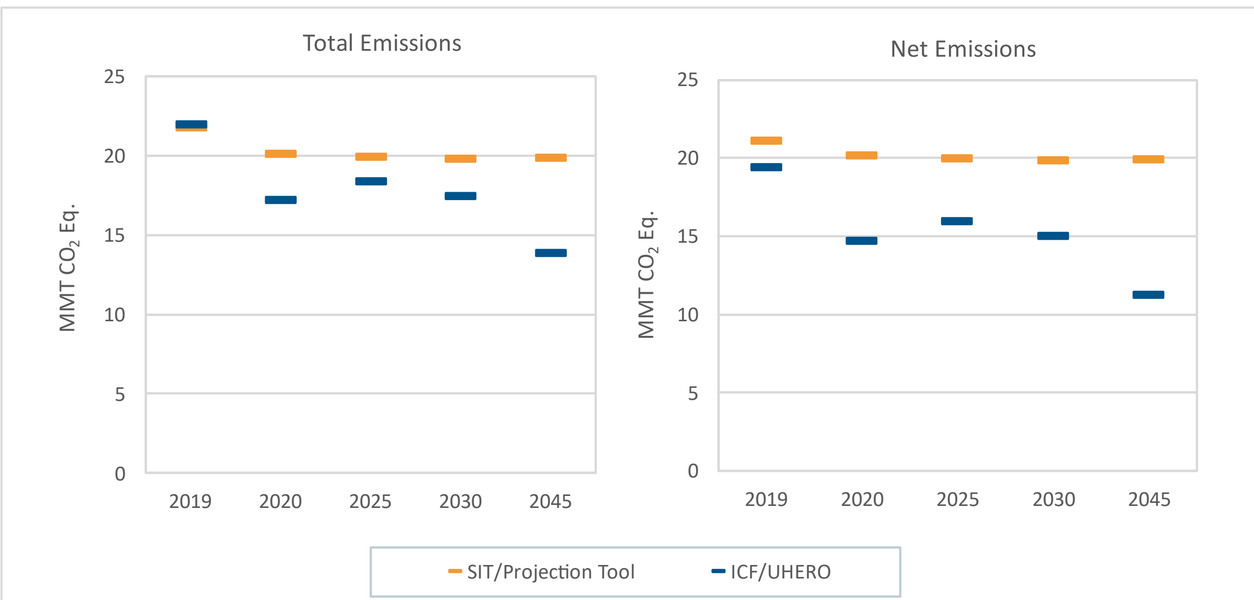
University of Hawaiʻi Economic Research Organization (UHERO).[80] This document presents the results of this comparison.

Key Observations and Conclusions

ICF's estimate of <u>total GHG emissions</u> for Hawaiʻi in 2019 is one percent greater than the SIT, while the difference in <u>net GHG emissions</u> is eight percent lower than the SIT.[81] The difference in net emissions is largely due to the lack of default forest carbon flux data available in the SIT.

Total GHG emissions for Hawaiʻi are 17 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, eight percent higher in 2025, 13 percent higher in 2030, and 43 percent higher in 2045. Net GHG emissions for Hawaiʻi are 37 percent higher in 2020 using the Projection Tool compared to ICF/UHERO's analysis, 25 percent higher in 2025, 32 percent higher in 2030, and 76 percent higher in 2045. 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 2019, 2020, 2025, 2030, and 2045 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 (2019, 2020, 2025, 2030, and 2045)



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[80] 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 October 2022.

[81] Net emissions take into account both emission sources and carbon sinks.

Key observations from using the SIT for 2019 GHG estimates include the following:

- Total GHG estimates from the SIT are 0.2 MMT CO_2 Eq. lower than ICF/UHERO. Net GHG estimates from the SIT are 1.64 MMT CO_2 Eq. greater than ICF/UHERO.
- ICF assessed contributions to differences in emissions using absolute values. While total emissions estimates from the SIT and ICF/UHERO are similar, the magnitude of the difference at the sector level varies. Higher emission estimates for the SIT for some sectors (e.g., in IPPU and Waste) counterbalances lower emissions estimates in other sectors (e.g., in the Energy sector).
- About 38 percent of the difference in net emissions is from Forest Carbon (see Table K-2). The SIT does not provide default data for estimating Forest Carbon sinks.
- About 40 percent of the difference in total emissions and 22 percent of the difference in net emissions is from Transportation (see Table K-2). One of the reasons for this difference is due to the inclusion of emissions from military non-aviation transportation, which is not accounted for in the SIT.
- Estimates for seven categories comprise 89 percent of the difference in net emissions between the SIT and ICF analysis. These include Forest Carbon, Transportation, Landfills, Iron and Steel Production, Incineration of Waste, Oil and Natural Gas Systems, and Substitution of Ozone-Depleting Substances (ODS). The likely reasons for these differences are discussed below in Methodology Comparison.
- Relative to ICF's estimates, the SIT estimated higher emissions from the IPPU, AFOLU, and Waste sectors, but lower emissions from Energy emission sources.

Key observations from using the Projection Tool for 2020, 2025, 2030, and 2045 GHG estimates include the following:

- The Projection Tool does not estimate emissions from LULUCF source and sink categories.
- The Projection Tool does not account for the COVID-19 pandemic in emission estimates, whereas the ICF/UHERO 2020 projections use some actual data for 2020 that account for the impacts of COVID-19.
- About 74 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 66 percent higher in 2020 using the SIT (however, it is only 29 percent higher in 2025). Some of this difference is because ICF/UHERO accounted for Light Duty Vehicle Miles Traveled reduction from the Honolulu Rail Project. Additionally, ICF/UHERO projections for domestic marine or military transportation emissions were assumed to remain constant in the future relative to 2019 due to a lack of available data and inconsistencies in the historical emissions trends.
- About 84 percent of the difference in 2025 net emission projections are from the Transportation, Forest Carbon, Stationary Combustion, Agricultural Soil Carbon, and Urban Trees 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 2020, 2025, and 2030. In 2045, the Projection Tool estimates higher emissions for Energy and IPPU, but slightly lower emissions for Waste.

- ICF/UHERO's projected emissions are much lower in 2045 than the Projection Tool. For this analysis, the Projection Tool estimates future emissions based on default historical activity data for Hawaiʻi. There is a large degree of uncertainty associated with the default activity data within the Projection Tool, as most of the data is from national sources, rather than Hawaiʻi-specific sources. Additionally, some of the default activity data within the Projection Tool are from older sources and may not capture recent economic, political, or social trends that impact activity data, such as decreased consumption of certain fuels or decreased livestock populations. The ICF/UHERO team used Hawaiʻi-specific assumptions for each sector to project future emissions, which is likely the cause of the disparity between the Projection Tool and ICF/UHERO in 2045. The likely reasons for these differences are discussed in more detail in Methodology Comparison.

Detailed results, observations, and likely reasons for differences in the estimates can be found in the body of this report.

Comparison of Results

To compare the results from the SIT against the 2019 inventory developed by ICF, results from each estimation module were compared against the source and sink categories defined in the 2019 inventory.[82] Figure K-3 summarizes how the results from the SIT were mapped to the 2019 inventory.

[82] 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 Hawaiʻi.

Figure K-3: Mapping of SIT Modules to Hawai‘i’s 2019 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	CO_2FFC (Transportation and Industrial)
IPPU	Substitution of ODS	IP (ODS Substitutes)
	Electrical Transmission and Distribution	IP (Electric Power Transmission and Distribution Systems)
	Cement Production	IP (Cement)
AFOLU	Enteric Fermentation	Ag (Enteric Fermentation)
	Manure Management	Ag (Manure Management)
	Agricultural Soil Management	Ag (Ag Soils)
		LULUCF (N_2O from Settlement 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	

Please note, the inventory source category list in Figure K-3 omits source categories that were assumed to be not occurring (NO) within Hawai‘i by the ICF/UHERO inventory team. However, because the SIT was run using the default data assumptions for each sector, the tool estimates emissions for some of these not occurring IPPU and AFOLU source categories, such as soda ash manufacture and consumption, iron and steel production, urea consumption, and liming of agricultural soils. Please see Table K-12 and Table K-13 in the Methodology Comparison section for additional detail on the methodology of these categories estimated in the SIT.

2019 Inventory Comparison

For the state of Hawai'i, ICF estimates that in 2019 total GHG emissions were 22.01 MMT CO_2 Eq., which is one percent greater than the SIT's estimate of 21.81 MMT CO_2 Eq. ICF estimates that in 2019 net emissions were 19.42 MMT CO_2 Eq., while the SIT estimates 21.06 MMT CO_2 Eq., a difference of eight percent. A summary of 2019 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 2019 Total and Net Emission Results (MMT CO_2 Eq.)

Sector/Category	ICF	SIT	Difference	Percent Difference
Energy	**19.44**	**18.01**	**(1.44)**	**(7%)**
Transportation	10.68	9.59	(1.09)	(10%)
Stationary Combustion	8.33	8.26	(0.07)	(1%)
Incineration of Waste	0.28	0.16	(0.12)	(44%)
Oil and Natural Gas Systems [a]	0.11	NE	NA	NA
Non-Energy Uses [b]	0.04	IE	NA	NA
IPPU	**0.84**	**1.05**	**0.21**	**25%**
Substitution of ODS	0.83	0.73	(0.10)	(12%)
Electrical Transmission and Distribution	0.01	0.01	+	3%
Cement Production	NO	NO	0.00	NA
Soda Ash Manufacture and Consumption [c]	NO	0.01	0.01	NA
Urea Consumption [c]	NO	+	+	NA
Iron and Steel Production [c]	NO	0.30	0.30	NA
Limestone and Dolomite Use [c]	NO	NO	0.00	NA
AFOLU	**(1.28)**	**0.71**	**1.99**	**(156%)**
Agricultural Soil Carbon	0.83	0.89	0.07	8%
Enteric Fermentation	0.25	0.26	+	1%
Agricultural Soil Management	0.18	0.23	0.05	30%
Forest Fires [a]	0.04	NE	NA	NA
Manure Management	0.02	0.05	0.03	195%
Urea Application	+	+	+	5%
Field Burning of Agricultural Residues	NO	NO	0.00	NA
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.05)	+	(1%)
Urban Trees	(0.63)	NE	NA	NA
Forest Carbon [a]	(1.91)	NO	1.91	NA
Liming	NO	0.03	0.03	NA
N_2O from Settlement Soils [d]	IE	0.01	NA	NA
Waste	**0.41**	**1.29**	**0.88**	**213%**
Landfills	0.30	1.13	0.83	273%
Wastewater Treatment	0.07	0.16	0.08	111%
Composting [e]	0.03	NE	NA	NA
Total Emissions (Excluding Sinks)	**22.01**	**21.81**	**(0.20)**	**(1%)**

Net Emissions (Including Sinks)	19.42	21.06	1.64	8%

+ 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 does not provide default data for Oil and Natural Gas Systems, Forest Fires, or Forest Carbon in Hawaiʻi.

[b] The SIT includes emissions from Non-Energy Uses in emissions CO_2 from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.

[c] ICF estimates that this activity is not applicable to Hawaiʻi, and therefore emissions are not occurring.

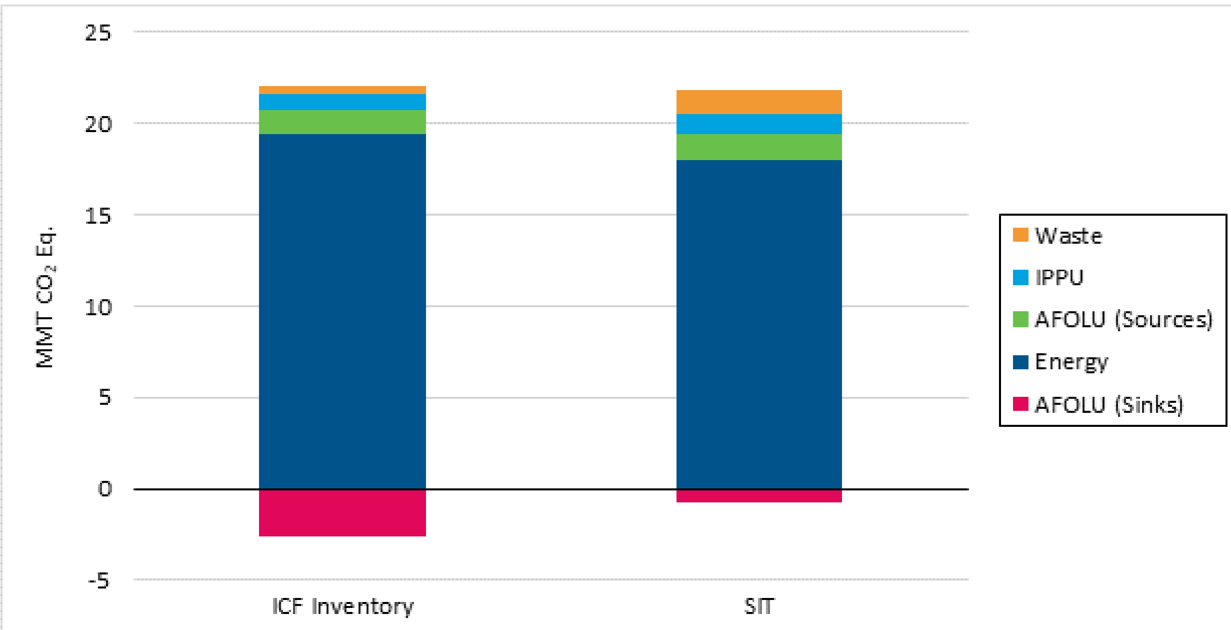
[d] Emissions are included under Agricultural Soil Management.

[e] The SIT does not estimate emissions from Composting.

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

Emissions by sector as calculated by ICF and the SIT are presented in Figure K-4.

Figure K-4: Comparison of 2019 Emission Results (Including Sinks and Aviation)



Seven source and sink categories account for 89 percent of the absolute difference between ICF's Inventory and the SIT's estimates. Table K-2 summarizes the absolute and cumulative difference in emission estimates for these seven categories. The likely reasons for these differences are discussed below in Methodology Comparison.

Table K-2: Key Sources of Differences between ICF Inventory and SIT 2019 Net Emission Results

Category	ICF	SIT	Absolute Difference	Cumulative Percent of Total Difference
Forest Carbon	(1.91)	NE	1.91	38%
Transportation	10.68	9.59	1.09	60%

Landfills	0.30	1.13	0.83	77%
Iron and Steel Production	NO	0.30	0.30	83%
Incineration of Waste	0.28	0.16	0.12	85%
Oil and Natural Gas Systems	0.11	NE	0.11	87%
Substitution of ODS	0.83	0.73	0.10	89%
All Other Categories			0.53	100%

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

2020 Projection Comparison

ICF, with support from UHERO, projects 2020 total GHG emissions to be 17.24 MMT CO_2 Eq., while net emissions are projected to be 14.70 MMT CO_2 Eq. The Projection Tool, which does not project emissions from LULUCF categories, projects total and net emissions in 2020 to be 20.17 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 Total and Net Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Energy	**14.79**	**17.63**	**2.84**	**19%**
Transportation	7.41	12.27	4.86	66%
Stationary Combustion	7.02	5.29	(1.73)	(25%)
Incineration of Waste	0.27	0.05	(0.21)	(80%)
Oil and Natural Gas Systems	0.06	0.02	(0.04)	(66%)
Non-Energy Uses [a]	0.03	IE	NA	NA
IPPU	**0.74**	**1.09**	**0.35**	**48%**
Substitution of ODS	0.73	0.67	(0.06)	(8%)
Electrical Transmission and Distribution	0.01	0.01	+	(17%)
Cement Production	NO	NO	0.00	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.41	0.41	NA
Limestone and Dolomite Use	NO	NO	0.00	NA
AFOLU	**(1.25)**	**0.54**	**1.78**	**(143%)**
Agricultural Soil Carbon [b]	0.81	NE	NA	NA
Enteric Fermentation	0.25	0.23	(0.01)	(5%)
Agricultural Soil Management	0.18	0.25	0.07	41%
Forest Fires [b]	0.05	NE	NA	NA
Manure Management	0.02	0.05	0.03	184%
Urea Application	+	+	+	(4%)
Field Burning of Agricultural Residues	NO	NO	0.00	NA
Landfilled Yard Trimmings and Food Scraps [b]	(0.04)	NE	NA	NA
Urban Trees [b]	(0.64)	NE	NA	NA

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Forest Carbon [b]	(1.86)	NE	NA	NA
Liming	NO	0.01	0.01	NA
N_2O from Settlement Soils [b,c]	IE	NE	NA	NA
Waste	**0.42**	**0.91**	**0.49**	**117%**
Landfills	0.31	0.71	0.40	130%
Wastewater Treatment	0.08	0.20	0.12	160%
Composting [b]	0.03	NE	NA	NA
Total Emissions (Excluding Sinks)	**17.24**	**20.17**	**2.92**	**17%**
Net Emissions (Including Sinks)	**14.70**	**20.17**	**5.47**	**37%**

+ 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 Projection Tool includes projected emissions from Non-Energy Uses under CO_2 emissions from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.

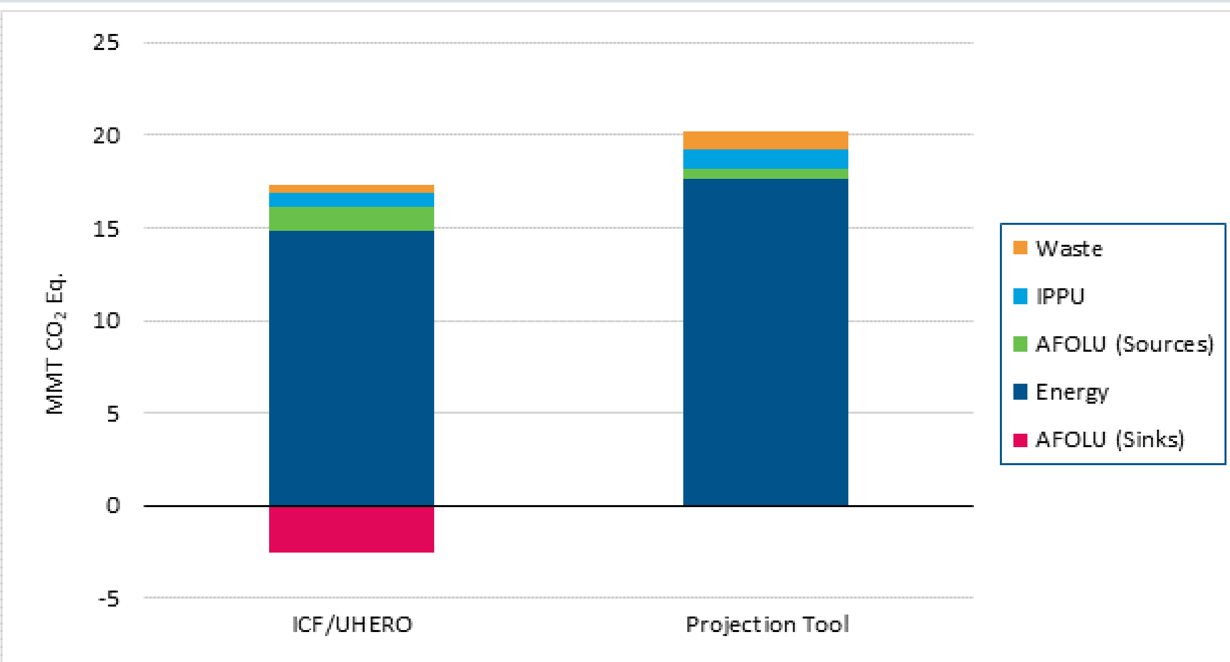
[b] The Projection Tool does not project emissions from LULUCF categories or Composting.

[c] Emissions are included under Agricultural Soil Management.

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 and Aviation)



Seven source and sink categories account for 94 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. The likely reasons for these differences are discussed below in Methodology Comparison.

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 Percent of Total Difference
Transportation	7.41	12.27	4.86	43%
Forest Carbon	(1.86)	NE	1.86	59%
Stationary Combustion	7.02	5.29	1.73	74%
Agricultural Soil Carbon	0.81	NE	0.81	81%
Urban Trees	(0.64)	NE	0.64	87%
Iron and Steel Production	NO	0.41	0.41	90%
Landfills	0.31	0.71	0.40	94%
All Other Categories			0.71	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 18.43 MMT CO_2 Eq., while net emissions are projected to be 15.93 MMT CO_2 Eq. The Projection Tool projects total and net emissions to be 19.93 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 Total and Net Emission Projection Results (MMT CO_2 Eq.)

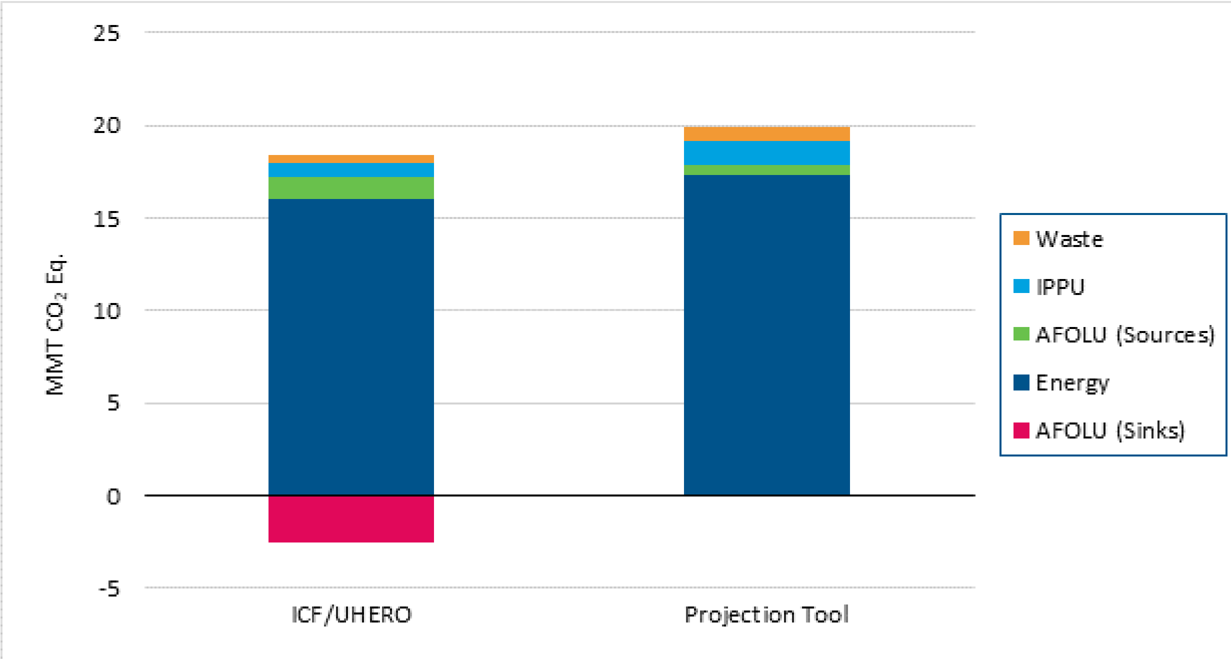
Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Energy	**16.02**	**17.37**	**1.35**	**8%**
Transportation	10.07	13.02	2.95	29%
Stationary Combustion	5.52	4.27	(1.25)	(23%)
Incineration of Waste	0.29	0.05	(0.24)	(81%)
Oil and Natural Gas Systems	0.10	0.02	(0.08)	(78%)
Non-Energy Uses [a]	0.03	IE	NA	NA
IPPU	**0.77**	**1.26**	**0.49**	**64%**
Substitution of ODS	0.76	0.81	0.05	7%
Electrical Transmission and Distribution	0.01	0.01	+	(26%)
Cement Production	NO	NO	0.00	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.43	0.43	NA
Limestone and Dolomite Use	NO	NO	0.00	NA
AFOLU	**(1.29)**	**0.52**	**1.81**	**(141%)**

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Agricultural Soil Carbon [b]	0.74	NE	NA	NA
Enteric Fermentation	0.24	0.23	(0.01)	(4%)
Agricultural Soil Management	0.18	0.24	0.06	31%
Forest Fires [b]	0.05	NE	NA	NA
Manure Management	0.01	0.05	0.03	282%
Urea Application	+	+	+	(7%)
Field Burning of Agricultural Residues	NO	NO	0.00	NA
Landfilled Yard Trimmings and Food Scraps [b]	(0.04)	NE	NA	NA
Urban Trees [b]	(0.69)	NE	NA	NA
Forest Carbon	(1.77)	NE	NA	NA
Liming	NO	0.01	0.01	NA
N_2O from Settlement Soils [b,c]	IE	NE	NA	NA
Waste	**0.43**	**0.78**	**0.35**	**82%**
Landfills	0.31	0.58	0.27	86%
Wastewater Treatment	0.08	0.20	0.12	147%
Composting	0.04	NE	NA	NA
Total Emissions (Excluding Sinks)	**18.43**	**19.93**	**1.50**	**8%**
Net Emissions (Including Sinks)	**15.93**	**19.93**	**4.00**	**25%**

+ 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 Projection Tool includes projected emissions from Non-Energy Uses under CO_2 emissions from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.
[b] The Projection Tool does not project emissions from LULUCF categories or Composting.
[c] Emissions are included under Agricultural Soil Management.
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 and Aviation)



Seven source and sink categories account for 92 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. The likely reasons for these differences are discussed below in Methodology Comparison.

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 Percent of Total Difference
Transportation	10.07	13.02	2.95	33%
Forest Carbon	(1.77)	NE	1.77	54%
Stationary Combustion	5.52	4.27	1.25	68%
Agricultural Soil Carbon	0.74	NE	0.74	76%
Urban Trees	(0.69)	NE	0.69	84%
Iron and Steel Production	NO	0.43	0.43	89%
Landfills	0.31	0.58	0.27	92%
All Other Categories			0.72	100%

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

2030 Projection Comparison

ICF, with support from UHERO, projects 2030 total GHG emissions to be 17.49 MMT CO_2 Eq., while net emissions are projected to be 15.02 MMT CO_2 Eq. The Projection Tool projects total and net emissions to be 19.82 MMT CO_2 Eq. in 2030. A summary of projected emissions and sinks by sector and category, as estimated by ICF/UHERO and the Projection Tool for 2030, are provided in Table K-7.

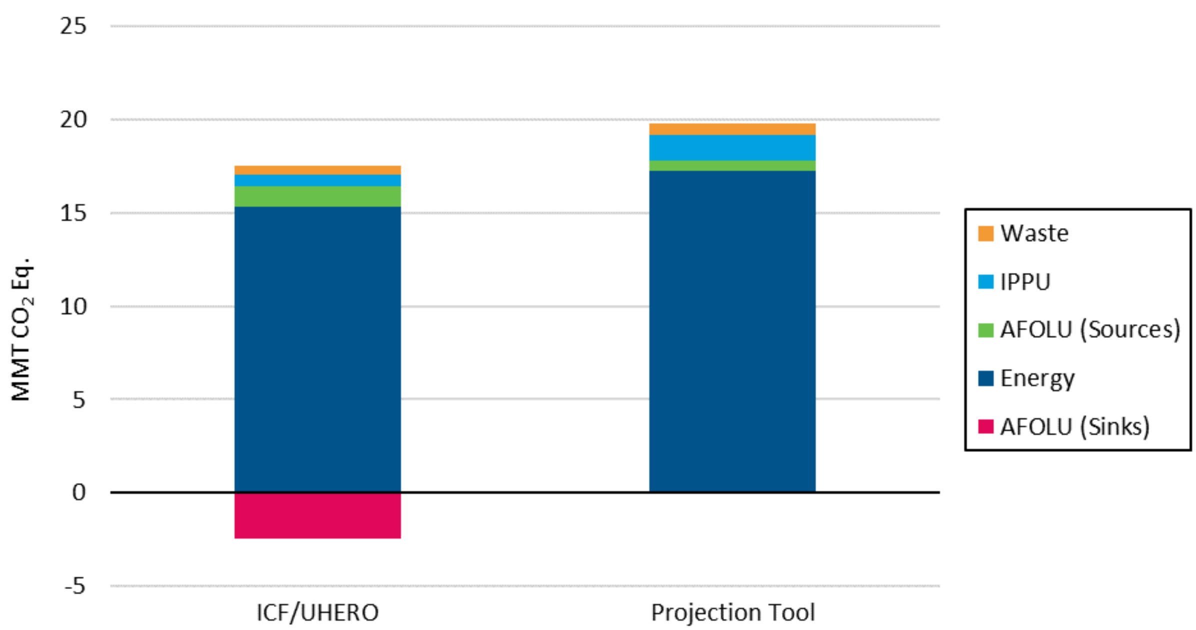
Table K-7: Comparison of 2039 Total and Net Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Energy	**15.29**	**17.27**	**1.98**	**13%**
Transportation	9.91	13.14	3.23	33%
Stationary Combustion	4.95	4.05	(0.90)	(18%)
Incineration of Waste	0.29	0.06	(0.24)	(81%)
Oil and Natural Gas Systems	0.10	0.02	(0.08)	(79%)
Non-Energy Uses [a]	0.04	IE	NA	NA
IPPU	**0.62**	**1.36**	**0.74**	**120%**
Substitution of ODS	0.61	0.89	0.28	46%
Electrical Transmission and Distribution	0.01	0.01	+	(32%)
Cement Production	NO	NO	0.00	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.46	0.46	NA
Limestone and Dolomite Use	NO	NO	0.00	NA
AFOLU	**(1.32)**	**0.51**	**1.83**	**(138%)**
Agricultural Soil Carbon [b]	0.67	NE	NA	NA
Enteric Fermentation	0.23	0.22	+	(2%)
Agricultural Soil Management	0.19	0.23	0.04	23%
Forest Fires [b]	0.05	NE	NA	NA
Manure Management	0.01	0.04	0.04	488%
Urea Application	+	+	+	(11%)
Field Burning of Agricultural Residues	NO	NO	0.00	NA
Landfilled Yard Trimmings and Food Scraps [b]	(0.04)	NE	NA	NA
Urban Trees [b]	(0.74)	NE	NA	NA
Forest Carbon [b]	(1.68)	NE	NA	NA
Liming	NO	0.01	0.01	NA
N_2O from Settlement Soils [b,c]	IE	NE	NA	NA
Waste	**0.43**	**0.68**	**0.24**	**56%**
Landfills	0.31	0.48	0.17	54%
Wastewater Treatment	0.09	0.20	0.12	136%
Composting	0.04	NE	NA	NA
Total Emissions (Excluding Sinks)	**17.49**	**19.82**	**2.33**	**13%**
Net Emissions (Including Sinks)	**15.02**	**19.82**	**4.80**	**32%**

+ 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 Projection Tool includes projected emissions from Non-Energy Uses under CO_2 emissions from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.
[b] The Projection Tool does not project emissions from LULUCF categories or Composting.
[c] Emissions are included under Agricultural Soil Management.
Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions projections for 2030 by sector as calculated by ICF/UHERO and the Projection Tool are presented in Figure K-7.

Figure K-7: Comparison of 2025 Emission Projection Results (Including Sinks and Aviation)



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-8 summarizes the absolute and cumulative difference in emission estimates for these top seven categories. The likely reasons for these differences are discussed below in Methodology Comparison.

Table K-8: Key Sources of Differences between ICF/UHERO Projections and Projection Tool Estimates in 2030

Sector/Category	ICF/UHERO	Projection Tool	Absolute Difference	Cumulative Percent of Total Difference
Transportation	9.91	13.14	3.23	37%
Forest Carbon	(1.68)	NE	1.68	56%

Sector/Category	ICF/UHERO	Projection Tool	Absolute Difference	Cumulative Percent of Total Difference
Stationary Combustion	4.95	4.05	0.90	66%
Urban Trees	(0.74)	NE	0.74	75%
Agricultural Soil Carbon	0.67	NE	0.67	82%
Iron & Steel Production	NO	0.46	0.46	88%
Substitution of ODS	0.61	0.89	0.28	91%
All Other Categories			0.82	100%

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

2045 Projection Comparison

ICF, with support from UHERO, projects 2045 total GHG emissions to be 13.88 MMT CO_2 Eq., while net emissions are projected to be 11.26 MMT CO_2 Eq. The Projection Tool projects total and net emissions to be 19.87 MMT CO_2 Eq. in 2045. A summary of projected emissions and sinks by sector and category, as estimated by ICF/UHERO and the Projection Tool for 2045, are provided in Table K-9.

Table K-9: Comparison of 2045 Total and Net Emission Projection Results (MMT CO_2 Eq.)

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Energy	**12.16**	**17.49**	**5.32**	**44%**
Transportation	8.77	14.49	5.72	65%
Stationary Combustion	3.02	2.92	(0.11)	(4%)
Incineration of Waste	0.22	0.06	(0.16)	(73%)
Oil and Natural Gas Systems	0.10	0.02	(0.08)	(79%)
Non-Energy Uses [a]	0.05	IE	NA	NA
IPPU	**0.25**	**1.45**	**1.20**	**483%**
Substitution of ODS	0.24	0.89	0.65	277%
Electrical Transmission and Distribution	0.01	0.01	(0.01)	(42%)
Cement Production	NO	NO	0.00	NA
Soda Ash Manufacture and Consumption	NO	0.01	0.01	NA
Urea Consumption	NO	+	+	NA
Iron and Steel Production	NO	0.55	0.55	NA
Limestone and Dolomite Use	NO	NO	0.00	NA
AFOLU	**(1.64)**	**0.46**	**2.10**	**(128%)**
Agricultural Soil Carbon [b]	0.52	NE	NA	NA
Enteric Fermentation	0.20	0.20	+	1%
Agricultural Soil Management	0.20	0.20	+	2%
Forest Fires [b]	0.05	NE	NA	NA
Manure Management	0.01	0.04	0.03	458%
Urea Application	+	+	+	(21%)

Sector/Category	ICF/UHERO	Projection Tool	Difference	Percent Difference
Field Burning of Agricultural Residues	NO	NO	0.00	NA
Landfilled Yard Trimmings and Food Scraps [b]	(0.01)	NE	NA	NA
Urban Trees [b]	(0.92)	NE	NA	NA
Forest Carbon [b]	(1.69)	NE	NA	NA
Liming	NO	0.01	0.01	NA
N_2O from Settlement Soils [b,c]	IE	NE	NA	NA
Waste	**0.49**	**0.47**	**(0.02)**	**(4%)**
Landfills	0.35	0.26	(0.08)	(24%)
Wastewater Treatment	0.10	0.21	0.11	111%
Composting	0.05	NE	NA	NA
Total Emissions (Excluding Sinks)	**13.88**	**19.87**	**5.98**	**43%**
Net Emissions (Including Sinks)	**11.26**	**19.87**	**8.61**	**76%**

+ 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 Projection Tool includes projected emissions from Non-Energy Uses under CO_2 emissions from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.

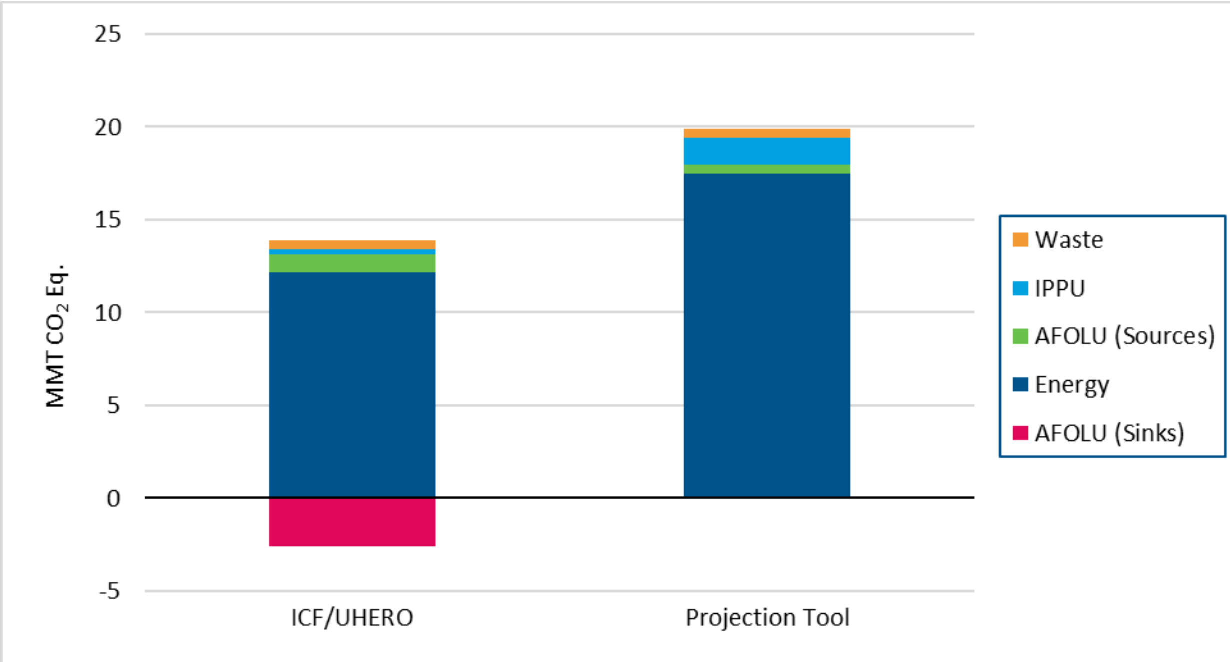
[b] The Projection Tool does not project emissions from LULUCF categories or Composting.

[c] Emissions are included under Agricultural Soil Management.

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

Emissions projections for 2045 by sector as calculated by ICF/UHERO and the Projection Tool are presented in Figure K-8.

Figure K-8: Comparison of 2045 Emission Projection Results (Including Sinks and Aviation)



Seven source and sink categories account for 95 percent of the absolute difference between the ICF/UHERO projections and the Projection Tool estimates. Table K-10 summarizes the absolute and cumulative difference in emission estimates for these top seven categories. The likely reasons for these differences are discussed below in Methodology Comparison.

Table K-10: Key Sources of Differences between ICF/UHERO Projections and Projection Tool Estimates in 2045

Sector/Category	ICF/UHERO	Projection Tool	Absolute Difference	Cumulative Percent of Total Difference
Transportation	8.77	14.49	5.72	53%
Forest Carbon	(1.69)	NE	1.69	69%
Urban Trees	(0.92)	NE	0.92	77%
Substitution of ODS	0.24	0.89	0.65	84%
Iron and Steel Production	NO	0.55	0.55	89%
Agricultural Soil Carbon	0.52	NE	0.52	93%
Incineration of Waste	0.22	0.06	0.16	95%
All Other Categories			0.54	100%

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

Methodology Comparison

2019 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 2019 inventory estimates.

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 estimates emissions from non-energy uses of fossil fuels directly within CO_2FFC calculations, rather than by summarizing emissions in a distinct source category. 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-11.

Table K-11: 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 the estimates as it was determined that it is not used in Hawaiʻi.	• Fuel consumption data is taken from EIA's SEDS database and EIA's Natural Gas Annual report.
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. • Additional EIA fuel consumption data for military non-aviation applications are compiled through a data request to EIA, which is not accounted for in the SIT.	• Fuel consumption data is taken from EIA's SEDS database. Emissions from alternative fuel vehicles are calculated separately.
Incineration of Waste	• Emissions are taken from EPA's GHGRP.	• Calculates combustion of fossil-derived carbon in waste for plastics,

Source	ICF Inventory	SIT
		synthetic fibers, and synthetic rubber by estimating the mass of waste combusted (obtained from BioCycle), applying a carbon content, and assuming a 98 percent 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.	• The percentage of non-energy use consumption by fuel type are based on estimates from the U.S. Inventory; however, emission estimates are included in emissions CO_2 from Fossil Fuel Combustion (CO_2FFC). Therefore, these emissions are captured within the Stationary Combustion and Transportation emission sources.

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 Hawaiʻi; 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-12.

Table K-12: 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. Hawaiʻi's electricity sales data are taken from the State of Hawaiʻi 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. Hawaiʻi's population data are taken from the State of Hawaiʻi Data Book.	• Both national and state-level population are taken from the U.S. Census Bureau.

Source	ICF Inventory	SIT
	• National emissions estimates are taken from the 1990-2019 U.S. Inventory.	• National emissions estimates are taken from the 1990-2019 U.S. Inventory.
Soda Ash Manufacture and Consumption	• Emissions from soda ash manufacturing and consumption were determined to not occur in Hawaiʻi.	• 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 Hawaiʻi.	• 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 Hawaiʻi.	• 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. ICF also does not estimate emissions from Liming. 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-13.

Table K-13: 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 no commercial organic fertilizer is consumed in Hawaiʻi based on the Association of American Plant Food Control Officials	• Estimates state-level organic fertilizer consumption by applying the percentage of national fertilizer consumption that is organic fertilizer

Source	ICF Inventory	SIT
	(AAPFCO) Commercial Fertilizer reports. • Obtains 1990-2014 fertilizer consumption estimates from AAPFCO and estimates consumption in 2019 based on a five-year trend from 2010 to 2014. • 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.	to total state-level fertilizer consumption. • Uses the 2014 fertilizer consumption estimate from AAPFCO as a proxy for 2019. • 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 Hawaiʻi.
Field Burning of Agricultural Residues	• Assumes the fraction of sugarcane residue burned is zero in 2019, as the last sugarcane mill in Hawaiʻi closed in 2017. Emissions from the field burning of agriculture residue are assumed to be zero in 2019.	• Assumes that the fraction of Hawaiʻi sugarcane residue burned is zero. Data on the burning of sugarcane residue is not available from U.S. Inventory. Emissions from the field burning of agriculture residue are assumed to be zero.
Urea Application	• Extrapolates urea fertilization consumption to 2019 based on the historical five-year trend.	• Uses 2014 data from AAPFCO (2017) as a proxy for 2019 urea fertilization.
Agricultural Soil Carbon	• Emissions estimates are from the 1990-2019 U.S. Inventory.	• Emissions estimates are from the 1990-2019 U.S. Inventory.
Forest Fires	• Obtains forest area burned data from the Hawaiʻi Department of Land and Natural Resources.	• Does not include default data of forest area burned.
Landfilled Yard Trimmings	• Hawaiʻi population data were obtained from the State of Hawaiʻi Data Book. • Extrapolates waste generation to 2019 based on the historical five-year trend.	• Hawaiʻi population data were obtained from U.S. Census. • Uses 2018 waste generation data as reported in EPA's Advancing Sustainable Materials Management Fact Sheet as a proxy for 2019.
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 Hawaiʻi.
N_2O from Settlement Soils	• Emissions included under Agricultural Soil Management.	• Assumes one percent of synthetic fertilizer consumption is used on settlement soils.

Source	ICF Inventory	SIT
Liming	• Emissions from lime used for agricultural purposes are not estimated by ICF.	• Estimated using data on limestone used for agricultural purposes from the USGS's 2018 Mineral Yearbook.

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-14.

Table K-14: 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 Hawai'i Department of Health (DOH), Solid & Hazardous Waste Branch. • Volumes of landfill gas recovered for flaring and energy were obtained from EPA's GHGRP. • Historical MSW generation and disposal volumes were calculated using population data from the State of Hawai'i Data Book.	• Estimates state-level waste disposal by allocating national waste data from EPA's Municipal Solid Waste Report and BioCycle and based on population. • Hawai'i flaring data is from EPA's Landfill Methane Outreach Program (LMOP) Landfill and Landfill Gas Energy Project Database.
Composting	• Estimated based on data from the Hawai'i DOH, Solid & Hazardous Waste Branch.	• 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 Hawai'i DOH, Wastewater Branch and Clean Water Branch. • Population data from the State of Hawai'i Data Book were used to calculate wastewater treatment volumes. • The number of households on septic systems were calculated using data from the U.S. Inventory.	• Uses data from the 1990-2019 U.S. Inventory. • Municipal Wastewater emissions estimated using state population data from the U.S. Census Bureau. • State-specific red meat production data from USDA are used to estimate industrial emissions.

2020, 2025, 2030, and 2045 Emission Projections

This section compares the methodology used by ICF/UHERO and the Projection Tool to develop the 2020, 2025, 2030, and 2045 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-15. A more detailed description of the methodology and data sources used by ICF/UHERO can be found in the Technical Support Document: Preliminary Inventory Projections of Statewide Greenhouse Gas Emissions for 2020 – 2045, and Assessment of Statewide Progress.

Table K-15: 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 stationary combustion, electric sector emissions in 2020 were based on facility emissions reported to the GHGRP. • 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 RNG consumption in place of SNG consumption. • For ground transportation, emissions were projected based on estimates of future vehicle miles traveled, fuel efficiency by vehicle type, types of vehicles on the road, and their related fuel sources. Light Duty Vehicle emission projections account for Vehicle Miles Traveled reduction due to the Honolulu Rail Project. • 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,	• 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.

Sector	ICF/UHERO	Projection Tool
	emissions were projected 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 implementation of the American Innovation and Manufacturing (AIM) Act.	• 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 from landfills in 2020 were taken from EPA Facility Level Information on Greenhouse Gases Tool (FLIGHT) data and then scaled to match reported landfill tonnage as described for waste in the 2019 inventory. • Composting and Wastewater Treatment emissions were projected based on DBEDT population growth projections.	• Forecasts activity data based on projected population from the U.S. Census Bureau.