Preliminary Inventory of Statewide Greenhouse Gas Emissions for 2010 and 2015

Technical Support Document

AFOLU Info Draft - 1/30/2018

Prepared for:

HAWAII STATE DEPARTMENT OF HEALTH

Prepared by:

ICF

Acronyms and Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
Bbtu	Billion British Thermal Units
BOD	Biochemical oxygen demand
CH_4	Methane
CO_2	Carbon dioxide
DBEDT	Department of Business, Economic Development, and Tourism
DLNR	Department of Land and Natural Resources
DOH	Department of Health
EPA	Environmental Protection Agency
FOD	First order decay
GHG	Greenhouse gas
GWP	Global warming potential
GHGRP	Greenhouse Gas Reporting Program
HAR	Hawaii Administrative Rule
HFC	Hydrofluorocarbon
IBF	International Bunker Fuels
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
kt	kilotons
MCF	Methane conversion factor
MMT	million metric tons
MSW	Municipal solid waste
N_2O	Nitrous oxide
NOAA-CCAP	National Oceanic and Atmospheric Administration's Coastal Change Analysis Program
NPDES	National Pollutant Discharge Elimination System
ODS	Ozone Depleting Substance
PFC	Perfluorocarbon
SEDS	State Energy Data System
SF_6	Sulfur hexafluoride
SIT	State Inventory Tool
TJ	Terajoule
UNFCCC	United Nations Framework Convention on Climate Change
VMT	Vehicle miles traveled
VS	Volatile solids
WMS	Waste management system

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

This chapter presents GHG emissions from agricultural activities, land use, changes in land use, and land management practices. For the state of Hawaii, emissions and removals from agriculture, forestry, and other land uses (AFOLU) are estimated from the following source and sink categories[26] and gases:

- Agriculture
  - Enteric Fermentation (IPCC Source Category 3A1): CH_4
  - Manure Management (IPCC Source Category 3A2 and 3C6): CH_4, N_2O
  - Agricultural Soil Management (IPCC Source Categories 3C4 and 3C5): N_2O
  - Field Burning of Agricultural Residues (IPCC Source Category 3C1b): CH_4, N_2O
  - Urea Application (IPCC Source Category 3C3): CO_2

- Land Use, Land-Use Change, and Forestry
  - Agricultural Soil Carbon (IPCC Source Categories 3B2 and 3B3): CO_2
  - Forest Fires (IPCC Source Category 3C1a): CO_2, CH_4, N_2O
  - Landfilled Yard Trimmings and Food Scraps (IPCC Source Category 3B5a): CO_2
  - Urban Trees (IPCC Source Category 3B5a): CO_2
  - Forest Carbon (IPCC Source Category 3B1a): CO_2

Agricultural activities are categorized as GHG "sources," which emit GHGs into the atmosphere. Land use, changes in land use, and land management practices may either be "sources" of GHGs or "sinks" of GHGs (sinks remove CO_2 from the atmosphere). In Hawaii, Landfilled Yard Trimmings and Food Scraps, Urban Trees, and Forest Carbon are CO_2 sinks. The remaining AFOLU categories presented in this chapter are sources of GHGs.

Total emissions (excluding sinks) from the AFOLU sector were 1.20 MMT CO_2 Eq. in 2010 and 1.11 MMT CO_2 Eq. in 2015, accounting for 5 percent of total Hawaii emissions in both 2010 and 2015. Carbon sinks were 3.09 MMT CO_2 Eq. in 2010 and 3.07 MMT CO_2 Eq. in 2015, while net emissions were (1.89) MMT CO_2 Eq. in 2010 and (1.96) MMT CO_2 Eq. in 2015. Therefore, the AFOLU sector is a net sink of GHG emissions in Hawaii in both years. Figure 14 and Figure 15 show AFOLU emissions by source for 2010 and 2015. Emission sources and sinks by category and year are summarized in Table 15.

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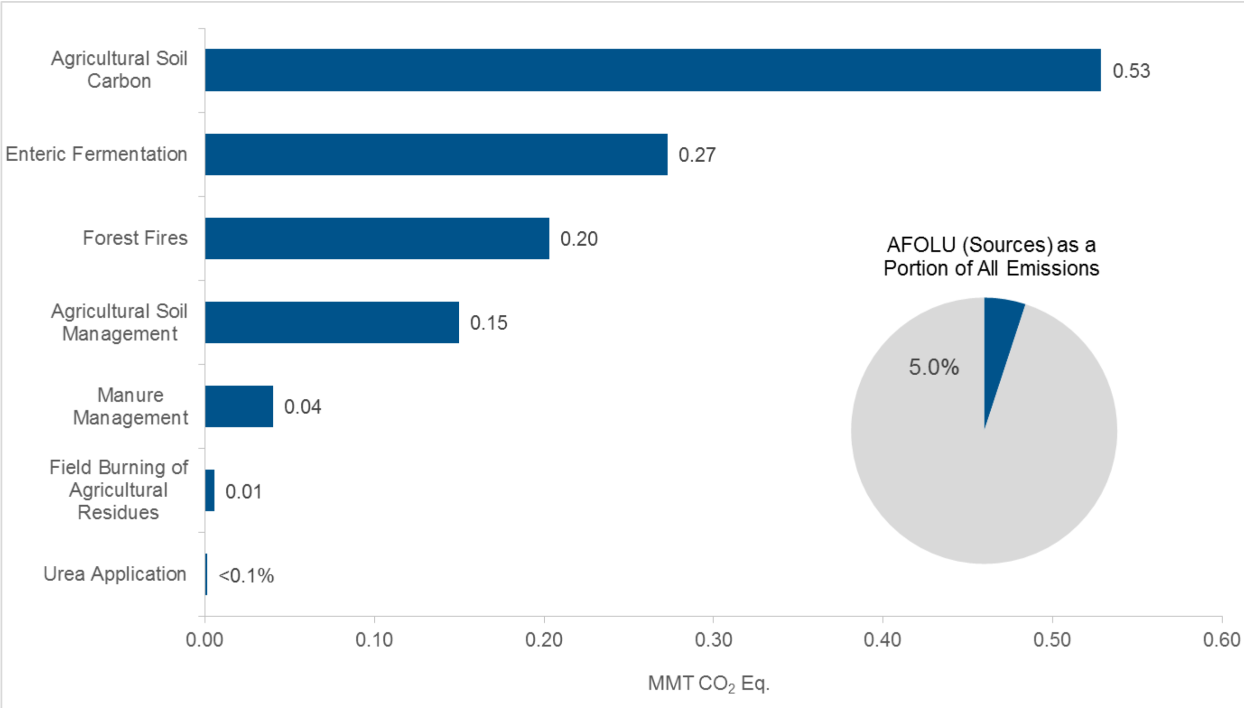
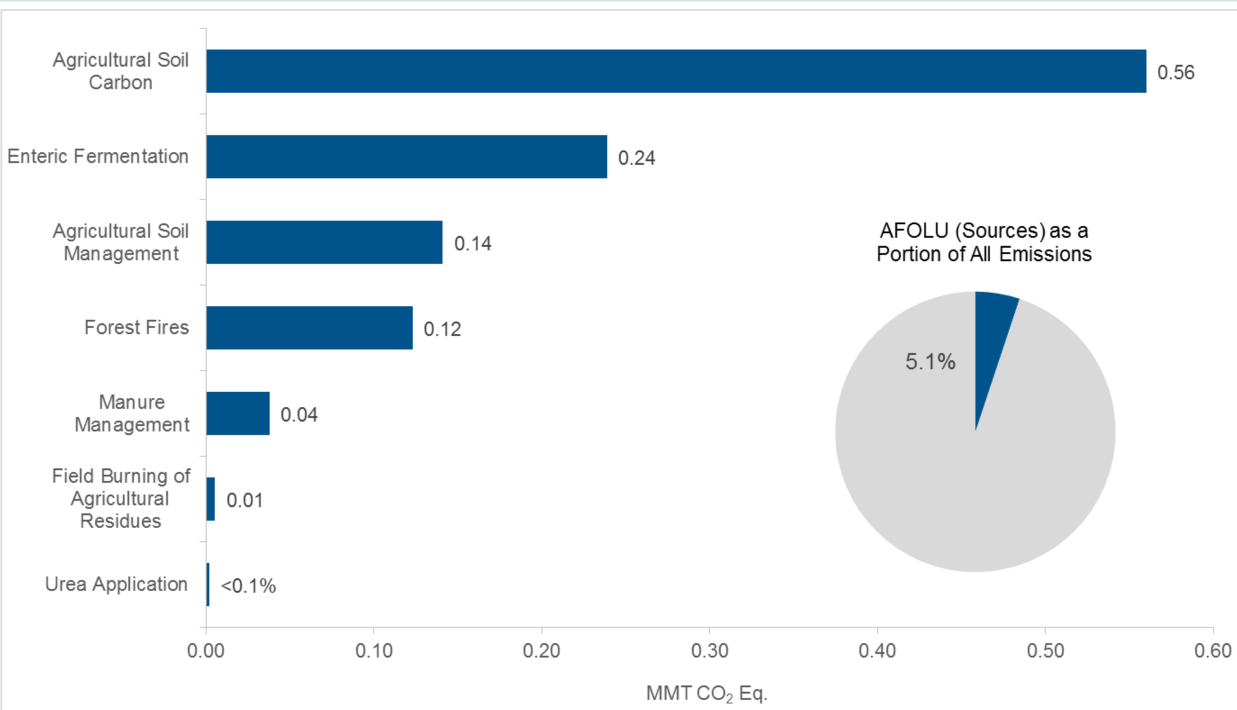
[26] IPCC Source and Sink Categories for which emissions were not estimated for the state of Hawaii include: Land Converted to Forest Land (3B1b), Wetlands (3B4), Land Converted to Settlements (3B5b), Other Land (3B6), Biomass Burning in Grassland (3C1c), Biomass Burning in All Other Land (3C1d), Liming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

Figure 14: 2010 AFOLU Emissions by Source (MMT CO_2 Eq.)



Note: Totals may not sum due to independent rounding.

Figure 15: 2015 AFOLU Emissions by Source (MMT CO_2 Eq.)



Note: Totals may not sum due to independent rounding.

Table 15: GHG Emissions from the AFOLU Sector by Category (MMT CO_2 Eq.)

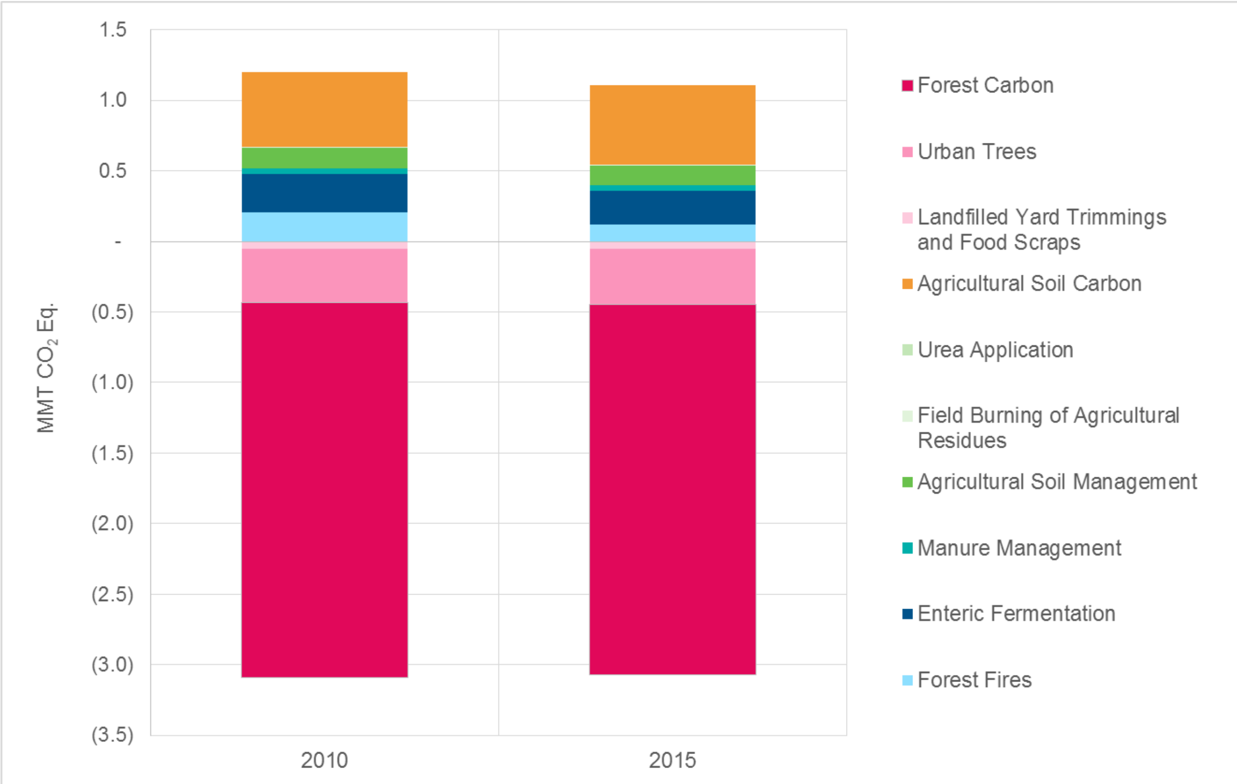
Category	2010	2015
Agriculture	**0.47**	**0.42**
Enteric Fermentation	0.27	0.24
Manure Management	0.04	0.04
Agricultural Soil Management	0.15	0.14
Field Burning of Agricultural Residues	0.01	0.01
Urea Application	+	+
Land Use, Land-Use Change, and Forestry	**(2.36)**	**(2.39)**
Agricultural Soil Carbon	0.53	0.56
Forest Fires	0.20	0.12
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.05)
Urban Trees	(0.38)	(0.40)
Forest Carbon	(2.66)	(2.62)
Total (Sources)	**1.20**	**1.11**
Total (Sinks)	**(3.09)**	**(3.07)**
Total Net Emissions	**(1.89)**	**(1.96)**

+ Does not exceed 0.005 MMT CO_2 Eq.

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

Agricultural soil carbon accounts for the largest share of AFOLU emissions in both 2010 and 2015, followed by enteric fermentation, forest fires, agricultural soil management, manure management, field burning of agricultural residues, and urea application. Forest carbon accounts for the largest carbon sink, followed by urban trees and landfilled yard trimmings and food scraps. Figure 16 presents AFOLU emissions and removals by source and sink category in Hawaii for 2010 and 2015.

Figure 16: AFOLU Emissions and Removals by Source and Sink Category, 2010 and 2015 (MMT CO_2 Eq.)



4.1. Enteric Fermentation (IPCC Source Category 3A1)

Methane is produced as part of the digestive processes in animals, a microbial fermentation process referred to as enteric fermentation. The amount of CH_4 emitted by an animal depends upon the animal's digestive system, and the amount and type of feed it consumes (U.S. EPA 2017a). This source includes CH_4 emissions from dairy and beef cattle, sheep, goats, swine, and horses. Table 16 summarizes emissions from enteric fermentation in Hawaii for 2010 and 2015.

Table 16: CH_4 Emissions from Enteric Fermentation (MMT CO_2 Eq.)

Source	2010	2015
Enteric Fermentation	0.27	0.24

Methodology

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

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

where,

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

Data Sources

Animal population data were obtained from the U.S. Department of Agriculture's (USDA) National Agriculture Statistics Service (NASS) (USDA 2017a, USDA 2017b). NASS reported annual population data for cattle and swine for 2010 and 2015. Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, which is compiled every five years. Population data for sheep, goats, and horses for 2010 and 2015 were interpolated and extrapolated based on population data for 2007 and 2012 from the 2012 USDA Census of Agriculture (USDA 2014).

Yearly emission factors for all cattle types available for the state of Hawaii for 2010 and 2015 were obtained from the U.S. Inventory (U.S. EPA 2017a).[27] Constant emission factors for sheep, goats, horses, and swine were also obtained from the U.S. Inventory (U.S. EPA 2017a).

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

The main GHGs emitted by the treatment, storage, and transportation of livestock manure are CH_4 and N_2O. Methane is produced by the anaerobic decomposition of manure. Direct N_2O emissions are produced through the nitrification and denitrification of the organic nitrogen (N) in livestock dung and urine. Indirect N_2O emissions result from the volatilization of N in manure and the runoff and leaching of N from manure into water (U.S. EPA 2017a). This category includes CH_4 and N_2O emissions from dairy and beef cattle, sheep, goats, swine, horses, and chickens. Table 17 summarizes emissions from manure management in Hawaii for 2010 and 2015.

Table 17: Manure Management Emissions by Gas (MMT CO_2 Eq.)

Source	2010			2015		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Manure Management	0.03	0.01	**0.04**	0.03	0.01	**0.04**

Note: Totals may not sum due to independent rounding.

Methodology

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

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

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

where,

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

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

where,

WMS	= waste management system
P	= animal population (head)
TAM	= typical animal mass (kg per head per year)
Nex	= nitrogen excretion rate (kg animal mass per day)
V	= volatilization percent (%)
WMS VS	= fraction volatile solids distribution by animal type and waste management system (%)
EF_{WMS}	= emission factor for waste management system (kg N_20-N/kg N)
44/28	= conversion from N_2O-N to N_2O

Data Sources

Animal population data for cattle, swine, and chickens were obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c). Chicken population data were not available from NASS after 2010; chicken population in 2015 was estimated by extrapolating population data from 1990 through 2010. Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, with years 2010 and 2015 interpolated and extrapolated based on 2007 and 2012 population data from the 2012 USDA Census of Agriculture (USDA 2014).

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

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

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

Nitrous oxide is produced naturally in soils through the nitrogen (N) cycle. Many agricultural activities, such as the application of N fertilizers, increase the availability of mineral N in soils that lead to direct N_2O emissions from nitrification and denitrification (U.S. EPA 2017a). This category includes N_2O emissions from synthetic fertilizer, organic fertilizer, manure N, as well as crop residue inputs from sugarcane, pineapples, sweet potatoes, ginger root, taro and corn for grain. Table 18 summarizes emissions from agricultural soil management in Hawaii for 2010 and 2015.

Table 18: N_2O Emissions from Agricultural Soil Management (MMT CO_2 Eq.)

Source	2010	2015
Agricultural Soil Management	0.15	0.14

Methodology

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

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

The following equations were used to calculate direct emissions:

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

where,

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

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

where,

N_F = N inputs to agricultural soils from synthetic fertilizers

N_O = N inputs to agricultural soils from organic fertilizers

N_{CR} = N inputs to agricultural soils from crop residues

N_{PRP1} = N inputs to agricultural soils from pasture, range, and paddock manure from cattle, swine, and poultry

N_{PRP2} = N inputs to agricultural soils from pasture, range, and paddock manure from sheep, goats, and horses

EF_F = emission factor for direct N_2O emissions from synthetic and organic fertilizers and crop residues (0.01 kg N_2O-N/kg N input)

EF_{CR} = emission factor for direct N_2O emissions from crop residues (0.01 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 (0.02 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 (0.01 kg N_2O-N/kg N input)

AG_{DM} = above-ground residue dry matter (Mg/hectares)

A = crop area (hectares)

N_{AG} = N content of above-ground residue (kg N/dry matter)

N_{BG} = N content of below-ground residues (kg N/dry matter)

R_{BG-BIO} = Ratio of below-ground residues to harvested yield for crop

Yield = fresh weight yield (kg fresh weight harvested/hectares)

DRY = dry matter fraction of harvested product

Slope = default slope value for AG_{DM} for each crop type

Intercept = default intercept value for AG_{DM} for each crop type

44/28 = conversion from N_2O-N to N_2O

The following equations were used to calculate indirect emissions:

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

where,

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

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

where,

N_F = N inputs to agricultural soils from synthetic fertilizers

N_O = N inputs to agricultural soils from organic fertilizers

N_{CR} = N inputs to agricultural soils from crop residues

N_{PRP} = N inputs to agricultural soils from pasture, range, and paddock manure from all animals

L_{vol-F} = fraction N lost through volatilization from synthetic fertilizer inputs (0.10)

L_{vol-O} = fraction N lost through volatilization from organic fertilizer and manure inputs (0.20)

L_{leach} = fraction N lost through leaching/runoff from all N inputs (0.30)

EF_{vol}	= emission factor for indirect N_2O emissions from N volatilization (0.010 kg N_2O-N / kg NH_3–N + NOX–N volatilized)
EF_{leach}	= emission factor for N_2O emissions from pasture, range, and paddock manure from cattle, swine, and poultry (0.0075 kg N_2O-N / kg N leached/runoff)
44/28	= conversion from N_2O-N to N_2O

Data Sources

Annual sugarcane area and production estimates used to estimate emissions from crop residue N additions were obtained from NASS (USDA 2017d). For ginger root, taro, and corn for grain, data for 2010 and 2015 were estimated based on interpolations and extrapolations from 2007 and 2012 data from the 2012 USDA Census of Agriculture (USDA 2014). Pineapple crop production and crop acreage were not available in the 2012 Census of Agriculture, so pineapple data were estimated based on 1997 and 2002 data from the 2002 USDA Census of Agriculture (USDA 2004). Sweet potato production was not available in the 2012 Census of Agriculture, so sweet potato production data for 2010 and 2015 were estimated based on sweet potato acreage for 2007 and 2012 (USDA 2014). Percent distribution of waste to various animal waste management systems, used to estimate manure N additions to pasture, range, and paddock soils, were obtained from the U.S. Inventory (U.S. EPA 2017a).

Synthetic and organic fertilizer N application data were obtained from the annual publication of Association of American Plant Food Control Officials (AAPFCO 2010-2014). Synthetic fertilizer N application data were not available after 2013; 2015 data were extrapolated based on 2013 data. According to these data sources, commercial organic fertilizer is not applied in Hawaii.

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

Animal population data are used to calculate the N inputs to agricultural soils from pasture, range, and paddock manure from all animals. Animal population data for cattle, swine and chickens were obtained from the USDA NASS (USDA 2017a, USDA 2017b, USDA 2017c, USDA 2017d). Chicken population data were not available from NASS after 2010; chicken population for 2015 was estimated by extrapolating population data from 1990 through 2010. Population data for sheep, goats, and horses were obtained from the USDA Census of Agriculture, with years 2010 and 2015 data interpolated and extrapolated from data available for 2007 and 2012 in the 2012 USDA Census of Agriculture (USDA 2014).

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

Field burning is a method that farmers use to manage 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 (U.S. EPA 2017a). This source includes CH_4 and N_2O emissions from sugarcane burning, which is the only major crop in Hawaii whose residues are regularly burned (Hudson 2008). Table 19 summarizes emissions from field burning of agricultural residues in Hawaii for 2010 and 2015.

Table 19: Field Burning of Agricultural Residues Emissions by Gas (MMT CO_2 Eq.)

Source	2010			2015		
	CH_4	N_2O	Total	CH_4	N_2O	Total
Field Burning of Agricultural Residues	+	+	**0.01**	+	+	**0.01**

+ Does not exceed 0.005 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Methodology

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

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

where,

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

R_{RC} = residue-crop ratio; amount of residue produced per unit of crop production (0.19)

DMF = dry matter fraction; amount of dry matter per unit of biomass (62%)

$Frac_{BURN}$ = fraction of crop residue burned amount of residue which is burned per unit of total residue (95%)

BE = burning efficiency; the proportion of pre-fire fuel biomass consumed (0.81)

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 (0.68)

C or N content of residue = amount of C or N per unit of dry matter (42.4% and 0.4%, respectively)

$R_{emissions}$ = 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)

Data Sources

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

4.5. 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). Table 20 summarizes emissions from urea application in Hawaii for 2010 and 2015.

Table 20: CO_2 Emissions from Urea Application (MMT CO_2 Eq.)

Source	2010	2015
Urea Application	+	+

+ 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, 0.2 metric tons C/ton urea
44/12 = conversion of carbon to CO_2

Data Sources

Fertilizer sales data were obtained from the annual publication of Association of American Plant Food Control Officials (AAPFCO 2010-2014). AAPFCO reports fertilizer sales data for each fertilizer year (July through June).[28] Historical usage patterns were used to apportion these sales to the inventory calendar years (January through December). Synthetic fertilizer N application data were not available after 2013, so 2015 data were estimated based on 2013 data.

The *2006 IPCC Guidelines* default emission factor of 0.2 tonnes C/ton of urea was used to estimate the carbon emissions, in the form of CO_2, that result from urea application.

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

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

Agricultural soil carbon refers to the change in carbon stock in agricultural soils—either in cropland or grasslands—that have been converted from other land uses. Agricultural soils can be categorized into organic soils, which contain more than 12 to 20 percent organic carbon by weight, and mineral soils, which typically contain 1 to 6 percent organic carbon by weight (U.S. EPA 2017a). Organic soils that are actively farmed tend to be sources of carbon emissions as soil carbon is lost to the atmosphere due to drainage and management activities. Mineral soils can be sources of carbon emissions after conversion, but fertilization, flooding, and management practices can result in the soil being either a net source or net sink of carbon. Nationwide, sequestration of carbon by agricultural soils is largely due to enrollment in the Conservation Reserve Program, conservation tillage practices, increased hay production, and intensified crop production. Table 21 summarizes emissions from agricultural soils in Hawaii for 2010 and 2015.

Table 21: CO_2 Emissions from Agricultural Soils (MMT CO_2 Eq.)

Source	2010	2015
Agricultural Soil Carbon	0.53	0.56

Methodology

Emission estimates for Hawaii for this source were taken directly from the U.S. Inventory (U.S. EPA 2017a). These estimates were developed by Colorado State University using the DAYCENT biogeochemical simulation model, which simulates changes in soil carbon nationwide based on soil characteristics, weather patterns, crop and forage characteristics, and management practices (U.S. EPA 2017a).

Data Sources

Estimates of emissions from Hawaii's agricultural soils were available for the years 2010 and 2015 from the U.S. Inventory (U.S. EPA 2017a).[29]

4.7. Forest Fires (IPCC Source Category 3C1a)

Forest fires emit CO_2, CH_4, and N_2O as biomass is combusted. This source includes emissions from forest fires caused by lightning, campfire, smoking, debris burning, arson, equipment, railroads, children, and other miscellaneous activities reported by the Hawaii Department of Land and Natural Resources (DLNR). Table 22 summarizes emissions from forest fires in Hawaii for 2010 and 2015.

[29] State-level estimates from the U.S. Inventory do not include emissions from federal agricultural land, land enrolled in the Conservation Reserve Program after 2012, or the application of sewage sludge to soils, which were only estimated at the national scale (U.S. EPA 2017a).

Table 22: Forest Fire Emissions by Gas (MMT CO_2 Eq.)

Source	2010				2015			
	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total
Forest Fires	0.18	0.01	0.01	**0.20**	0.11	0.01	0.01	**0.12**

Note: Totals may not sum due to independent rounding.

Methodology

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

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

where,

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

Data Sources

Data for years 2010 and 2015 on acres burned by wildfire were obtained from the DLNR *Annual Wildfire Summary Report*, published by the Fire Management Program of the DLNR (and also found in DBEDT's Hawaii Data Book) (DLNR 2011, 2016).

Because acres burned data is related to wildland, it was necessary to develop a forestland to wildland ratio to estimate area of forestland burned. "Wildland under Protection" data, in million acres, were obtained for years 2010 and 2015 from the DLNR (DLNR 2011, 2016).

Managed forestland acreage time series data were obtained from the State of Hawaii Data Book (DBEDT 2017c). Area estimates of private forestland in the conservation district were summed with reserve forestland in the conservation district, forested natural areas and wooded farmland in order to generate total managed forested land area in Hawaii for 2010 and 2015. The annual carbon density for the lower 48 states (i.e., the fuel available for combustion) was provided by the U.S. Forest Service (USFS 2014).[30] The annual carbon density for the lower 48 states was not available after 2013, so carbon density in 2013 was used.

IPCC (2006) default combustion factors for tropical forest and shrubland were weighted using the ratio of Hawaii forest to shrubland area provided in the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA-CCAP) Descriptive Summary of the Changes in the Main Eight

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

Hawaiian Islands (2000). According to NOAA-CCAP, roughly half of Hawaii's forestland is shrub/scrubland, defined as land with vegetation less than 20 feet tall. Emission factors for CH_4 and N_2O emissions were obtained from IPCC (2006).

4.8. 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. Table 23 summarizes changes in carbon stocks in landfilled yard trimmings and food scraps in Hawaii for 2010 and 2015.

Table 23: CO_2 Flux from Landfilled Yard Trimmings and Food Scraps (MMT CO_2 Eq.)

Sink	2010	2015
Landfilled Yard Trimmings and Food Scraps	(0.05)	(0.05)

Note: Parentheses indicate negative values or sequestration.

Methodology

Estimates of the carbon sequestration in landfilled yard trimmings and food scraps for Hawaii were generated by the EPA's State Inventory Tool (U.S. EPA 2017d). 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 initial carbon that is stored for waste i
- ICC_i = the initial carbon content of waste i
- e = the natural logarithm
- k = the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition

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

Data Sources

Default values from the State Inventory Tool (U.S. EPA 2017d) 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 (U.S. EPA 2017d), were used to calculate the national-level estimates in 2010 and 2015. Hawaii population data were obtained from the State of Hawaii Data Book (DBEDT 2017c).

4.9. Urban Trees (IPCC Source Category 3B5a)

Trees in urban areas (i.e., urban forests) sequester carbon from the atmosphere. Urban areas in Hawaii represented approximately 5 percent of Hawaii's total area in 1990 and 6 percent of Hawaii's total area in 2010 (U.S. Census Bureau 1990 and 2012; DBEDT 2017b). Table 24 summarizes carbon flux from urban trees in Hawaii for 2010 and 2015.

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

Sink	2010	2015
Urban Trees	(0.38)	(0.40)

Note: Parentheses indicate negative values or sequestration.

Methodology

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

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

where:

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

Data Sources

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

Census-defined urbanized area and cluster values were used to calculate urbanized area in Hawaii.[31] Urban area and cluster data for 2010 were provided directly from the U.S. Census (2012). A linear trend was applied to the 2010 data to establish a time series from 2010 to 2015.

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

4.10. Forest Carbon (IPCC Source Category 3B1a)

Hawaii forests and shrubland contain carbon stored in various carbon pools, which are defined as reservoirs with the capacity to accumulate or release carbon (IPCC 2006). This category includes estimates of carbon sequestered in forests and shrubland aboveground biomass, which is defined as living vegetation above the soil, and belowground biomass, which is defined as all biomass below the roots (IPCC 2006). Table 25 summarizes carbon flux from forests and shrubland in Hawaii for 2010 and 2015.

Table 25: C Flux from Forests (MMT CO_2 Eq.)

Sink	2010	2015
Forest Carbon	(2.66)	(2.62)

Note: Parentheses indicate negative values or sequestration.

Methodology

The Tier 1 Gain Loss Method as outlined by the *2006 IPCC Guidelines* (IPCC 2006) was used to calculate carbon flux in managed Hawaii forests.[32] This method requires forestland acreage time series data as well as aboveground biomass growth rate, the ratio of below ground biomass to aboveground biomass,

[31] 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" (U.S. EPA 2017a).
[32] 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.

and the carbon fraction. The Gain Loss method calculates annual increase in biomass carbon stocks using the following equation:

$$Forest\ CO_2\ Flux = \sum_i (A_i \times G_{TOTAL\,i} \times CF_i) \times \frac{44}{12}$$

where,

A	= forest land area, hectares
G_{TOTAL_i}	= mean annual biomass growth, tonnes of dry matter/hectare
CF_i	= carbon fraction of dry matter, tonnes C/tonne of dry matter
44/12	= conversion of carbon to CO_2
i	= forest type (forest or shrubland in Hawaii)

Data Sources

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

Roughly half of Hawaii's forestland is shrub/scrubland, defined as land with vegetation less than 20 feet tall (NOAA-CCAP 2000). Forestland was divided into two sub-categories: forest and shrub/scrubland using the island-specific forestland:shrubland ratios derived from the NOAA-CCAP study.

Mean biomass growth is derived by multiplying the average annual above-ground biomass growth by the sum of one and the ratio of below ground biomass to above ground biomass. This biomass growth was then multiplied by a carbon factor to determine the net addition of carbon. In obtaining the mean annual biomass growth and carbon fraction factors, the tropical Asia Insular IPCC (2006) default values were used as default factors for forest and shrubland.[33]

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

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Appendix A: IPCC Source and Sink Categories

Table 30: Summary of IPCC Source and Sink Categories Included/Excluded from the Analysis

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

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

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