Review of Agricultural Greenhouse Gas Emissions and Sequestration in Vermont

Inventory Tools and Methodological Recommendations

03/28/2024

AGENDA

1. Project Overview
2. GHG Inventory Analysis
3. Tool Review
4. Mitigation Practices
5. Conclusions & Recommendations

Project Overview

PROJECT GOALS

1. Evaluate Vermont's agricultural inventory for completeness and IPCC alignment
2. Identify greatest opportunities for inventory refinement
3. Assess GHG inventory tools and existing datasets for applicability to Vermont
4. Recommend a methodology approach for each IPCC agriculture category

Approach to the Work

Completeness and Inventory Assessment

- Assess Vermont's 2020 GHG inventory for completeness
- Review activity data provided to ICF for relevance for GHG reporting

Review GHG Tools & Models

- Review 10 existing tools, models and data for:
  - Applicability
  - Alignment with IPCC,
  - Ability to completely cover the category

Assess Practice Implementation Tracking Capacity

- Identify the key climate smart agricultural practices for Vermont
- Evaluate how to track climate change mitigation impacts

Provide Methodology Recommendations

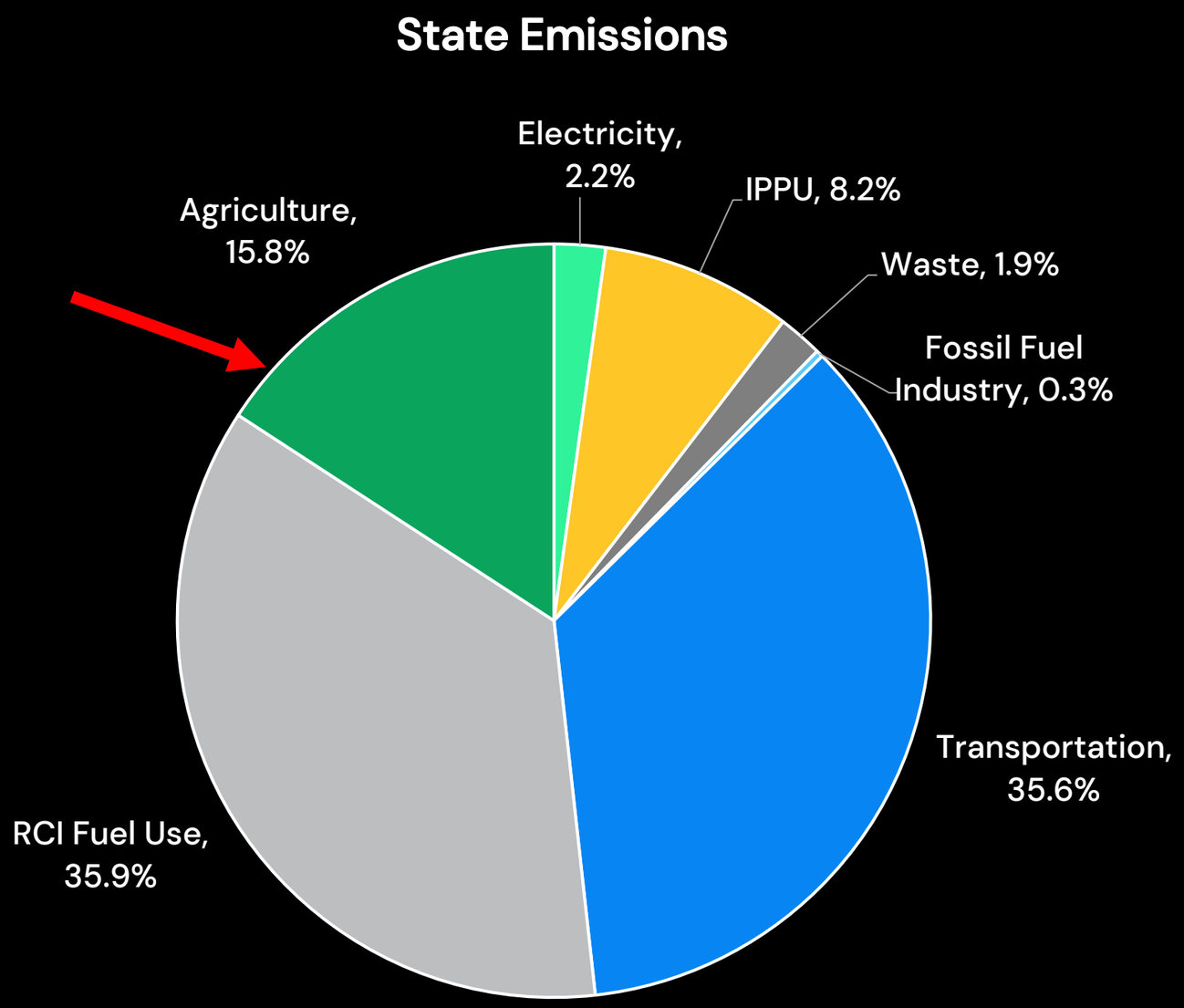
- Recommend inventory approach for each of the relevant IPCC agricultural categories

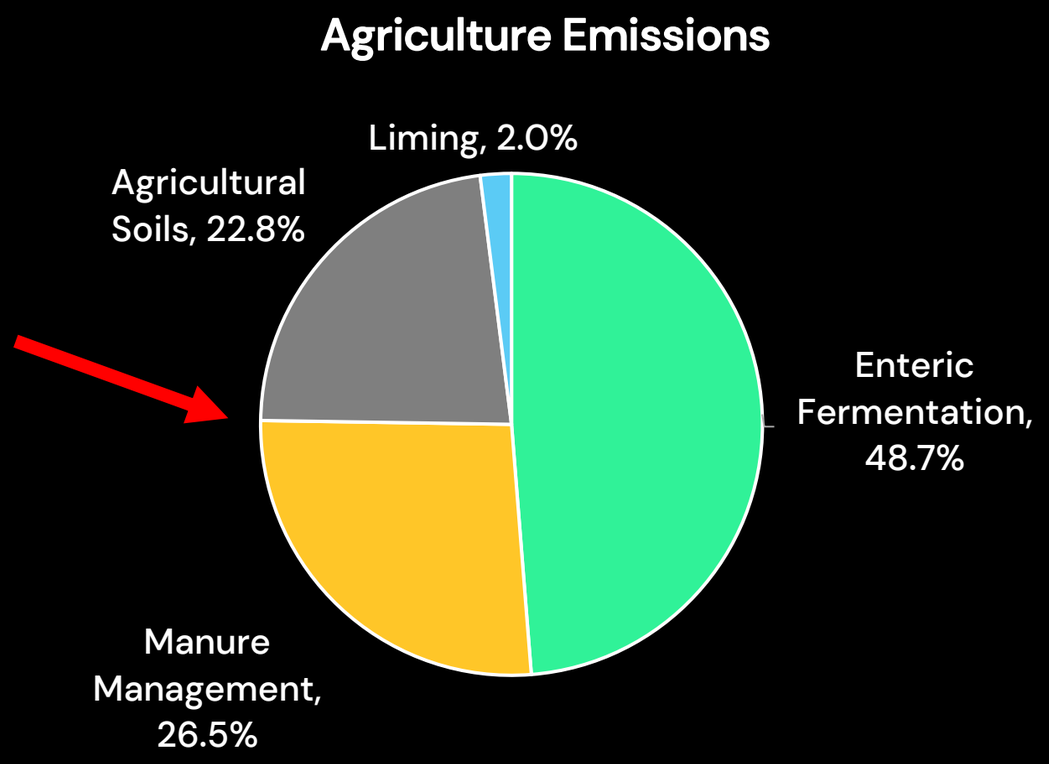
Identify Key Opportunities

- Identify the key opportunities for inventory refinement, including:
  - Reporting of a complete inventory
  - Developing more robust accounting methods

GHG Inventory Analysis

Vermont's 2020 GHG Inventory





Gross and Net Emissions from Agriculture

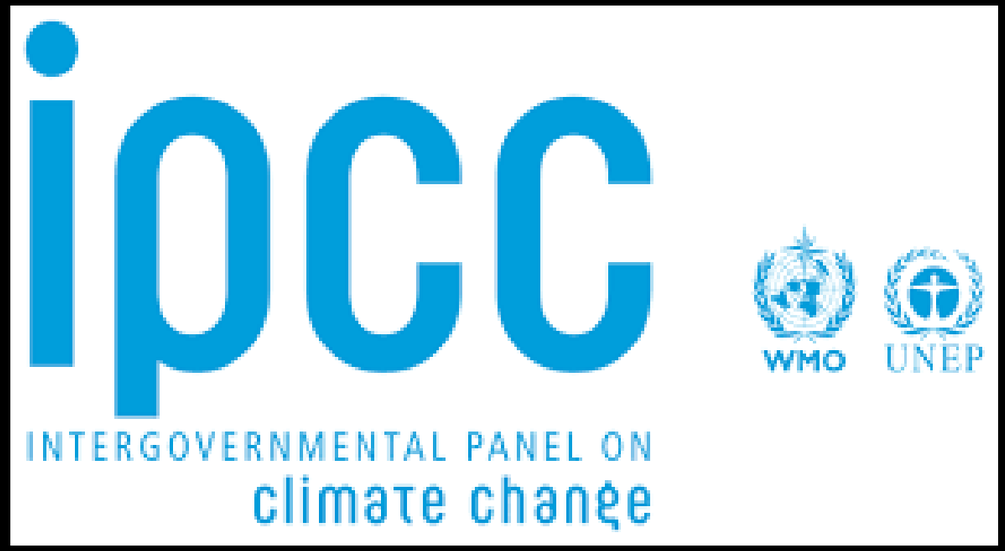
SIT Module	Agriculture Emission Source	Metric Tonnes CO_2e	Percent of Net Emissions
Agriculture	Enteric Fermentation	613,833	38%
	Manure Management	333,758	21%
	Agricultural Soils (N_2O)	286,546	18%
	Liming and Urea Fertilization	25,212	2%
Agricultural Lands (Croplands and Grasslands	Cropland Remaining Cropland	(114,961)	23%
	Land Converted to Cropland	482,036	
	Grassland Remaining Grassland	2,024	-1%
	Land Converted to Grassland	(24,815)	
Total Emissions		1,743,436	
Total Removals		-140,776	
Net Emissions		**1,602,660**	

State Inventory Tool (SIT)

- Vermont has utilized the SIT Inventory tool to produce it's GHG inventory
- Free, easy-to-use, and user friendly
- The primary source of activity data in SIT is EPA's U.S. Greenhouse Gas Inventory of Emissions and Sinks
- Emission sources in the *Agriculture module* include crop and livestock emissions
- The *LULUCF module* includes soil carbon fluxes on agricultural land (grassland and cropland) that can be added to GHG estimates from Agriculture module
- **SIT does have limitations that can hinder Vermont tracking adoption of climate smart practices**

IPCC Alignment in Vermont's SIT Inventory

- The Intergovernmental Panel on Climate Change (IPCC) have developed GHG emission estimation methods for anthropogenic GHG emissions
- The IPCC GHG estimation guidance is used to report national GHG emissions to the United Nations and ensure that national emissions estimates are comparable
- The guidance therefore is also important for sub-national groups, such as the State of Vermont
- Since SIT is developed based on U.S. GHG Inventory Reporting and uses the U.S. methods aligned with the IPCC guidance, deepening the understanding of the IPCC methods is important for Vermont



Vermont's SIT Inventory Completeness Assessment

IPCC CATEGORY	EMISSION SOURCE DESCRIPTION	COMPLETENESS ASSESSMENT	IN 2022 INVENTORY
3A - ENTERIC FERMENTATION	CH_4 from dairy and beef cattle, swine and other species (e.g., sheep, goats and horses)	Complete	Yes
3B - MANURE MANAGEMENT	CH_4 and N_2O from dairy and beef cattle, swine, poultry and other species (e.g., sheep, goats and horses)	Complete	Yes
3C – CH4 FROM RICE CULTIVATION	CH_4 from rice ebullition (N_2O reported in direct and indirect N_2O sources)	Complete	NA – de miniums
3Da - DIRECT N_2O EMISSIONS FROM MANAGED SOILS	From organic and inorganic (synthetic) N fertilizers applied to agricultural soils, crop residues, managed soils and manure deposited onto pastures by grazing animals	Complete	Yes
	Direct N_2O from N mineralization and drainage of organic soils (Histosols)	Incomplete	No
3Db - INDIRECT N_2O EMISSIONS FROM MANAGED SOILS	Atmospheric deposition Volatilization and run-off	Incomplete	Sources missing for direct N2O also missing for indirect N2O
3F – FIELD BURNING OF AGRICULTURAL RESIDUES	CH_4, CO, NO_x and N_2O from biomass burning	Complete	NA - de minimus
3G – LIMING, UREA APPLICATION AND OTHER CARBON CONTAINING FERTILIZERS	CO_2 from Liming, Dolomite and Urea application, and other carbon containing fertilizers	Complete	Yes
4B – CROPLAND SOIL CARBON	Soil carbon fluxes	Complete	Yes
4C – GRASSLAND SOIL CARBON	Soil carbon fluxes	Complete	Yes

Activity Data Assessment – Livestock Management

Name	File Type	Included Data
PDB Practice Export Examples for ICF	Excel	Crop type, acres applied, practice applied, and location applied.
VT_P_Index_6.3 (1)	Excel	Vermont specific information on growing season runoff, runoff adjustment factors, % cover, average precipitation, manure incorporation information, and hydrologic soil groups
CowPower_forICF_20230609	Excel	Farms with anaerobic digesters (count and number of head covered) and estimated biogas production
2022_Ag Module	Excel	Default data on fertilizer application, crop acreage, animal population, and limestone and urea application
Example Ag Data for ICF	PDF	General information on farm animal population number, waste, and land area data

- 37 Large Farm Operation Nutrient Management Plans
- Publicly available datasets from the Vermont Carbon Budget report

Comparison of Manure Data in the VCB and SIT Default Data

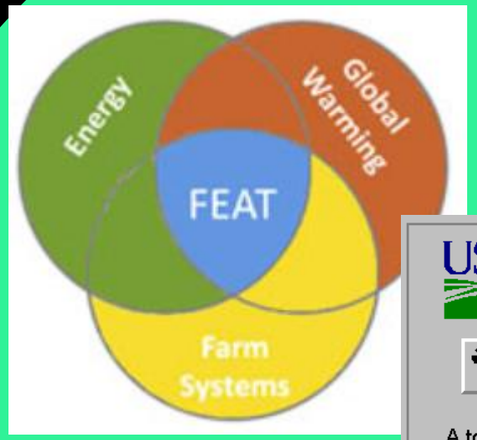
Table 3. Distribution of dairy cow manure managed in different manure management systems for the year 2020

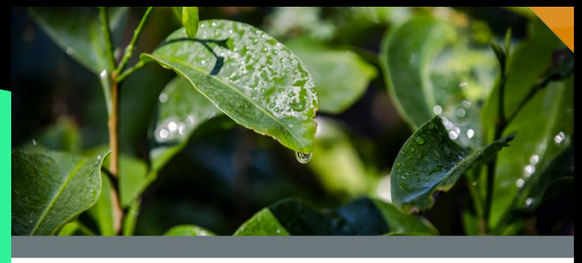
	EPA SIT AWMS%	Vermont Carbon Budget AWMS%	Percent Difference
Anaerobic Lagoon	23%	Not Included	23%
Liquid/Slurry	5%	47%	42%
Daily Spread	3%	4%	1%
Solid Storage	16%	7%	8%
Pasture	14%	29%	15%
Deep Pit	26%	Not Included	26%
Anaerobic Digester	Not included	4%	4%
Deep bedding	Not Included	8%	8%
Composting	Not Included	1%	1%

Tool Review

Models and Tools Evaluated

Quantification Tools





Ex-Ante Carbon-balance Tool | EX-ACT

GUIDELINES

Second edition – Tool version 9

USDA

Pasture Systems and Watershed Management Research Unit

USDA / Agricultural Research Service

Integrated Farm System Model

Version 4.7

A tool for evaluating and comparing alternative technologies and management strategies on representative farms.

This program is available to download from the address *http://ars.usda.gov/naa/pswmru*.

COMET-Planner USDA Natural Resources Conservation Service U.S. DEPARTMENT OF AGRICULTURE COLORADO STATE UNIVERSITY

EPA United States Environmental Protection Agency

State Inventory and Projection Tool

Holos

A tool to estimate and reduce GHGs from farms

Process Based Models

Century 100 DayCent

APEX Agricultural Policy Environmental eXtender model

The DNDC Model

EPA Data

EPA United States Environmental Protection Agency

Greenhouse Gas Inventory Data Explorer

Evaluation Criteria

- 10 reviews were conducted
  - 6 quantification tools
  - 3 process-based models
  - EPA's state level inventory data
- Analysis was conducted through
  - direct tool/model use, where possible
  - a literature review
  - tool user resources
- The tools were ranked based on 7 key criteria across each IPCC ag sub-category
- **SIT emerged as 1st or 2nd choice across all categories**

Key Criteria	Description
Whether the tool is current	Publication Year / Last Updated
	Ongoing maintenance
Alignment with IPCC / Other Relevant Guidance	Methodology
	Emission Factors
	Alignment with IPCC
Fit for Purpose	Scope - Spatial Resolution
	Scope - Temporal Resolution
	Scope - Emission Sources Included
Scope	Scope - GHG's
	Scope - Management Practices
	Scope - Mitigation
User Experience	Tool Type
	Input Parameters
	Outputs
Complexity	Technical abilities required
	Level of Effort
Cost	Cost (financial)
	Extent of use among peers

Tool Recommendations by IPCC Ag Sub-Category

IPCC CATEGORY	RECOMMENDED MODEL OR TOOL
3B – Manure Management	EPA State Inventory Tool
3A – Enteric Fermentation	EPA State Inventory Tool
3C – CH4 from Rice Cultivation	NA – de minimus
3D – N_2O Emissions from Managed Soils	EPA State Inventory Tool
3F – Field Burning of Agricultural Residues	NA – de minimus
3G – Liming, urea application and other carbon containing fertilizers	EPA State Inventory Tool
4B – Cropland Soil Carbon	EPA State Inventory Tool GHG Impacts from Adoption of Climate Smart Agricultural Practices from COMET-Planner
4C – Grassland Soil Carbon	EPA State Inventory Tool GHG Impacts from Adoption of Climate Smart Agricultural Practices from COMET-Planner

Models and Tools Evaluated: Key Takeaways

Recommended for Vermont's AFOLU Inventory Estimates:

- **SIT**
  - Free and easy to use
    - Able to be accurately run with moderate levels of expertise and minimal time investment
  - Uses U.S. EPA GHG Inventory default data,
  - Employs mostly IPCC Tier 2 methods
- **COMET-Planner**
  - Able to estimate the GHG impacts of adoption of climate smart practices
  - Could be used in combination of SIT tool to estimate GHG reductions
- The **U.S. Disaggregated Data**
  - Useful to validate estimates generated either by SIT or another emission estimation tool

COMET-Planner 3.1

COMET Planner is a USDA-hosted free tool based on DayCENT outputs that is designed to provide generalized estimates of the greenhouse gas impacts of conservation practices

- It can be used to find state and county-level emission factors associated with the adoption of climate smart practices, specifically:

Cropland Management

- Reduced till and no-till
- Nutrient management
- Conservation crop rotation
- Cover Crops
- Mulching
- Strip Cropping

Cropland to Herbaceous Cover

- Forage and biomass planting
- Wind barriers
- Vegetative barriers
- Riparian herbaceous cover
- Contour buffer strips
- Field Border
- Filter strip
- Grassed waterway

Cropland to Woody Cover

- Tree/shrub establishment
- Windbreak/shelterbelt
- Riparian Forest buffer
- Hedgerow Planting
- Alley Cropping
- Multi-story Cropping

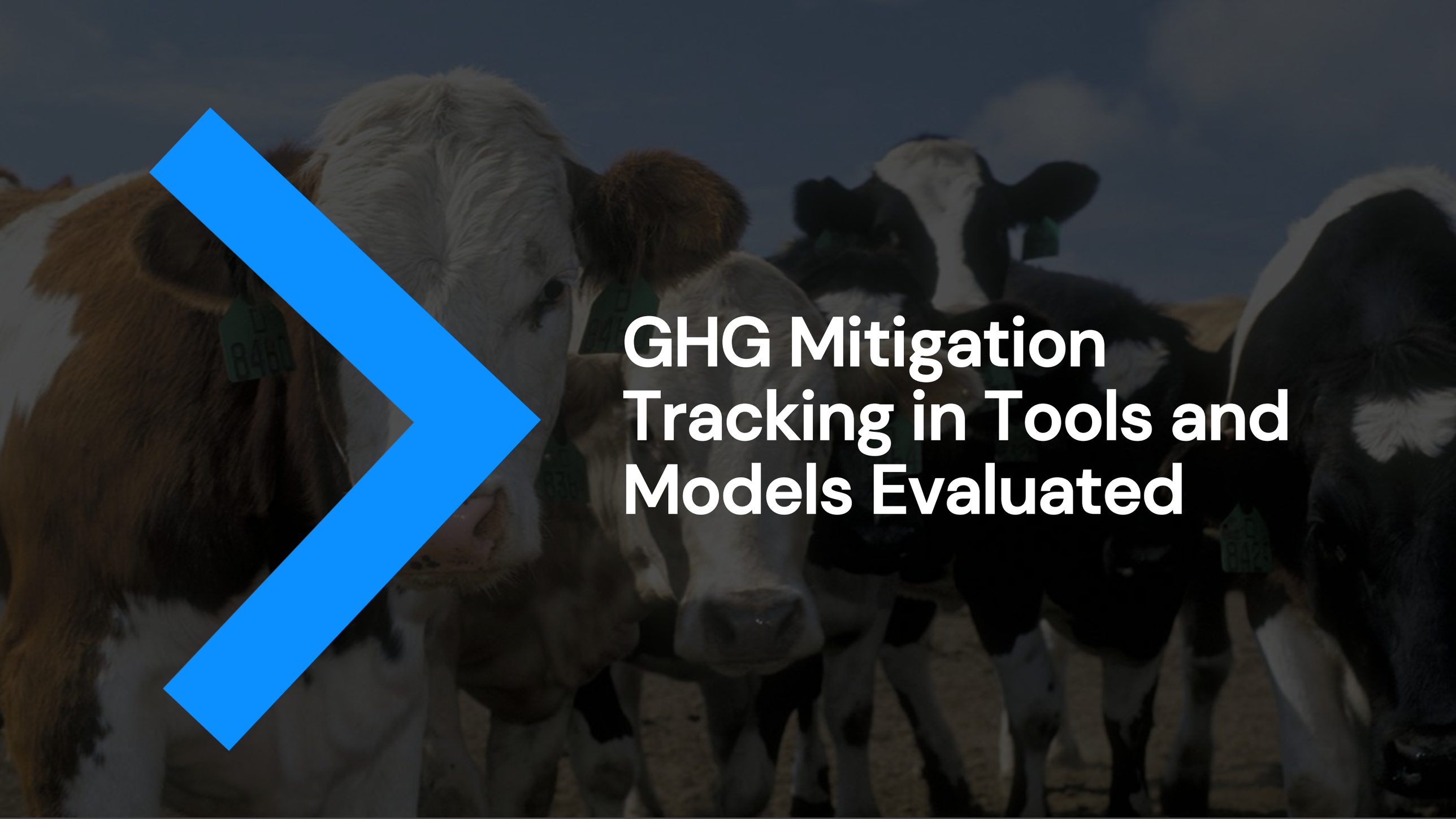
Grazing Lands

- Nutrient management
- Range planting
- Silvopasture
- Prescribed grazing

Models and Tools Evaluated: Key Takeaways

Not Recommended for Vermont's AFOLU Inventory Estimates:

- **APEX** requires further processing to model outputs to align emissions with IPCC categories and does not model CH4 emissions
- **DayCENT** and **DNDC** both require model expertise and have costs associated. ICF recommend Vermont assess whether the expected modelled results will justify these costs
- **EX-Act** was developed to evaluate the GHG emissions and carbon stock changes for land management projects, and only considers one dominant soil and climate type at a time
- **FEAT** is a crop emissions farm scale GHG estimation tool and it does not estimate livestock emissions
- **Holos** is a farm scale GHG estimation and planning tool, and reports emissions from a farm production perspective
- **IFSM** is also a farm scale GHG estimation tool with a research and teaching focus, does not model long term soil carbon fluxes and requires a medium level of expertise to navigate



GHG Mitigation Tracking in Tools and Models Evaluated

Management Practice Climate Impact Ratings

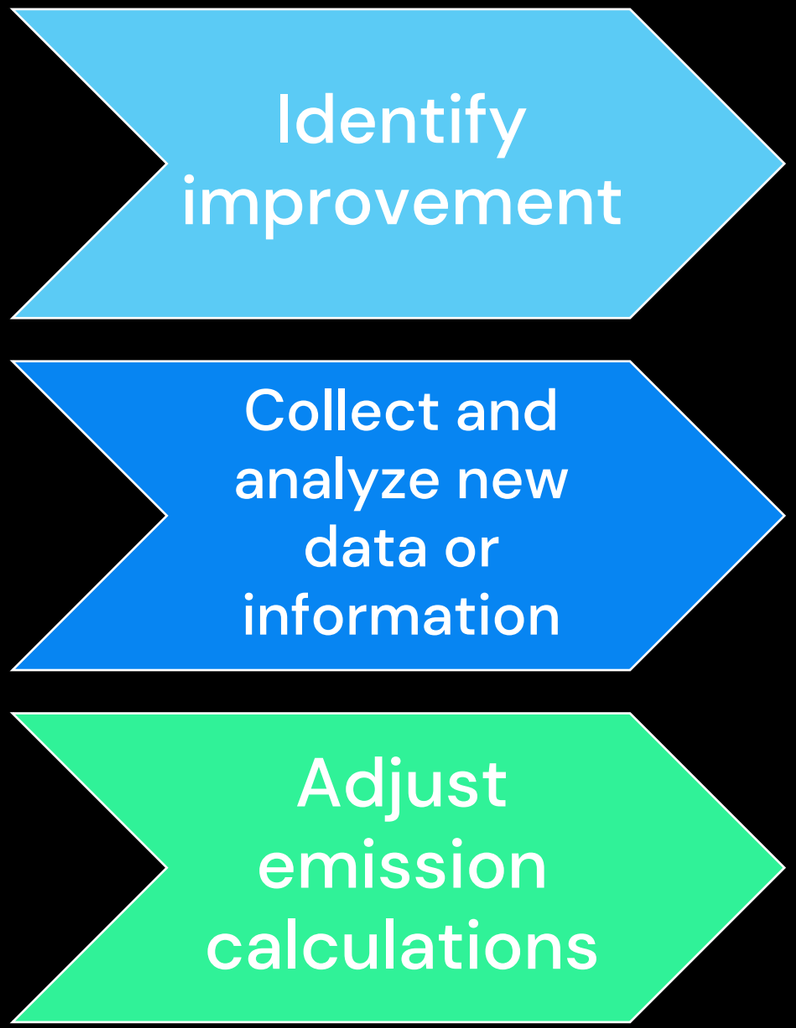
	Vermont Practices	NRCS Practice #(s)	Climate Rating
Livestock	Feed Management	592	4
	Manure Storage	366	4
	Manure Storage	367, 313, 359, 632	4
	Manure Injection	590	3
	Manure Incorporation	590	3
	Grazing Management	528	2
	Grazing Management	528, 512	2
	Grazing Management	E528R	2
	Application of nitrification or urease inhibitors	590	2
	Rumen manipulation	592	2
Crop	Crop to Hay (permanent seed down)	E512A, E512C	4
	Nutrient Management	590	3
	Reduced Tillage	345	3
	Riparian Forest Buffer	391	3
	No-Till	329	3
	Precision Agriculture	590, E590B	3
	Cover Crop	340	3
	Silvopasture	381	2
	Alley Cropping/Multi-Story Cropping	311, 585	2
	Sustainable Crop Rotation	328	2
	Filter Strip (grass buffer)	390, 412, 393	1
	Precision Agriculture		1

Key Takeaways for Tracking Progress Towards Mitigation

- **SIT is the recommended tool** for Vermont's Ag inventory,
  - However SIT lacks the ability to track impacts from adoption of climate smart practices
- **COMET-Planner is recommended to track impacts from adoption of climate smart practices**
  - To be used in combination SIT Agriculture/LULUCF modules and U.S. State Level Inventory Data.
- **Data in the NMP's could be used to generate Tier 2 activity data**
  - **Provides** the greatest opportunity to improve Vermont's ag inventory as enteric fermentation and manure management are largest GHG sources

GHG Inventory Improvements

Opportunities for Inventory Improvements Overview



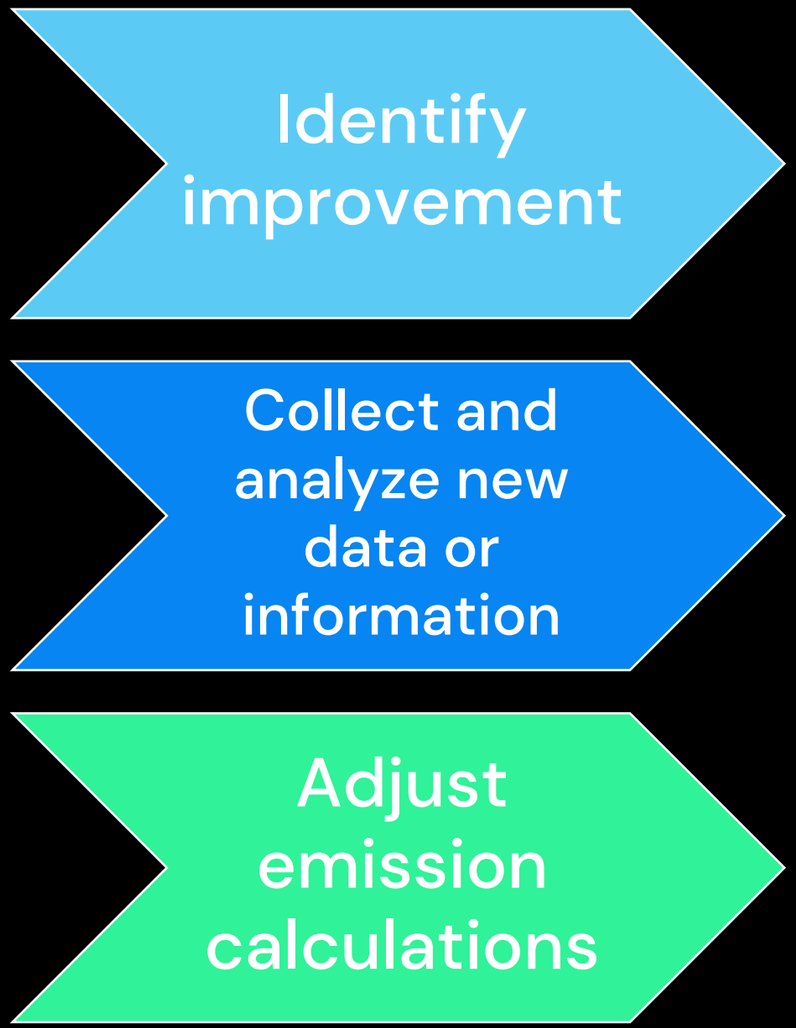
CHALLENGE

- SIT does not track changes in emissions due to adoption of climate smart agricultural practices
- SIT GHG estimates emissions based on changes in activity data (i.e., livestock population, manure managed in a specific system etc.)

(LONG-TERM) SOLUTION

- We recommended Vermont develops a state specific Ag GHG inventory tool to:
  - Accurately account for Vermont's ag GHG emissions as climate smart practices are adopted
  - Inform policy decisions related to emission mitigation practices
- We recommend that Vermont develop an inventory improvement prioritization process to
  - Focus limited resources on high impact updates
  - Establish a funding pool dedicated to maintaining and improving the ag GHG inventory

Opportunities for Inventory Improvements: Livestock



Livestock Emissions Based on Population:

CHALLENGE

- Livestock population activity data underpins livestock GHG emission estimates
- There are discrepancies across population input data

SOLUTION

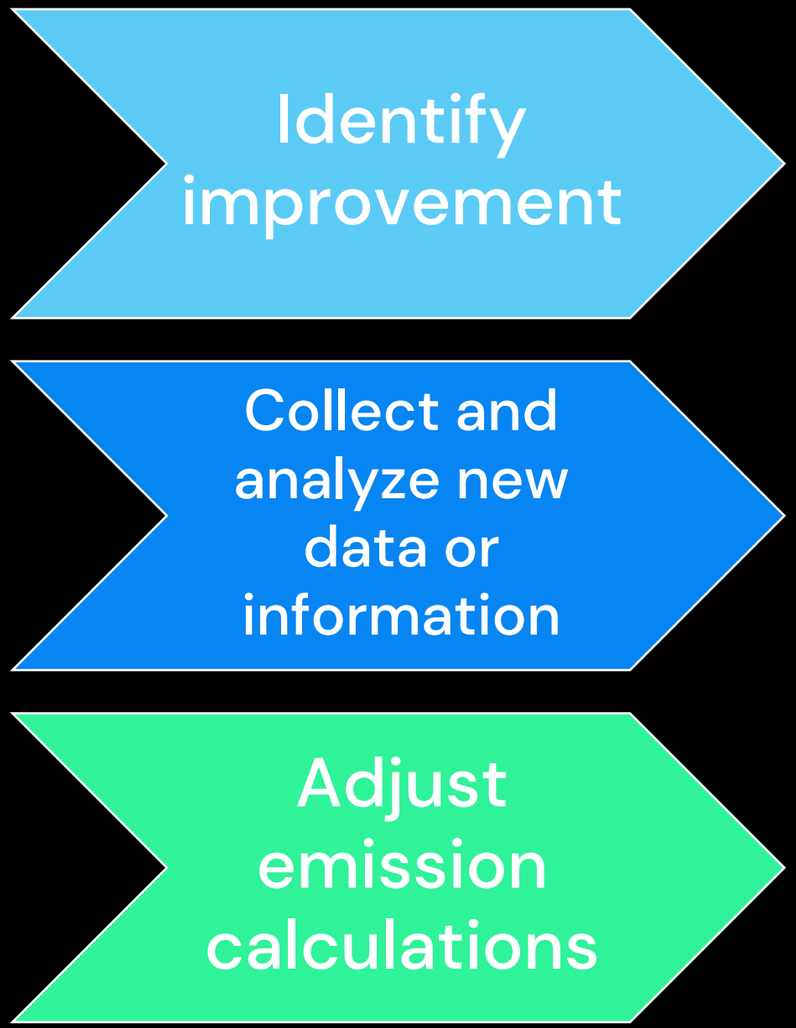
- ICF recommend consistent population data for all livestock types and sources, to avoid under–/over-estimations

E.g., Activity Data Needed for Livestock Estimates

- Data needed :
  - annual average population (number of livestock or poultry as per calculations for Tier 1)
  - average daily feed intake, estimated based on daily energy requirements in megajoules (MJ) per day and / or kg per day of dry matter, derived from:
    - weight (kg)
    - average weight gain per day (kg)
    - feeding situation: confined, grazing, pasture conditions
    - milk production per day (kg/day) and fat content (%)
    - average amount of work performed per day (hours day-1)
    - percentage of females that give birth in a year
    - wool growth (sheep)
    - number of offspring
    - feed digestibility (%)
  - methane conversion factor (percentage of feed energy converted to methane)
  - other data (e.g., milk fat and or protein content)

Reference: IPCC 2006 Guidelines Vol 4, Chapter 10, Section 10.2 (no refinement to this section in 2019) https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf

Opportunities for Inventory Improvements: Livestock



Enteric Fermentation:

CHALLENGE

- SITs default digestible energy (DE) data for Vermont comes from U.S. GHG Inventory, where data are weighted regionally for the Northeast region (see Annex 3–Part B)

SOLUTION

- ICF recommends Vermont assess whether the Northeast regional average accurately reflects the energy requirements of Vermont's cattle systems

Opportunities for Inventory Improvements: Livestock

Identify improvement

Collect and analyze new data or information

Adjust emission calculations

Manure Management:

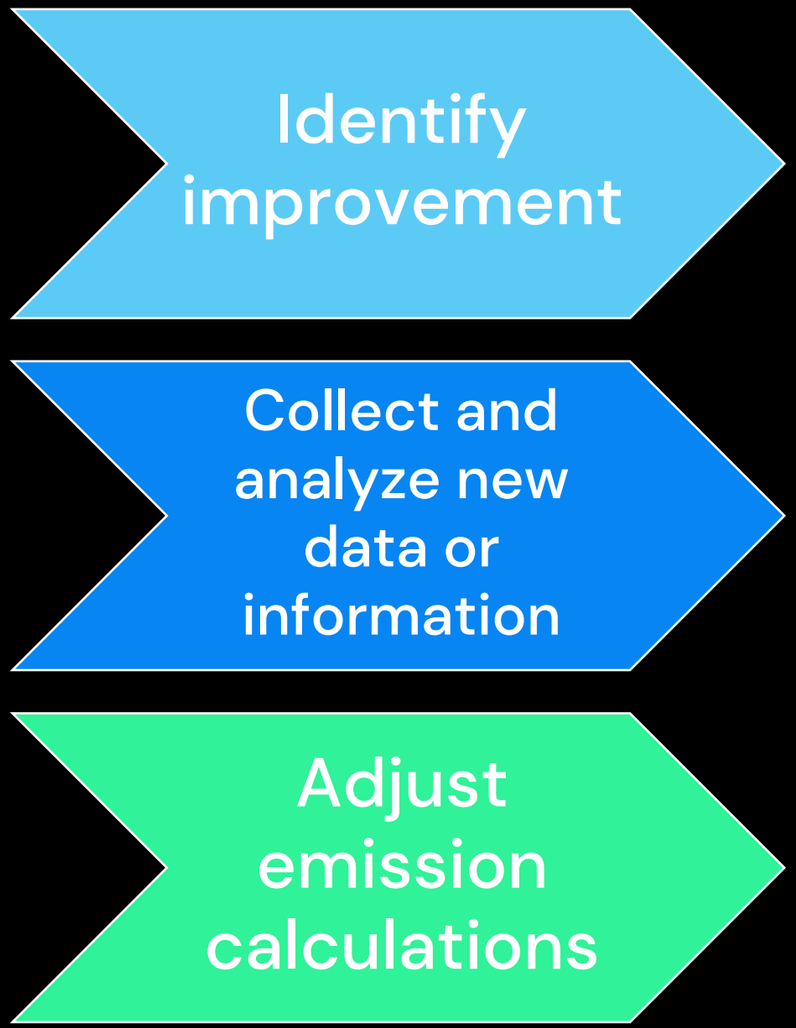
CHALLENGE

- SIT uses a regionally weighted CH_4 conversion factor (MCF), to estimate methane production from manure management system (MMS)
- This is problematic as
  i. it cannot be adjusted as the proportion of manure increases in a given MMS, e.g., anerobic digestors, over time, and
  ii. The regional weighting may not accurately reflect Vermont's production circumstances
  iii. ICF found that the ratio of MM systems used in SIT for VT does not align with the ratio of MM systems reported in the VT Carbon Budget

SOLUTION

- ICF recommends that Vermont develop more sophisticated estimates of manure management emissions, so that emission mitigation efforts can be tracked over time

Opportunities for Inventory Improvements: Agricultural Soils



Soil Carbon from Croplands and Grasslands:

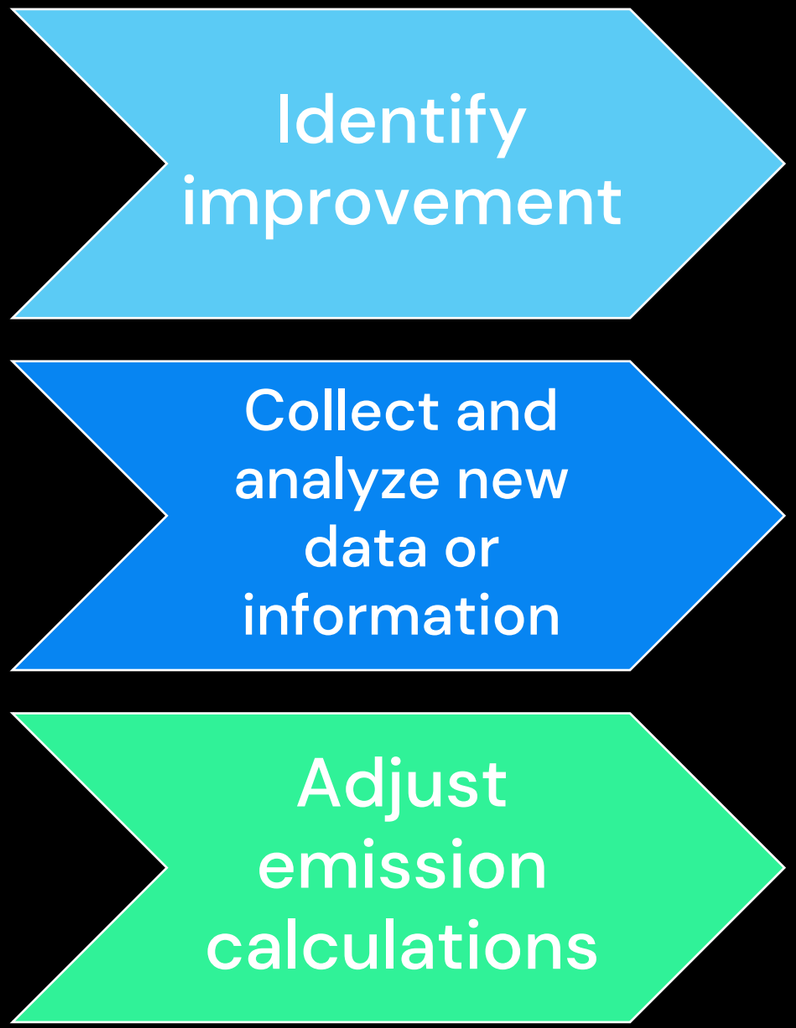
CHALLENGE

- SIT modelling of soil carbon is based on U.S. GHG inventory modelling, which was performed in 2015 at the Tier 3 level using the DayCENT model and USDA source data

SOLUTION

- ICF recommends asking EPA for 2015 modelling assumptions for climate smart ag practice adoption rates and the Vermont specific outputs
- These could be as a baseline to track SOC changes from climate smart agriculture practice adoption using COMET-Planner

Opportunities for Inventory Improvements: Agricultural Soils



N_2O from Agricultural Soils:

CHALLENGE

- The SIT Agriculture module utilizes a Tier 1 approach for N_2O from Agricultural Soils, where as the US GHG Inventory is based on a combination of Tier 1 and Tier 3 modelling
- SIT does not currently account for indirect emissions from N mineralization or crop residues

SOLUTION

- ICF recommends adding indirect emission from N mineralization and crop residues to the Vermont inventory based on guidance in the IPCC 2019 Refinement

Conclusions

Key Takeaways for Tracking Progress Towards Mitigation

- **While SIT is the recommended tool** for Vermont to produce its state level inventory, SIT lacks the ability to track the GHG and carbon sequestration impacts from changes to management practices
- **COMET-Planner is recommended to account for GHG impacts from management practices**, in combination with the SIT Agriculture/LULUCF modules and U.S. State Level Inventory Data.
- The greatest opportunity identified for refinement of Vermont's agricultural GHG inventory is use of the **data in the NMP's to produce robust Tier 2 activity data** for calculation of Vermont's largest agricultural sub-categories, which are enteric fermentation and manure management
- Process-based models (e.g. DayCENT and DNDC) are available to produce Tier 3 estimates, but require region specific calibrations and significant time/resource investments to use; hence this route is not recommended for Vermont's inventory compilation

Greatest Opportunities for Inventory Improvement

Sub-Sector Methodological Recommendations

- **Enteric fermentation** estimates could be improved by ensuring the energy requirements of animals in SIT accurately reflect the requirements of Vermont's cattle as the highest emitters
- **Manure Management** estimates could be improved by using a more sophisticated estimation method, that can accurately account for the emissions from manure managed in different manure management systems
- **N_2O from Agricultural Soils** estimates could be made more complete by accounting for indirect emissions from the sources that are currently unable to be estimated in SIT
- SITs **soil organic carbon stock** estimates are based on combination Tier 1 and 3 modelling from 2015, but aren't able to track the effects of climate smart agricultural practices. It is recommended to supplement the estimate with practice implementation data from COMET-Planner

Implications for Vermont

- When comparing the same reporting year for a previous inventory and updated inventory (e.g., for 2020), these inventory improvements may result in either an increase or decrease in reported emissions from enteric fermentation and manure management, and may result in an increase in reported emissions for N_2O from agricultural soils

Thank you!