

GHG Modeling of Alternative Farm Bill Scenarios

Report

Prepared for

The Platform for Agriculture and Climate Transformation

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Contents

Introduction	1
Input Data	2
Alternative Budget Scenarios	3
Steps to Constructing Budget Scenarios.....	4
Climate-Smart Agriculture and Forestry Practices 2024	9
Emissions Reductions and Implementation Costs of CSAF Activities	11
Multi-Model Approach	12
Marginal Abatement Cost Curve Model (MACC Model).....	12
REAP Assessment Tool	15
The U.S. FABLE Calculator	18
Calibration of FABLE Calculator Data.....	20
Model Functionality Changes to Represent CSAF Practices in MACC Model Results	22
Results	22
National Results	22
Mitigation	22
Cost of Mitigation	28
Direct and Indirect Land Use Change and Indirect Emissions.....	29
State and Regional Results	33
Conclusions	36

Figures

Figure 1. U.S. Greenhouse Gas Inventory for Agriculture, Forestry, and Other Land Uses (AFOLU; bars represent individual categories, black line represents net emissions)	1
Figure 2. Annual Investment in CSAF Activities across Each Scenario, Shown as Baseline Farm Bill Funding, and Additional Funding.....	7
Figure 3. Cumulative Funding by CSAF Practice for each Scenario (2023-2050).....	8
Figure 4. Illustration of Coupled Modeling Approach to Estimate Net GHG Impacts.....	12
Figure 5. Simplified Marginal Abatement Cost Curve (MACC) for the Rural Energy for America Program (REAP), Derived from FY2023 Grant-Funded Projects	18
Figure 6. Annual Emissions Reductions across Each Scenario Broken out by Mitigation Category, 2023–2050	24
Figure 7. Historical AFOLU Emissions for the United States, U.S. EPA Projected Baseline Emissions for 2020-2050, EPA Projected Mitigation Focused Emissions from 2020–2050, and Alternative Farm Bill Funding Scenarios Projected Emissions 2023–2050	26
Figure 8. Abatement vs. Total Investment by Mitigation Category under Reinvest IRA, with Climate Focus	29
Figure 9. Land Area Enrolled in CSAF Activities Grouped by Productivity Impacts Category (Positive, Large Positive, and Negative Yield Impacts).....	30
Figure 10. Induced Land Use and Land Cover Change Due to Adopted CSAF Practices in Alternative Budget Scenarios.....	31
Figure 11. Acres of Direct Land Conversion Due to Enrolled CSAF Practices across Alternative Budget Scenarios	32
Figure 12. Induced Land Use Change Emissions and Indirect Crop Emissions: Difference from Current Farm Bill Scenario	33
Figure 13. Share of National Mitigation by State across Scenarios (2023-2050)	34
Figure 14. Top Mitigation Category in Each State under the Reinvest IRA with Climate Focus Scenario (2023-2050)	35

Tables

Number		Page
Table 1.	Projected Funding for Climate-Smart Agriculture and Forestry across Each Scenario during the IRA Period (2023–2031) and Post-IRA (2032–2050)	4
Table 2.	List of CSAF Practices Which Were Excluded from this Analysis	10
Table 3.	Constraints Used in the MACC Model, along with the Dimensions Included in the Constraint, and Data Sources	13
Table 4.	Per Unit Installation Cost for Manure Management Systems (2024 USD)	15
Table 5.	CSAF Practices Included in the REAP Assessment Tool	16
Table 6.	Cumulative Emissions Reductions Across Each Scenario from 2023 to 2050 and Cumulative Emissions Reductions During the Near-Term (2023–2031) and Long-Term (2032-2050) for Each Scenario. Average Annual Emissions (MtCO ₂ e/yr.) for Each Period are Shown in ().	23
Table 7.	Greenhouse Gas Mitigation by Specific GHGs Across Scenarios	25
Table 8.	Greenhouse Gas Mitigation from Each USDA Program and Cumulative Emissions Changes from Land Use Change (LUC) Across Scenarios (MtCO ₂ e)	28

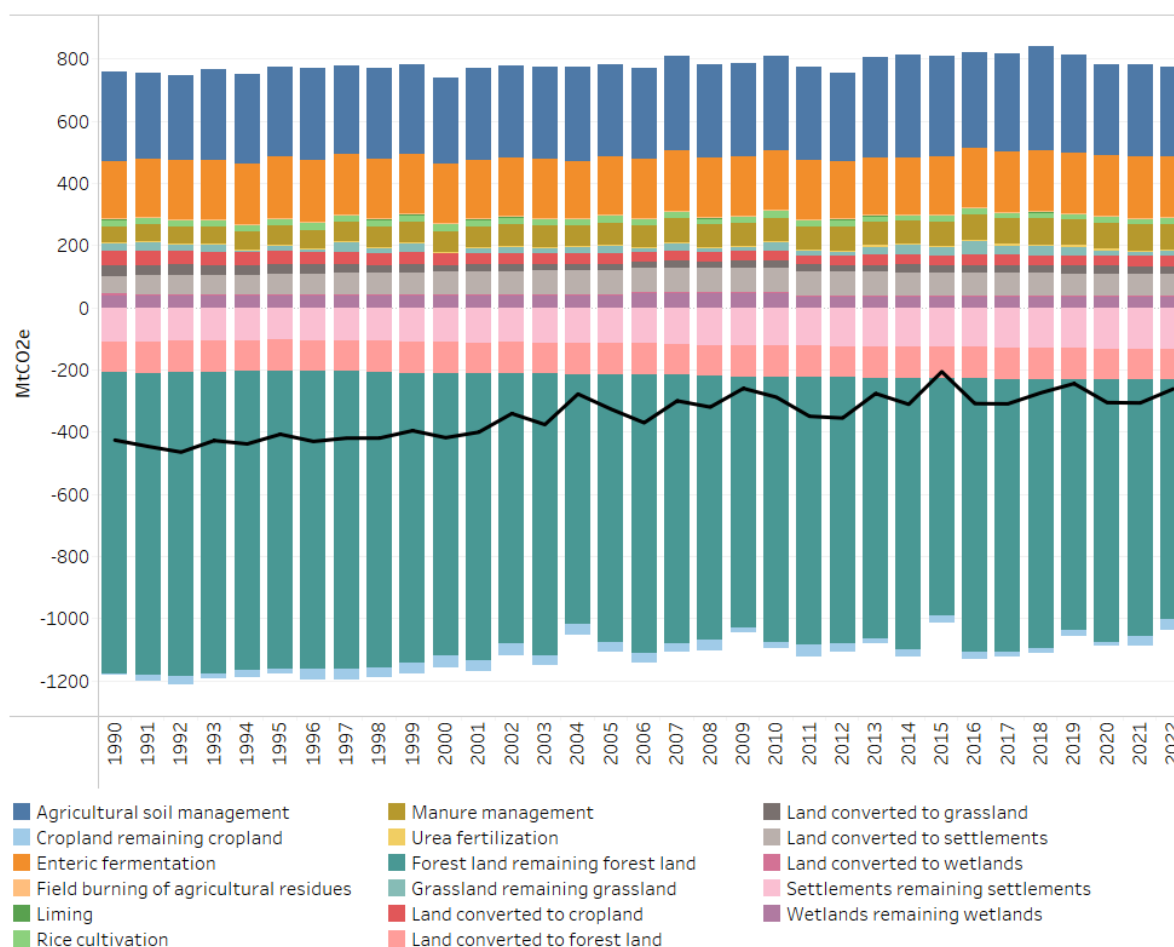
List of Acronyms

ACEP	Agricultural Conservation Easement Program
AFOLU	Agriculture, Forestry, and Other Land Use
AWD	Alternating Wetting and Drying
BAU	Business as usual
CBO	Congressional Budget Office
CSAF	Climate-smart agriculture and forestry
CSP	Conservation Stewardship Program
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
GDP	Gross Domestic Product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
LUC	Land Use Change
MACC	Marginal Abatement Cost Curves
NRCS	Natural Resources Conservation Service
PSD	Production, Supply and Distribution
RCA	Resources Conservation Act
RCPP	Regional Conservation Partnership Program
REAP	Rural Energy for America Program
USDA	U.S. Department of Agriculture

Introduction

The agriculture sector presents significant opportunities to reduce greenhouse gas (GHG) emissions. Currently, the sector is responsible for 9.4% of U.S. GHG emissions¹ and is a major source of the potent GHGs methane and nitrous oxide (**Figure 1** shows emissions from the U.S. agriculture, forestry, and other land use sectors (AFOLU) from 1990–2022). A broad range of strategies can be employed to reduce these emissions and help the sector contribute to reaching the nation’s climate targets for 2030 and 2050.

Figure 1. U.S. Greenhouse Gas Inventory for Agriculture, Forestry, and Other Land Uses (AFOLU; bars represent individual categories, black line represents net emissions²)



¹ EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022>.

² EPA (2024) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022. U.S. Environmental Protection Agency, EPA 430-R-24-004. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022>.

The U.S. Department of Agriculture’s Natural Resources Conservation Service (USDA NRCS) conservation programs are important funding sources for these strategies. Five USDA programs, including the Rural Energy for America Program (REAP), the Conservation Stewardship Program (CSP), the Environmental Quality Incentives Program (EQIP), the Agricultural Conservation Easement Program (ACEP), and the Regional Conservation Partnership Program (RCPP) provide grant payments to farmers for voluntary implementation of on-farm conservation practices. These result in a variety of benefits, including enhanced soil health, improved water quality and use efficiency, improved energy efficiency, resilience to changing climate conditions, and wildlife habitat improvements. Dozens of these practices reduce GHG emissions from agricultural operations, and many increase carbon sequestration in soils and biomass. Funding for these “climate-smart” practices was therefore prioritized in the 2022 Inflation Reduction Act (IRA). Here, we analyze how changes to spending on USDA’s climate-smart practices would affect GHG and other outcomes through 2050.

We set out to answer the following questions:

- What is the expected GHG emissions reduction potential of the IRA’s climate-focused NRCS conservation investments?
- How might increased long-term funding to NRCS conservation programs, including climate-smart practices, impact U.S. agricultural GHG emissions?
- What, if any, are the domestic and international land use impacts of climate-focused NRCS investments?
- What, if any, are the tradeoffs between GHG emissions reductions and agricultural productivity, commodity trade balance, and land use change?

We found that NRCS investments in climate-smart agriculture through the primary on-farm conservation programs—EQIP, CSP, RCPP, ACEP, and REAP—can be expected to yield significant GHG mitigation benefits over time. GHG mitigation is correlated with the total annual funding available for climate-smart practices while the cost-effectiveness of achieving GHG mitigation varies across practices. Increased funding and cost-based optimization of spending across all climate-smart practices to maximize mitigation achieved within the available budget therefore results in the greatest possible expected GHG mitigation benefits over time. Additionally, we find that even with budgets expanded beyond historical levels, adoption of many practices remains untapped, suggesting that these sectors could further reduce emissions if additional funding were allocated to these conservation practices.

Input Data

We assess the impacts of climate-smart spending using a nested modeling approach that allows us to simulate how USDA is likely to spend dollars on the ground. While there have been previous studies analyzing U.S. agricultural mitigation potential, they typically simulate representative scenarios, abstracting from policy-specific details. Our policy modeling framework represents a step forward in U.S. national agricultural GHG modeling, in that programmatic restrictions and regionally specific mitigation information and cost data are

incorporated to more accurately model the location, timing, and level of practice adoption. Our analysis framework includes three complementary models, across which results are compared and tradeoffs related to land use change, emissions, production, and yields are assessed. Details on the input data used in this report are provided in the subsections below, summarizing the information used to develop alternative budget scenarios; define climate-smart forestry and agricultural practices modeled; and estimate greenhouse gas emissions reductions and costs associated with each practice.

Alternative Budget Scenarios

We analyze five budget and policy scenarios, presented in nominal dollars, that vary by the amount of funding made available for climate-smart NRCS practice implementation.

- Scenario 1 (Base Farm Bill/No IRA) represents a pre-Inflation Reduction Act world, where additional funds from IRA are not included in programmatic budgets.
- Scenario 2 (IRA as Enacted) reflects the budget for climate-smart practices under currently authorized legislation (including IRA), where the budget for climate-smart agriculture and forestry (CSAF) activities is significantly increased during 2023–2031 before falling back to the current Farm Bill baseline starting in 2032.
- Scenarios 3 through 5 reflect budgets where IRA funding is rescinded and reallocated to the Farm Bill baseline.
 - In scenario 3 (Reinvest IRA, No Climate Focus, Broad Spending), there are no climate-smart requirements on reallocated IRA dollars, that is, additional funding from IRA is spent using historical distributions across practices from 2014–2021.
 - In scenarios 4 (Reinvest IRA, With Climate Focus, Broad Spending) and 5 (Reinvest IRA, Non-CO₂ Mitigation Sideboards), requirements outlined under IRA requiring additional funds to be spent on climate-smart practices are maintained, meaning that IRA funds are only spent on practices included on the CSAF list. All practices that reduce GHGs are eligible for climate-smart funding in scenario 4, while only practices that reduce methane and nitrous oxide are eligible in scenario 5. Scenario 5 assumes that all additional funding is spent on practices that are included in this analysis, while scenario 4 assumes continued funding for CSAF practices that are not modeled but have historically been funded.³

Table 1 presents funding available for modeled CSAF practices under each scenario during the IRA period (2023–2031), after the IRA period (2032–2050), and the total funding (2023–2050). Additional details on the calculations are provided below.

³ Because a portion of the scenario 4 budget is allocated to activities that are defined as CSAF by USDA but for which no estimates of associated GHG mitigation are available, the funding available for CSAF practices that are quantified within our models is reduced relative to scenario 5.

Table 1. Projected Funding for Climate-Smart Agriculture and Forestry across Each Scenario during the IRA Period (2023–2031) and Post-IRA (2032–2050)

Scenario	Budget Description	Climate-Smart Funding (\$)		
		2023–2031	2032-2050	Total
1	Current Farm Bill baseline	10,641,000,667	20,519,419,696	31,160,420,363
2	Current Farm Bill baseline and IRA	21,128,258,557	20,519,419,696	41,647,678,253
3	Farm Bill baseline increased; no climate focus	14,538,812,337	26,919,749,366	41,458,561,703
4	Farm Bill baseline increased; with climate focus	19,395,787,749	37,568,439,991	56,964,227,740
5	Farm Bill baseline increased; non-CO ₂ GHG mitigation sideboards	24,754,027,207	48,396,535,430	73,150,562,637

Steps to Constructing Budget Scenarios

Baseline Farm Bill Funding

Baseline Farm Bill funding is estimated first at the national level by collecting and aggregating program-level budget totals for all programs. Projected budget information for NRCS programs was taken from Congressional Budget Office (CBO) net outlays for ACEP, RCPP, CSP, and EQIP.⁴ REAP budget values are taken from the USDA budget for Fiscal Year 2023.⁵ The USDA budget contains only budget authority values and does not provide outlays. To fill this gap, net outlays for REAP are estimated by taking a calculated share of net outlays to budget authority for NRCS programs provided by the CBO for years 2022 to 2034 and applying that to the REAP budget authority provided in the USDA budget. Baseline REAP projected funding is held constant, based on permanent baseline funding from the 2014 and 2018 Farm Bill.⁶ REAP activities are determined by descriptions of REAP awardees.⁷ REAP funding used for activities focused on energy efficiency or renewable energy sources are assumed to mitigate emissions and meet climate-smart criteria.⁸

Program funding is then used to estimate spending at the state and activity level by using USDA data to estimate breakout shares. NRCS financial assistance data were used to determine historical activity funding allocation by state and program. Climate-smart activities were defined

⁴ USDA Farm Programs. Congressional Budget Office. (February 2024). <https://www.cbo.gov/system/files/2024-02/51317-2024-02-usda.pdf>

⁵ The Budget for Fiscal Year 2023. Department of Agriculture. (2022).

<https://www.usda.gov/sites/default/files/documents/2023-usda-budget-summary.pdf>

⁶ The Farm Bill Energy Title: An Overview and Funding History. (October 2021). Congressional Research Service. <https://crsreports.congress.gov/product/pdf/R/R45943>

⁷ Retrieved from: <https://crsreports.congress.gov/product/pdf/R/R45943>

⁸ USDA Rural Development Rural Energy for America Program. (November 2023). <https://www.rd.usda.gov/media/file/download/usda-rd-rpn-chart-11-01-2023.pdf>

using the CSAF 2024 activities list provided by the NRCS.⁹ State-level funding by activity and program are available for REAP, EQIP, RCPP, and CSP. Equation 1 shows how budgets for CSP, RCPP, EQIP, and REAP are calculated. Practice-specific financial assistance data for ACEP are not available, but the number of acres covered for each activity are available by state from Resources Conservation Act (RCA) Conservation Program Reports.¹⁰ Thus, the baseline share of funding allocated to climate-smart practices for ACEP is determined by creating an aggregated, average regional cost per acre for each activity from other NRCS programs that is multiplied by the total number of acres treated per activity to serve as a proxy for obligated dollars for ACEP CSAF practices in a given state. Equations 2 and 3 shows the steps for estimating cost per acre for available practices. Breakout shares of funding by climate-smart activities are held constant at 2021 values across all scenarios. Farm Bill funding for years 2032 to 2050 is held constant. Cost per acre estimates are calculated for each state and practice, taking the average for all programs and historical years. Gaps in the cost per acre for each practice code, state, and USDA program are presented in Table E in the Summary Appendix. As Table E shows, most cost per acre data rely heavily on available EQIP data. States without any cost per acre estimates for a practice instead used a regional average based on all programs and years based on USDA regions.

$$Budget_{s,p,y,i,r} = Outlays_{y,p} * State\ share_r * CSAF\ share_{p,f} * \frac{\sum_{i,r,p} CSAF\ Obligated\ dollars}{\sum_{r,p} CSAF\ Obligated\ dollars} \quad (1)$$

$$Cost\ per\ acre_{CSP,RCPP,EQIP,REAP} = \frac{\sum_y Financial\ assistance\ (CSP,EQIP,RCPP)_{r,p,y}}{\sum_y Acres\ (CSP,EQIP,RCPP)_{r,p,y}} \quad (2)$$

$$Est\ ACEP\ practice\ cost = Acres\ (ACEP)_{i,r,y} \times Cost\ per\ acre\ (CSP,EQIP,RCPP)_{i,r,y} \quad (3)$$

Where:

s = scenario

$CSAF$ = Climate-Smart Activities

i = CSAF practice

p = program

r = state region

y = year

f = funding type

Additional Funding

Additional funding for NRCS programs from IRA also comes from the CBO. Projected net outlays for IRA funding are available for 2023–2031. Additional funding for REAP comes from IRA bill description.¹¹ For the Reinvest IRA scenarios, remaining IRA funding from years 2025

⁹ Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List for FY2024. Natural Resources Conservation Service. (November 2023). <https://www.nrcs.usda.gov/sites/default/files/2023-10/NRCS-CSAF-Mitigation-Activities-List.pdf>

¹⁰ RCA Conservation Program Reports. USDA. <https://www.nrcs.usda.gov/rca-conservation-program-reports>

¹¹ <https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf>

to 2031 have been summed and divided evenly from 2025 to 2034 for each program. This is assumed to more closely resemble outlay spending.

The Reinvest IRA without climate focus scenario (Scenario 3), which rescinds IRA funding and assumes no climate-smart requirements, uses the same proportional allocation of activity funding by state and program for all years. This proportion is calculated as the historical average share of spending between 2014 and 2021. Funding that is allocated to practices not included in the CSAF list are removed from the budget that is used in the model, which results in a smaller cumulative spend than what is outlined in the CBO projections.

The Reinvest IRA with Climate Focus scenario (Scenario 4), which rescinds IRA funding and increases Farm Bill funding with climate-smart requirements, allocates all additional funding based on the historical share of funding for all CSAF activities (based on 2023 spending). Of the CSAF activities, those with quantified GHG mitigation potential are included (see [Table 2](#) for CSAF activities identified as having limited GHG benefits). Annual funding amounts broken out by baseline Farm Bill and additional funding above Farm Bill are shown in [Figure 2](#). Additionally, [Figure 3](#) shows cumulative funding by CSAF activity for each scenario.

The Reinvest IRA with focus on N₂O and CH₄ (Scenario 5) applies the full CBO projection amount for IRA funding toward activities aimed at reducing non-CO₂ GHGs. Activity level spending is calculated as the proportion of spend from 2023 across only these non-CO₂ activities. This scenario results in the highest budget available, as funding that has previously been applied to CSAF activities with limited GHG benefits are redirected to practices with measured GHG reducing effects. In particular, additional funds are directed toward activities in the nitrogen management, livestock partnership, and rice mitigation categories in the CSAF list.

Figure 2. Annual Investment in CSAF Activities across Each Scenario, Shown as Baseline Farm Bill Funding, and Additional Funding

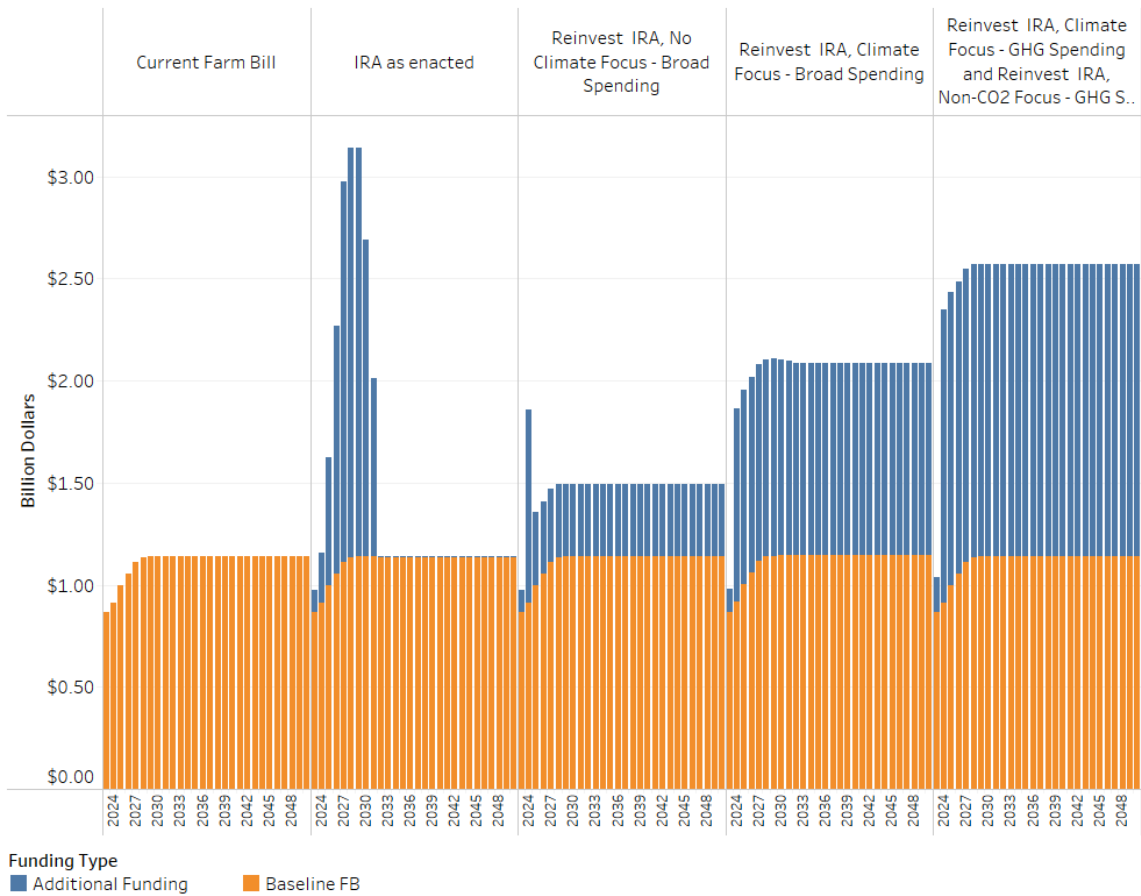
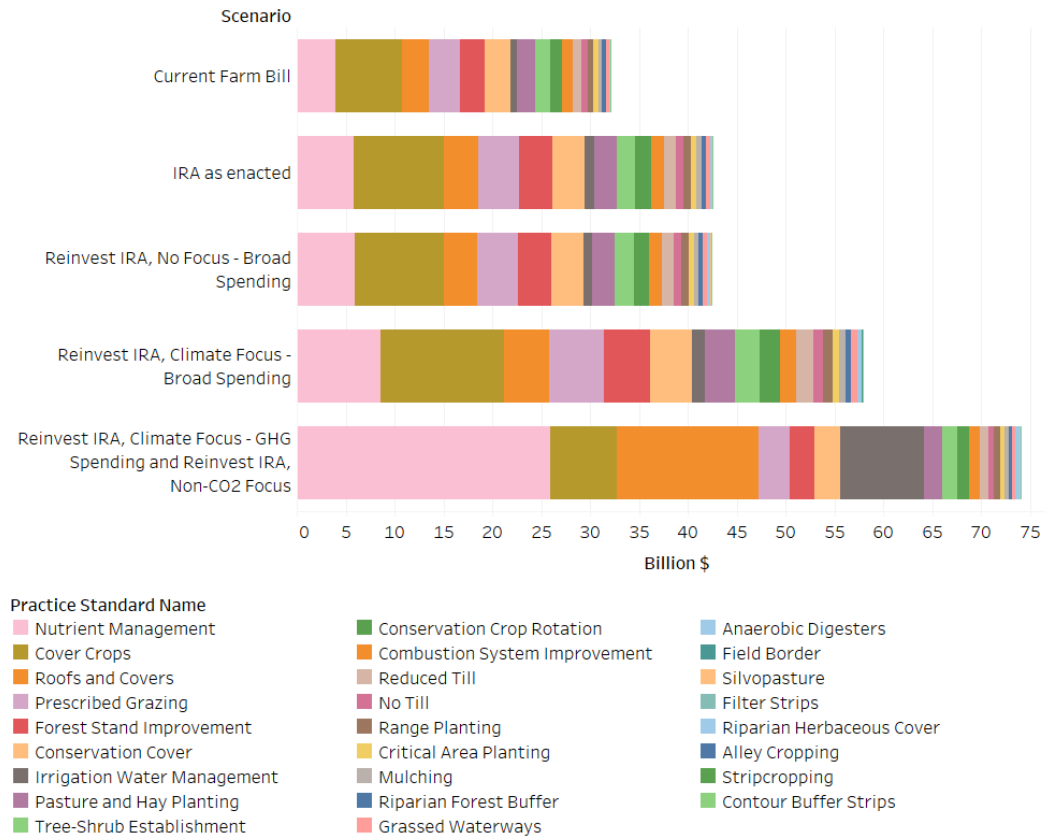


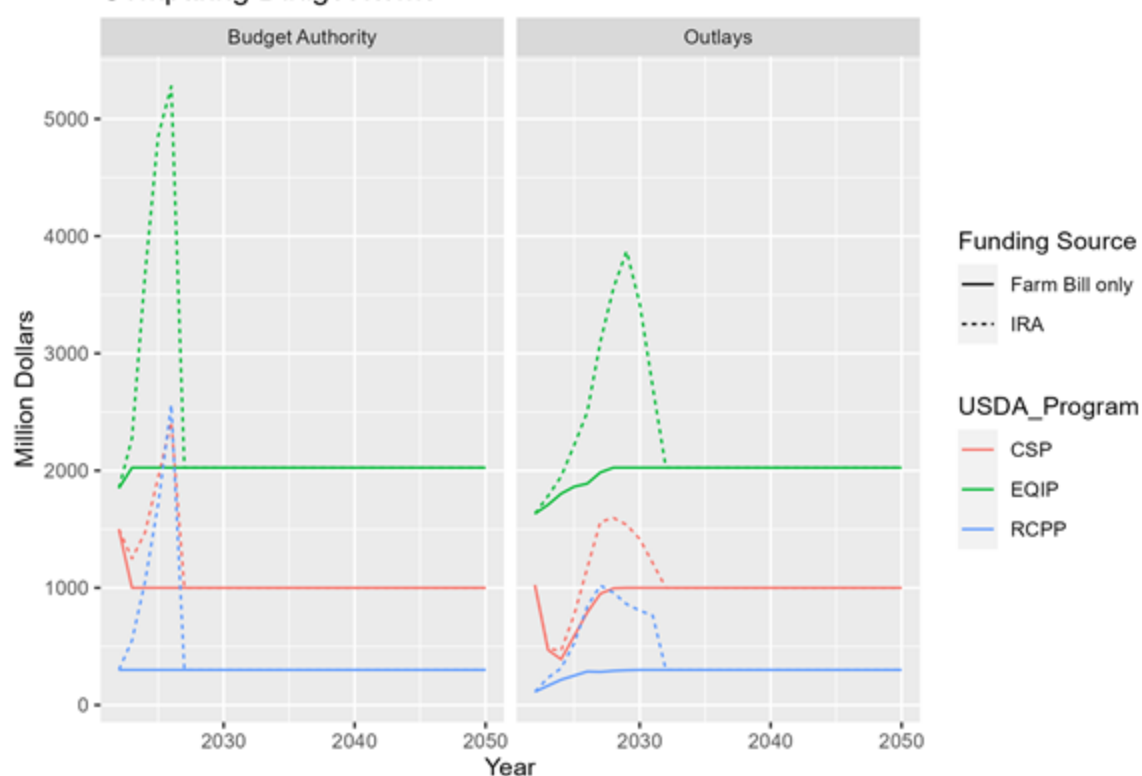
Figure 3: Cumulative Funding by CSAF Practice for each Scenario (2023-2050).

Box 1. Comparison of Budget Input Datasets For IRA as Enacted and Farm Bill only scenarios

Selecting Budget Items

There are different options when selecting which budget item available is most appropriate for projecting expected dollars spent on NRCS activities, primarily the budget authority and outlays provided by the Congressional Budget Office (CBO). The budget authority is determined by Congress and agencies can enter financial obligations for the Treasury to outlay funds to meet these obligations. Outlay amounts are based on the historical rate at which funds have been expended, and do not have to be equal to the budget authority for that year. Phase 1 of the model uses the outlays provided in the February 2024 CBO baseline projections for USDA Farm Programs as proxy for financial assistance payments to farmers.

Comparing Budget Items



Climate-Smart Agriculture and Forestry Practices 2024

NRCS provides Conservation Practice Standard Names and Codes for use in program applications and metric tracking. NRCS releases an updated list annually, the most recent available at the time this analysis was conducted being “Climate-Smart Agriculture and Forestry (CSAF) Mitigation Activities List for FY2024.”¹² The list includes the primary conservation

¹² A copy of this list is included in the appendix. The most recent list can be accessed on USDA’s website here: <https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/climate/climate-smart-mitigation-activities>

practices as well as codes for the CSP Enhancement Activities. Funding for enhancement activities was aggregated to the parent Conservation Practice Standard (CPS) 3-digit code for total obligated dollars dedicated to a given mitigation practice for each state and program.

This study focuses on the impacts of increased funding toward activities included in the 2024 NRCS CSAF list. This list contains 53 individual practices across 10 mitigation categories. Not all practices were included in this analysis, with varying reasons for why they were not included. Practices were excluded for having no mitigation estimates available within our input data sources, providing minimal direct greenhouse gas reduction benefits, and/or having no practice cost estimates available. See **Table 2** for a list of the practices not included in the analysis, along with the explanation as to why they were not included. Additionally, Table B in the Summary Appendix presents the practices included in the MACC model, while **Table 5** presents practices included in the REAP assessment.

Table 2. List of CSAF Practices Which Were Excluded from this Analysis

Practice Code	Conservation Practice Standard Name (Units)	Reason for Exclusion
313	Waste Storage Facility (number) - Used to implement compost bedded-pack	No cost or mitigation estimates
314	Brush Management (acres) • Used to remove woody invasive vegetation and the removed material will be left on site	Minimal GHG benefit
315	Herbaceous Weed Treatment (acres) • Used to release desired deep rooted perennial species	Minimal GHG benefit
317	Composting Facility (number)	Minimal GHG benefit
336	Soil Carbon Amendment (acres)	No cost estimates
338	Prescribed Burning (acres)	Minimal GHG benefit
383	Fuel Break (acres)	Minimal GHG benefit
384	Woody Residue Treatment (acres)	Minimal GHG benefit
420	Wildlife Habitat Planting	No mitigation estimates
422	Hedgerow Planting (feet)	No cost estimates
453	Land Reclamation, Landslide Treatment (acres)	No cost estimates and historically has only been applied in Hawaii
543	Land Reclamation, Abandoned Mined Land (acres)	No cost estimates and historically has only been applied in Hawaii
601	Vegetative Barriers (feet)	No cost estimates
603	Herbaceous Wind Barriers (feet)	No cost estimates
632	Waste Separation Facility (number)	No cost or mitigation estimates
643	Restoration of Rare or Declining Natural Communities (acres). Used to restore floodplain hydrology.	Minimal GHG benefit
645	Upland Wildlife Habitat Management (acres)	No mitigation estimates
657	Wetland Restoration (acres)	No cost or mitigation estimates

Emissions Reductions and Implementation Costs of CSAF Activities

Marginal abatement costs were gathered or derived from multiple sources for nearly 150 technologies that fit under the CSAF practice standard. Sources include EPA's Non-CO₂ Mitigation Report,¹³ USDA's Marginal Abatement Cost Curves for Greenhouse Gas Mitigation on U.S. Farms and Ranches,¹⁴ COMET-Planner,¹⁵ and USDA-RCA data on expenditures.¹⁶ Each of these sources vary in assumptions around spatial and temporal scope.

- The EPA report is the most detailed, in that it includes marginal abatement costs at the state level that vary over time, including estimates from 2025–2050 in 5-year increments. Baseline abatement potential varies over time based on projections of land-based activities such as herd size, acres planted, and others. Additionally, costs vary over time, assuming that technological improvement results in reduced costs through mid-century.
- The USDA estimates do not vary over time, representing present day mitigation costs and potential. But these estimates do vary over space, with marginal abatement cost curves (MACCs) available at the USDA production region.
- Some activities were not included in either of the other sources, which led us to deriving marginal abatement costs utilizing emissions reduction estimates from COMET-Planner and estimated implementation costs from USDA-RCA data. COMET-Planner estimates emission reductions for many USDA practices at the county level in tons of CO₂e per acre (as well as tons of N₂O and CH₄ for relevant activities). The USDA-RCA data include information on price per acre and enrolled acres of practices at the state level. To obtain estimates of total mitigation, RCA enrollment acres (which are only available at the state level) are allocated to counties relative to their proportion of the state's agricultural land, as reported in the USDA Census. When enrolled acres are joined with county-level mitigation per acre data from COMET-Planner, we can obtain county-level estimates on total mitigation. Combining these mitigation estimates with the costs derived from USDA-RCA allows us to construct a marginal abatement cost for activities not included in the EPA or USDA sources for each state.

To estimate the marginal abatement cost for forest stand improvement (CPS 666), which was not included in any of the previously mentioned sources, we relied on recent estimates from the U.S. EPA Greenhouse Gas Mitigation Potential in the U.S. Forestry and Agriculture Sector report.¹⁷ This report estimates MACCs for forestry activities, including forest management from 2020 to 2050. For this analysis, we used the 2035 MACC for afforestation, which was calculated at a spatial scale of 11 regions for the United States. Table B in the Summary Appendix lists

¹³ <https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases/us-state-level-non-co2-ghg-mitigation-report>

¹⁴ <https://www.usda.gov/sites/default/files/documents/Marginal-Abatement-Cost-Curve-Estimate-Methodology-Report.pdf>

¹⁵ <https://comet-planner-cdfahsp.com/>

¹⁶ <https://www.nrcs.usda.gov/rca-conservation-program-reports>

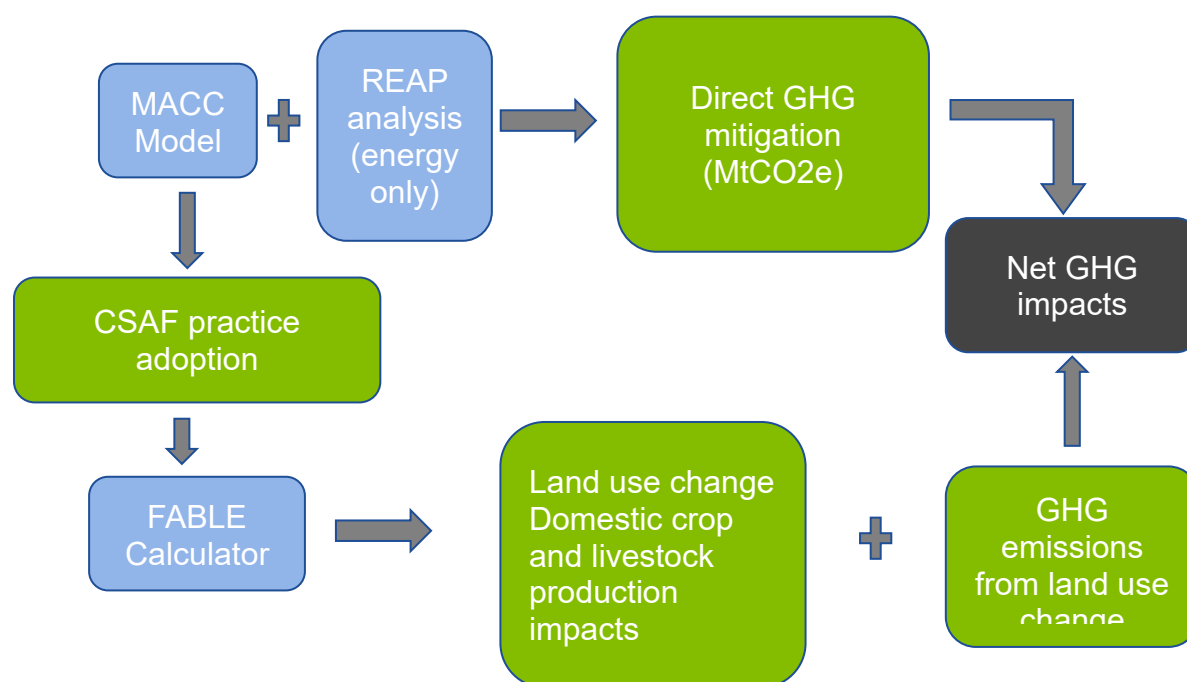
¹⁷ https://www.epa.gov/system/files/documents/2024-03/epa-430-r-23-004-mitigation-report_full_report_v2.pdf

each technology represented in this analysis, the CSAF practice code it falls under, and the data source used to populate marginal cost and emissions reductions.

Multi-Model Approach

We utilize a multi-model approach to assess the net GHG impacts from alternative Farm Bill funding scenarios. These models include an optimization model based on MACCs to assess land-based activities, a REAP analysis tool focused on energy system activities funded under REAP, and the FABLE Calculator—an Excel-based tool for the U.S. land sector to assess indirect land use change emissions from the adoption of CSAF activities. **Figure 4** presents how net GHG impacts for each scenario are tracked using each model, where the MACC model and REAP analysis tool result in direct GHG mitigation estimates for enrollment in CSAF activities. These enrollment projections are then used in the FABLE Calculator to assess yield and productivity impacts that may drive land use change. The FABLE Calculator also provides market projections such as production of crop and livestock commodities.

Figure 4. Illustration of Coupled Modeling Approach to Estimate Net GHG Impacts



Marginal Abatement Cost Curve Model (MACC Model)

The first step in assessing the impact of Farm Bill funding on emissions reductions from agriculture includes estimating enrollment in CSAF activities under various funding scenarios and the mitigation potential from these activities. To do this, we developed a constrained optimization model that allocated funding across the five USDA programs previously mentioned (REAP, CSP, ACEP, EQIP, and RCPP). Each program is granted an annual budget to be spent on CSAF activities, which varies by scenario, as described previously.

The model solves on an annual time step from 2023 to 2050, where each period maximizes emissions reductions subject to budget and physical constraints. The model chooses levels of enrollment for each practice across states and USDA programs as to maximize total emissions reductions (subject to budget constraints which are driven by historical proportions of USDA programs). Physical constraints included in the model, the dimensions for which they hold, and sources used to parameterize these constraints are included in **Table 3**. Acres available to enroll in each activity are limited by total acres at the state level. The number of acres enrolled in mutually exclusive cropland based CSAF activities must be less than the total acres in a state (note that many activities can be implemented simultaneously on the same plot of land, Table C in the Summary Appendix maps which activities may be colocated and thus are not double counted in physical land constraints). In addition to total cropland, limits are also set for irrigated and non-irrigated cropland, forestland, and rangeland. Additionally, exogenous limits for land converting away from cropland toward forestry is limited to 1% of total state-level cropland each year. Mapping of CSAF practices to relevant physical constraints is shown in Table D in the Summary Appendix.

Table 3. Constraints Used in the MACC Model, along with the Dimensions Included in the Constraint, and Data Sources

Physical Constraint Type	Category	Dimensions	Source
Area	Cropland	State	USDA NASS ¹⁸
	Irrigated cropland	State	USDA NASS ¹⁹
	Non-irrigation cropland	State	Calculated as difference of irrigated cropland from total cropland
	Land conversion	State, irrigated/dryland	Exogenous constraint
	Forest management	Region, State	USDA NRI 2017 ²⁰
	Afforestation/reforestation	State	Cook-Patton et al. 2020 ^{21,22}
	Rangeland	State	USDA NRI 2017 ²³
	Biochar application	USDA Region	USDA Marginal Abatement Cost Curve Report ²⁴

¹⁸ <https://quickstats.nass.usda.gov/results/E665C472-C308-322D-9ED8-3AA0BFDB9D46>

¹⁹ [https://www.nass.usda.gov/Publications/AgCensus/2017/Online Resources/Farm and Ranch Irrigation Survey/index.php](https://www.nass.usda.gov/Publications/AgCensus/2017/Online%20Resources/Farm%20and%20Ranch%20Irrigation%20Survey/index.php)

²⁰ https://publicdashboards.dl.usda.gov/t/FPAC_PUB/views/RCADVLandUseDownloadNRI20171/LandUseDownload?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

²¹ [https://www.cell.com/one-earth/fulltext/S2590-3322\(20\)30603-5](https://www.cell.com/one-earth/fulltext/S2590-3322(20)30603-5)

²² <https://www.reforestationhub.org/>

²³ https://publicdashboards.dl.usda.gov/t/FPAC_PUB/views/RCADVLandUseDownloadNRI20171/LandUseDownload?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

²⁴ <https://www.usda.gov/sites/default/files/documents/Marginal-Abatement-Cost-Curve-Estimate-Methodology-Report.pdf>

	Rice	State	USDA NASS ²⁵
Animal Units (head)	Beef Cattle	State	USDA NASS ²⁶
	Dairy Cattle	State	USDA ²⁷
	Swine	State	USDA ²⁸
Capital Constraint	Methane Digesters	Animal, State	EPA ²⁹ , USDA NASS ^{30,31}

The MACC model is designed to solve on an annual basis, so it is choosing which activities and how much land to enroll in each period based on annualized costs and mitigation benefits. Most practices included in the MACC model can be represented as an annual decision of whether to enroll or not, which farmers and landowners make. For these practices, costs and mitigation potential are annualized, assuming that if funding were to disappear, GHG benefits would not continue into the future. However, a number of practices represent capital-intensive or land use change activities which require larger up-front investments but will continue to provide GHG benefits in years following implementation.³² This includes practices such as the planting of cover crops, the use of conservation or no-till, and changes to input intensities. Other practices, such as those that focus on the construction of technology or infrastructure or those that involve land use change and biomass planting, are treated as long-term enrollments. To represent the dynamics from these systems, we use an ex-post process to convert annual investment projections into total funding of capital expenditures, and project the lifetime emissions reductions from these activities.

Specifically, after the MACC model is solved, we convert annual investment for each “permanent” activity into the number of capital projects funded, or acres converted each year. For manure methane digesters, installation costs from the EPA Non-CO₂ Mitigation Report are used,³³ which has total installed capital costs (in dollars per head) for various abatement technologies for different animal systems (**Table 4**). Using USDA NASS data, we calculate the weighted average size of livestock and swine operations for each state (in number of head). Finally, we calculate the average installation cost for each state by multiplying the installation cost from EPA by the weighted average operation size. The annual investment for each technology and state pair is then divided by average installation cost to estimate the number of digesters installed in each period. Annual emissions reductions associated with the digesters installed in each year were then held constant over the remaining periods following their installation. Finally, the number of digesters which could be installed in a state over the entire

²⁵ <https://quickstats.nass.usda.gov/results/3479F714-1633-3F11-B51F-7DA29AE0701E>

²⁶ <https://quickstats.nass.usda.gov/results/C51A1EF4-AAD6-31DA-99A4-E3A966966F4B>

²⁷ <https://downloads.usda.library.cornell.edu/usda-esmis/files/cz30ps66x/jd473517g/bk128k88x/mcprsb19.pdf>

²⁸ <https://usda.library.cornell.edu/concern/publications/02870v85d>

²⁹ <https://www.epa.gov/agstar/anaerobic-digestion-right-your-farm>

³⁰ <https://downloads.usda.library.cornell.edu/usda-esmis/files/cz30ps66x/jd473517g/bk128k88x/mcprsb19.pdf>

³¹ <https://quickstats.nass.usda.gov/results/C51A1EF4-AAD6-31DA-99A4-E3A966966F4B>

³² This includes CSAF practices 366 anaerobic digesters, 367 roofs and covers, 311 alley cropping, 342 critical area planting, 381 silvopasture, 391 riparian forest buffer, 612 tree-shrub establishment, and 666 forest stand improvement.

³³ https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf table 5-60

simulation horizon is constrained to be less than the total number of animal operations above 500 head for dairy operations and 2,000 head for swine operations based on EPA estimates³⁴.

A similar approach is used to convert tree planting activities³⁵. Annual investments from the MACC model are converted to the number of acres which could be afforested. Total planting costs are from Nielsen et al.³⁶ which looked at Conservation Reserve Program payouts to estimate total tree planting costs at the county-level. We calculate state-level cost by taking the mean of the estimated county cost for each state, which results in an average per acre cost for tree planting. Dividing the annual investment level from the MACC model by this average per acre tree planting cost gives the number of acres on which tree planting can occur. We then assume that mitigation from these activities will continue into the future. Limits on the amount of afforestation/reforestation that can occur in each state are taken from Cook-Patton et al.³⁷ which estimated the afforestation and reforestation potential across the US.

Table 4. Per Unit Installation Cost for Manure Management Systems (2024 USD)

Abatement Option	Total Installed Capital Cost (2024 USD per head)
Complete-mix digester, with engine, hogs	144.00
Complete-mix digester, without engine, hogs	87.84
Complete-mix digester, with engine, dairy cattle	1,379.52
Complete-mix digester, without engine, dairy cattle	846.72
Plug-flow digester, with engine, dairy cattle	1,854.72
Plug-flow digester, without engine, dairy cattle	1,137.60
Fixed-film digester, with engine, hogs	184.32
Fixed-film digester, without engine, hogs	146.88
Covered lagoon, with engine, large-scale, hogs	61.92
Covered lagoon, without engine, large-scale, hogs	36.00
Covered lagoon, with engine, large-scale, dairy cattle	1,702.08
Covered lagoon, without engine, large-scale, dairy cattle	1,113.12

REAP Assessment Tool

The REAP Assessment Tool was developed to assess the impact of funding allocated to projects focused on installing clean energy systems on farms, specifically, **Table 5** presents the CSAF activities represented in the REAP Assessment Tool. To estimate GHG emissions

³⁴ We limit installation to farms above these minimum number of head due to substantial economies of scale in implementing anaerobic digesters.

³⁵ 311 alley cropping, 342 critical area planting, 381 silvopasture, 391 riparian forest buffer, 612 tree-shrub establishment, and 666 forest stand improvement.

³⁶ <https://research.fs.usda.gov/treesearch/45563>

³⁷ [https://www.cell.com/one-earth/fulltext/S2590-3322\(20\)30603-5](https://www.cell.com/one-earth/fulltext/S2590-3322(20)30603-5)

reductions attributable to REAP, a list of funded projects for FY2023 is derived from USDA reports.³⁸

Table 5. CSAF Practices Included in the REAP Assessment Tool

Practice Code	Conservation Practice Standard Name (Units)
374	Energy Efficient Agricultural Operation (number)
430	Irrigation Pipeline (feet)
441	Irrigation System, Micro-irrigation (acres)
442	Sprinkler System (acres)
533	Pumping Plant (number)
670	Energy Efficient Lighting System (number)
672	Energy Efficient Building Envelope (number)

An initial review of descriptions of the 696 projects in the dataset suggested typographical or transcription errors in 9 projects. Some projects include estimates of power displaced in units of kilowatt hours (kWh), but contextual information (e.g., number of homes powered) suggests units of megawatt hours (MWh) instead. Alternatively, some projects include estimates of power displaced that seem accurate but estimates of homes powered that seem to be incorrect. Other projects contain estimates with unit divider errors (“33,3643 MMBTUs”) or outlier estimates that suggest mistyped numbers or missing decimals. A cursory review of projects with identified errors found similar errors online, suggesting that data are being reproduced from the same source table. To rectify and allow these projects to be included in the total, a “best guess” correction is applied to each record based on other contextual information provided (e.g., cost of investment, number of homes powered, annual cost savings). An additional 17 projects contain insufficient detail to allow for calculation of their net emission impact and are therefore excluded from further analysis. Two projects are classified as loans and are likewise excluded from the resulting supply curve.

Once errors in units of displaced energy are resolved, projects are sorted into categories by their emissions impact: electricity displacement (solar, wind, geothermal, efficiency upgrades) or liquid fuel displacement (ethanol, RNG). For electricity displacement projects where kWh of displaced power is specified, we use those numbers. For projects where only gross capacity is provided (e.g., 50kW array), we convert to kWh using theoretical maximum output (24 hours * 365 days) adjusted by Energy Information Administration (EIA) state- and technology-specific capacity factors.³⁹ We note that this approach potentially overestimates production given the influence of site-specific conditions and the absence of data on small-scale generators. For

³⁸ <https://www.rd.usda.gov/media/file/download/usda-rd-reap-chart-11-01-2023.pdf> (last accessed August 8, 2024)

³⁹ https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_cf.html; last accessed August 8, 2024.

projects where only dollar savings are provided, we use EIA average state-level electricity costs to determine kWh displaced.⁴⁰ This approach provides an approximation of displaced power but fails to capture other elements that could influence actual costs faced by the project (e.g., demand charges or important daily or seasonal variations).

Once displaced power is estimated for electricity displacement projects, we apply state-level emissions intensities (tCO₂e/MWh) using EIA electric power sector emissions and total retail sales data to calculate total emissions avoided.⁴¹ The use of state emissions factors does not necessarily capture the true emissions associated with a particular project. Some states, like Vermont, have remarkably low electric power sector emissions. The interconnected nature of the grid, however, implies that the true emissions displaced by a project will be a function of the broader portfolio of regional generation providing power at a particular place and time. For fuel displacement projects, we calculate displaced emissions from natural gas (e.g., renewable natural gas/biogas, biomass boilers), gasoline (ethanol), or, when stated directly, propane, again using EIA emission factors.⁴² In doing so, we follow EIA practice to treat biomass-derived fuels as non-emissive for the purposes of GHG calculations.

Having estimated emission reductions associated with each project, we generate an implied carbon price (\$/tCO₂e) for estimated reductions by dividing project grant amount by estimated reductions. Projects are then ordered by carbon price and cumulative emissions reduction and sorted into general project type categories (renewable power, digester, lighting/efficiency/HVAC, dryer, liquid fuels) to generate a MACC (**Figure 5**).

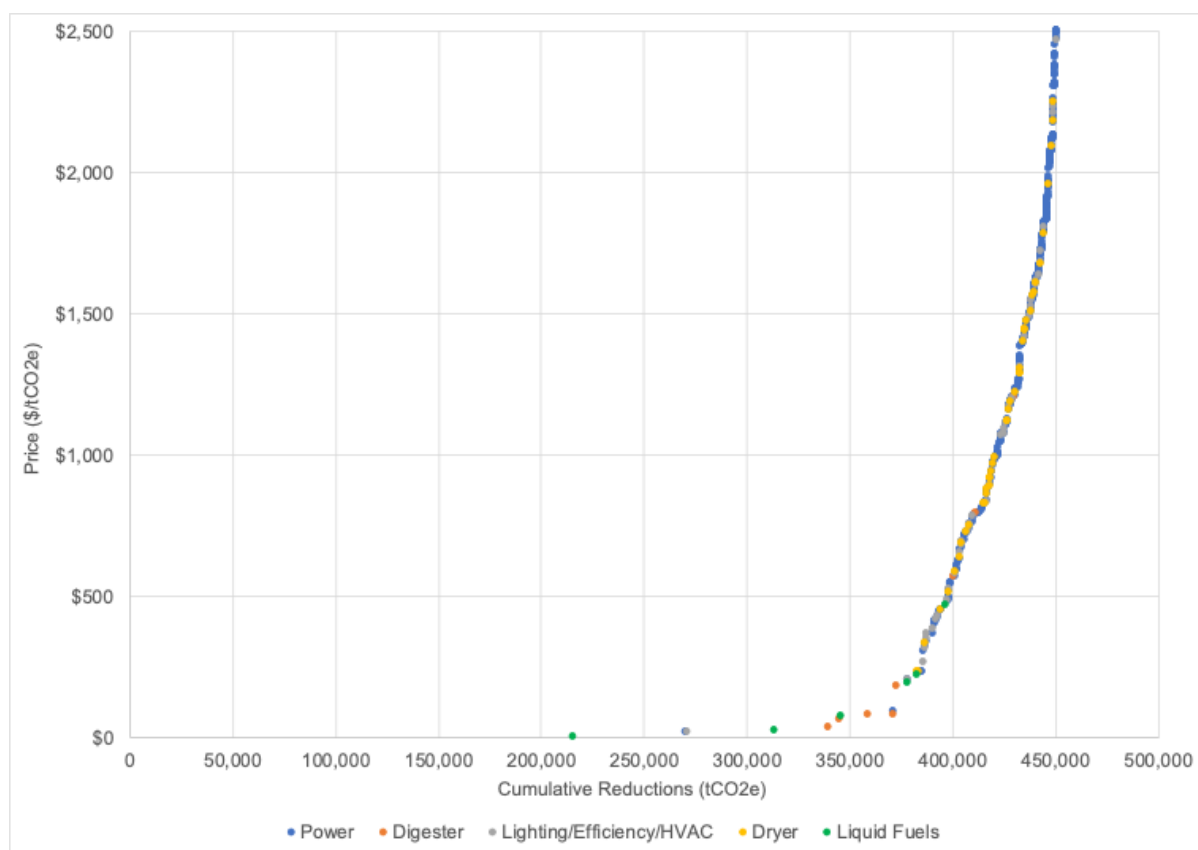
There are a few observations worth noting in these data. First, **Figure 5** captures nearly 99% of all emissions reductions associated with FY2023 funded projects but is heavily truncated along the y-axis; there are nearly 250 projects with cost estimates over \$2,500/tCO₂e that are not shown here. A related second observation is that REAP is not an emissions reduction program but achieves emission reductions by way of its primary directive to facilitate improved energy efficiency and the installation of renewable energy systems. We should therefore not expect to see prices in line with other interventions that specifically target GHG emissions as a first priority. Even so, over 80% of GHG emission reductions attributable to FY2023 REAP projects are estimated to be achieved at prices less than \$100/tCO₂e.

⁴⁰ <https://www.eia.gov/electricity/state/>; last accessed August 8, 2024.

⁴¹ electric power sector emissions: <https://www.eia.gov/environment/emissions/state/>; total retail sales: <https://www.eia.gov/electricity/state/>. Both last accessed August 8, 2024. One project provided its own estimate of emissions reductions, which was adopted directly.

⁴² https://www.eia.gov/environment/emissions/co2_vol_mass.php; last accessed August 8, 2024.

Figure 5. Simplified Marginal Abatement Cost Curve (MACC) for the Rural Energy for America Program (REAP), Derived from FY2023 Grant-Funded Projects



Reviewing the methodology, it is entirely possible that misinterpretations were made regarding project data given the errors observed above. Even so, projects with potential errors were found to make up less than 1% of total estimated emissions reductions. It is likewise possible that individual project estimates will be either higher or lower than reported given the use of average emission intensities, electricity prices, and capacity factors to calculate displaced power and GHG emissions. Furthermore, the composition of projects selected in a particular funding tranche, particularly given the outsized contribution of just a few large projects to total program emissions reductions estimated here, have the potential to strongly influence the emissions reductions associated with REAP from year to year. The estimates provided here should therefore be seen as indicative, not comprehensive.

The U.S. FABLE Calculator

The final step in the multi-model approach is estimating the land use change, indirect land use change emissions, and production impacts of the portfolio of CSAF practices adopted in each MACC model scenario. For this, we adopted and improved upon the U.S. FABLE Calculator, a customized version of the open access FABLE Calculator developed by the Sustainable Development Solutions Network. Training videos and other resources for how to operate and

interpret the results of the FABLE Calculator can be found on the [FABLE Calculator GitHub wiki page](#). See the “Model functionality changes” subsection below for a summary of the key changes made to the calculator to represent CSAF activities and how to select the new Farm Bill scenarios.

Below we briefly describe the design of the calculator. For details, see the complete model documentation⁴³. The FABLE Calculator represents 76 crop and livestock products using data from the FAOSTAT database. The model first specifies demand for these commodities under selected scenarios (including to satisfy human dietary needs, livestock feed, and international trade assumptions), the calculator computes agricultural production and other metrics, land use change, food consumption, trade, GHG emissions, water use, and land for biodiversity. The key advantages of the calculator include its speed, the number and diversity of scenario design elements, high customizability, simplicity, and its transparency. However, unlike economic models using optimization techniques, the calculator does not consider commodity prices in generating the results and does not have any spatial representation.

The following assumptions can be adjusted in the calculator to create scenarios: Gross Domestic Product (GDP), population, diet composition, population activity level, food waste, imports, exports, livestock productivity, crop productivity, agricultural land expansion or contraction, reforestation, climate impacts on crop production, protected areas, post-harvest losses, biofuels, and various assumptions related to this study (details below). Scenario assumptions in the calculator rely on “shifters” or time-step-specific relative changes that are applied to an initial historic value using a user-specified implementation rate.

The calculator performs a model run through a sequence of steps or calculations, as follows: (1) calculate human demand for each commodity; (2) calculate livestock production; (3) calculate crop production; (4) calculate pasture and cropland requirements; (5) compare the land use requirements with the available land accounting for restrictions imposed and reforestation targets; (6) calculate the amount of feasible pasture and cropland; (7) and (8) calculate the feasible (constrained) crop and livestock production; (9) calculate feasible (constrained) human demand; (10) calculate indicators (e.g., GHG emissions, kcal consumed, water use).

For this study, we made several major improvements to the U.S. FABLE Calculator to more accurately represent the U.S. agricultural sector, as follows, with details in the below subsections:

- Model calibration—updated crop and livestock historic and projected productivity, import, and export values using the U.S. Department of Agriculture (USDA) data where available (as a new scenario)
- Model calibration—replaced model default GHG emissions data with EPA GHG Inventory data where available (as a new scenario) to more accurately reflect US-specific data

⁴³ <https://fableconsortium.org/tools/fablecalculators/>

- Model functionality—added new scenarios that allow estimating production, land use, and emissions impacts of Farm Bill scenarios that adopt CSAF practices.

Calibration of FABLE Calculator Data

Productivity, Export, and Import Projections

Productivity projections are generated to calibrate the FABLE Calculator. This is done by calculating a shifter value relative to 2020. Since a shifter value is a percent change, a shifter value relative to 2020 is a measure of how much a certain value has changed compared to 2020. To calculate this shifter value, data from 2020 and data from years for which the shifter needs to be calculated are required. The calculated shifter values are then used to generate a regression model to extrapolate to the year 2050. We use productivity data for 2020 from the Production, Supply and Distribution (PSD) database⁴⁴. When 2020 data are not available, 2021 data from the PSD database are used. Data for the other years are from the USDA Agricultural Baseline database⁴⁵. When possible, we select 2023 as the “year of projection,” but for some crops and livestock only data from 2024 are available. For crops and livestock where only projections generated in 2024 are available, the 2021 data had to be covered by the PSD database. For crops, we use “exports,” “imports,” and “yield/harvested acres” attributes and for livestock, we use “exports,” “imports,” “production” and “inventory” attributes. The “production” and “inventory” attributes are used to calculate the productivity of the livestock where the “production” is divided by “inventory” to yield productivity data in units of produce over headcount. Since the PSD and USDA Agricultural Baseline Database have different units, all values are converted to SI units before the shifter relative to 2020 is calculated.

Utilizing the shifters calculated, we generate a regression model. This regression model is used to extrapolate the projections made by the USDA Agricultural Baseline Database, which are typically available through 2030 to 2050. A regression model is not generated for any attributes where the projections do not change for the final four to five measurements under the rationale that the extrapolated 2050 value should also not observe a change from the final values. For attributes that necessitate a regression analysis, the best model is decided based on the R-squared value and how reasonable the extrapolated 2050 value is. Models such as exponential models are not utilized in this study due to the 2050 values being unreasonably large or small. As such, most models are either linear or logarithmic. For logarithmic models, the variable “year” against which the shifter values are plotted has to be converted to “year relative to 2020” with 2020 being 1 due to the nature of logarithmic models. Furthermore, we exclude outliers before generating a model that better aligns with the majority of the data available.

EPA Emissions Inventory Scenario

We created a new scenario that allows users to select the underlying data source for GHG emissions in order to align historic and projected emissions with values reported in the [EPA Inventory of U.S. Greenhouse Gas and Emissions: 1990-2022](#). All new data in the EPA scenario

⁴⁴ <https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery>

⁴⁵ <https://www.ers.usda.gov/data-products/agricultural-baseline-database>

are sourced from the EPA inventory report and compiled in new sheets within the calculator titled “EPA_emitot_c,” “EPA_eflive_c,” and “EPA_efcrop_c.” The new sheets are copies of the FAO equivalent data, wherever available, replaced by the equivalent EPA data. All EPA-specific data within the EPA sheets are indicated by yellow highlighted cells with the source of the data tabulated on the right (including the table number from the inventory report). The EPA data are used for all GHG calculations and reporting if the new “EPA” scenario is selected under S.26 titled “Scenario on EPA or FAO Emissions Data.” If “FAO” is selected, the calculator operates as it has prior to the addition of this new scenario. The EPA data are referenced in the sheets “GHG” and “8_data_emissions.” In “GHG,” emissions from sources found only in the inventory report are added to the total agricultural, livestock, and crop emissions. In “8_data_emissions,” data in tables “FAOTotalEmis” and “FAOLiveEmis” reference EPA data instead of FAO data if the “EPA” scenario is selected.

The EPA data includes the following three new sources of N₂O emissions which were determined to be relevant to the scope and design of the calculator to improve the accuracy of its projections: “Mineralization and Asymbiotic Fixation,” “Indirect Volatilization & Asymbiotic Deposition,” and “Indirect Surface Leaching & Leaching.” The three sources were determined to be relevant and feasible to incorporate due to their emissions being closely tied to agricultural practices such as fertilizer use and land use change, which are both modeled/tracked by the calculator. We created two new tables in the sheet “8_data_emissions” titled “EPA_Emissions_Factor” and “EPA_Specific_Emissions.” “EPA_Emissions_Factor” is responsible for calculating the N₂O emissions factor and “EPA_Specific_Emissions” is responsible for calculating the total emissions.

To incorporate “Mineralization and Asymbiotic Fixation” into the calculator, the emissions data from the inventory report is divided by the sum of cropland and pastureland data from “4_data_land” for the same historic years (to calculate emissions factors) and then remultiplied by projected (future) cropland and pasture land values separately from “4_calc_land.” That is, the emissions data from the inventory report are first divided by historical land use data to derive the emissions factor and then remultiplied by the value within the calculator to reflect changes in land use projected by the scenario. The emissions factor is separately multiplied by cropland and pastureland so they can be accounted for separately in the “GHG” sheet for crop and livestock emissions.

To incorporate “Indirect Volatilization & Asymbiotic Deposition” and “Indirect Surface Leaching & Fixation” into the calculator, we replicated the methodologies utilized in the inventory report. First, fertilizer use per hectare is calculated by dividing the total fertilizer use values from “10_calc_costs” by cropland area values from “4_calc_land.” Calculated values are used to reflect any changes in fertilizer use or land use based on the scenario. Furthermore, the total fertilizer use is divided by cropland area only because the data from “10_calc_costs” calculates fertilizer use per crop. The derived fertilizer use per hectare is then multiplied by nitrogen loss factors calculated by the Intergovernmental Panel on Climate Change (IPCC). The values are taken from page A-369 and A-370 of the [inventory report annex 3 part B](#). The estimated nitrogen loss per hectare is then multiplied by the IPCC default N₂O emissions factor to derive

the N₂O emission per hectare. The IPCC default emissions factors are taken from page A-385 of the [inventory report annex 3 part B](#). The emissions factors for volatilization and runoff are then multiplied by the cropland and pastureland values separately from “4_calc_land.”

The emissions from the three new sources are summed in “TABLE: EPA_Specific_Emissions.” This sum is referenced in the sheet “GHG” under the “EPA” data scenario.

Model Functionality Changes to Represent CSAF Practices in MACC Model Results

Literature Review of Productivity Impacts

Literature review of the practices included in the FABLE Calculator was conducted to represent productivity impacts of CSAF practice adoption. Research was primarily conducted on Google Scholar. While studies within the United States and generally within the last one or two decades were prioritized, global data and older data were also gathered for practices with fewer studies, under the assumption that the data from the studies would largely be applicable to current U.S. conditions. Other specific assumptions made and the specific data from the sources used in the calibration are noted in the Summary Appendix.

Results

Using each of the three models outlined above, we estimate the potential emissions reductions from Farm Bill and IRA funding for agricultural and forestry activities. The MACC model is used to estimate direct emissions reductions from CSAF practice adoption, the REAP assessment tool estimates emissions reductions from on-farm energy efficiency and renewable energy programs, and the FABLE Calculator is used to assess emissions from indirect land use change driven by CSAF practice adoption. The following sections present detailed results from this suite of models.

National Results

Mitigation

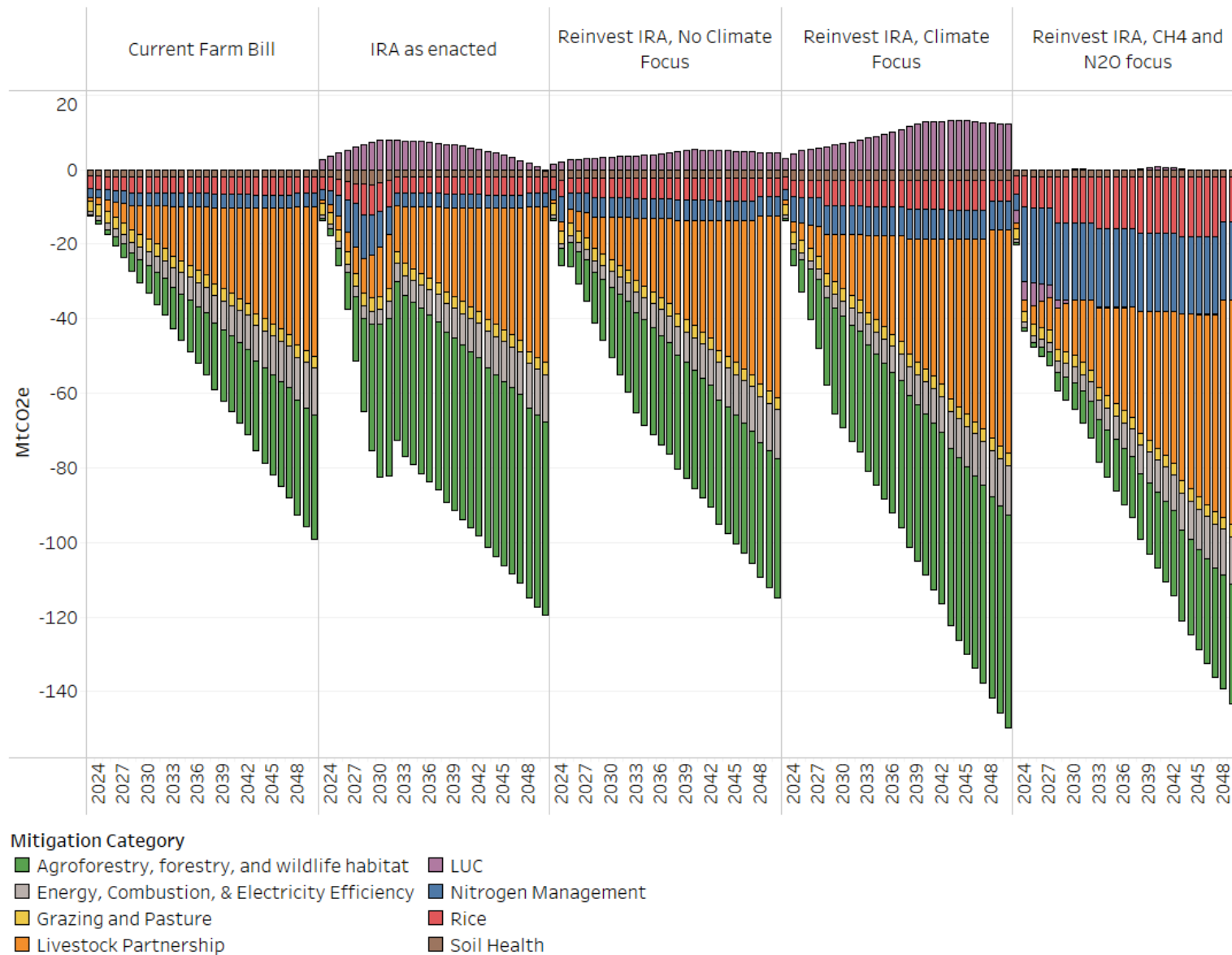
Emissions Reduction Projections

We find that the Farm Bill and IRA funding could result in cumulative mitigation of 1,521 and 2,575 MtCO₂e (54 MtCO₂e/yr. and 92 MtCO₂e/yr.) during the 2023–2050 period, across our five scenarios. Cumulative emissions results for each scenario are shown in [Table 6](#). Baseline Farm Bill investments are projected to accomplish the majority of emissions reductions as they are implemented “first” in the modeling framework, allowing for these funds to take advantage of lower marginal cost activities, while IRA or reinvested IRA funding is invested after all Farm Bill funds have been spent, which results in higher marginal cost options being available. [Table 6](#) also shows cumulative emissions reduction during the IRA period (2023–2031) as well as after the IRA investments (2032–2050). Due to the permanence of livestock-focused and tree planting activities, even as annual investment declines post-IRA, average annual mitigation has

the potential to increase. **Figure 6** highlights this result, looking specifically at the IRA as enacted scenario, emissions reductions after 2035 are higher than any previous year, despite annual investment being lower.

Table 6. Cumulative Emissions Reductions Across Each Scenario from 2023 to 2050 and Cumulative Emissions Reductions During the Near-Term (2023–2031) and Long-Term (2032–2050) for Each Scenario. Average Annual Emissions (MtCO₂e/yr.) for Each Period are Shown in ().

Scenario	Cumulative Mitigation (MtCO ₂ e)	Period (MtCO ₂ e)	
		IRA	Post-IRA
Base Farm Bill	1,521.29 (54.33)	216.07 (24.01)	1,305.23 (68.70)
IRA as enacted	2,134.63 (76.24)	399.72 (44.41)	1,734.91 (91.31)
Reinvest IRA without Climate Focus	1,893.67 (67.63)	300.10 (33.34)	1,593.57 (83.87)
Reinvest IRA with Climate Focus	2,306.43 (82.37)	376.21 (41.80)	1,930.22 (101.59)
Reinvest Non-CO ₂ Focus	2,574.67 (91.95)	467.46 (51.94)	2,107.20 (110.91)

Figure 6. Annual Emissions Reductions across Each Scenario Broken out by Mitigation Category, 2023–2050

Key technologies driving mitigation do not change drastically across scenarios, but it is worth noting that the current enactment of the Farm Bill (Scenario 1) does not account for FABLE in the LUC mitigation category, while IRA (Scenario 2) and IRA reinvestment scenarios (scenarios 3-5) do. Agroforestry activities and livestock partnership activities drive the growth of mitigation potential over time, as the cumulative impact of these permanent activities is felt. Specifically, tree planting in the agroforestry mitigation category, and covered lagoons in the livestock mitigation category contribute the largest portion of mitigation across scenarios. Additionally, REAP technologies follow a similar trend as agroforestry and livestock (energy, combustion, and electricity efficiency mitigation category) in that they accumulate over time resulting in large annual emissions reductions near the end of the simulation period. In Scenario 5 (Reinvest IRA, with CH₄ and N₂O Focus) mitigation from rice practices and nutrient management increase significantly compared to the other four scenarios. Specifically, alternating wetting and drying (AWD) and slow-release fertilizer technologies are the activities contributing the largest amount of mitigation in the rice category. While in the nitrogen management mitigation category, replacing nitrogen fertilizer with compost on arid lands shows the greatest mitigation potential. Additionally, sequestration is achieved through LUC as many of the non-CO₂ focused activities result in increased agricultural productivity, thus reducing total cropland area. The IRA as enacted scenario (Scenario 2) results in over 11% more mitigation than Scenario 3 (Reinvest IRA, without Climate Focus) despite funding in this scenario being only marginally greater (roughly 0.5% higher). This finding shows the importance of early investments in permanent activities which result in long-term mitigation potential.

Emissions Reductions by GHG

Table 7 outlines mitigation for each major agricultural greenhouse gas (CO₂, CH₄, and N₂O) in MtCO₂e. The majority of mitigation comes in reductions of CO₂ for each scenario, followed by CH₄, with N₂O providing the least mitigation. We find evidence that increased investment in reducing CO₂ and CH₄ emissions may result in increases in N₂O emissions as shown in the Reinvest IRA with a Non-CO₂ focus scenario given potential tradeoffs between GHGs from agricultural systems that emit multiple GHGs. Specifically, practices such as alternating wetting and drying may result in net emissions decrease but a gross increase in N₂O emissions. Key activities driving the increase in CH₄ reductions in the Non-CO₂ focused scenario include livestock manure management (such as covered lagoons without an engine on dairy farms).

Table 7. Greenhouse Gas Mitigation by Specific GHGs Across Scenarios

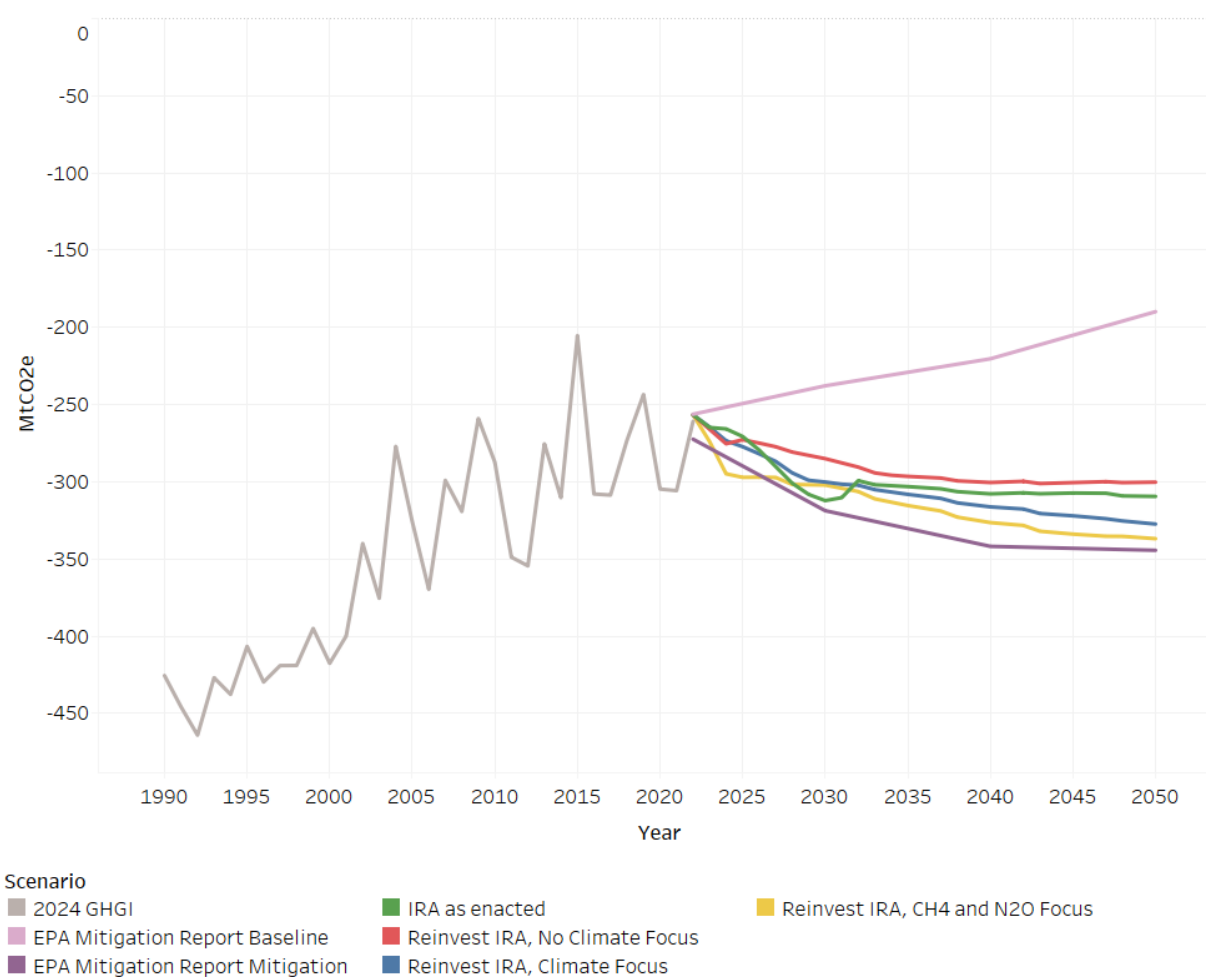
Scenario	Total Mitigation	CO ₂	N ₂ O	CH ₄
Base Farm Bill	1521.3	816.6	70.7	633.9
IRA As Enacted	2134.6	1342.7	87.5	704.6
Reinvest IRA Without Climate Focus	1893.7	1183.2	156.0	554.7
Reinvest IRA with Climate Focus	2306.4	1246.4	91.3	968.7
Reinvest IRA with Non-CO ₂ Focus	2574.7	1319.5	95.3	1159.9

Note: All values in MtCO₂e

Projected Emission Profiles of the AFOLU Sector

Emissions reduction estimates can be combined with forward-looking models of the land sector to project future emissions profiles. For example, the U.S. EPA Mitigation Report⁴⁶ uses three land use models to project baseline and mitigation focused futures of the domestic land sector (including both agriculture and forestry). Using these results, we combine the emissions reductions projections from this analysis to construct additional future projections. Specifically, mitigation projections from Farm Bill and IRA scenarios are subtracted from the EPA Baseline scenario (light purple in **Figure 7**) to estimate the total emissions from the AFOLU sector.

Figure 7. Historical AFOLU Emissions for the United States, U.S. EPA Projected Baseline Emissions for 2020-2050, EPA Projected Mitigation Focused Emissions from 2020–2050, and Alternative Farm Bill Funding Scenarios Projected Emissions 2023–2050



⁴⁶ https://www.epa.gov/system/files/documents/2024-03/epa-430-r-23-004-mitigation-report_full_report_v2.pdf

Figure 7 shows the impact that NRCS programs could have on AFOLU emissions through mid-century. This figure also includes historical emissions from the AFOLU sector based on the EPA 2024 GHG Inventory.⁴⁷ We use these combined sectors because NRCS investments are impacting both, in terms of both direct investments and indirect land use change. Our policy scenarios are bracketed by two projections of AFOLU emissions from EPA’s 2024 report. The light purple line is EPA’s projection of AFOLU emissions in a “no-policy” scenario; this is the “business as usual” (BAU) projection and shows what emissions would be in the absence of any policy targeting these sectors. The BAU projection is one of increasing net GHG emissions over time. This is the result of (1) a small increase in agricultural GHG emissions driven by demand, even though productivity gains are made and (2) reduced carbon sequestration capacity of forests nationwide. The dark purple line is EPA’s “mitigation policy.” We are showing the maximum mitigation potential from that report for AFOLU from the FASOMGHG and GLOBIOM models across mitigation scenarios modeled as carbon prices (these two models include both agriculture and forestry; the third model used in the analysis, GTM, does not include agriculture). EPA’s projection assumes that the majority of these funds will be spent on improved forest management and afforestation because those are the most cost-effective means of reducing net GHG emissions. We find that emissions reductions from the Farm Bill, across all scenarios, have the potential to reduce the baseline trend of declining sinks in the U.S. land sector; however, we still find that these investments do not result in reaching levels at or below 2005 emissions.

Emissions Reductions by USDA Program

Table 8 presents cumulative emissions reductions across each scenario by USDA NRCS Program. Across each scenario, EQIP results in the highest level of emissions reductions. This is driven by agroforestry activities and livestock partnership programs. Under the Non-CO₂ Focus scenario, mitigation from rice, and nitrogen management increase significantly under EQIP. RCPP and EQIP achieve most mitigation through the installation of roofs and covers (CPS code 367) and tree establishment (CPS code 612). The highest amount of mitigation under CSP comes from tree establishment and nutrient management. REAP is dominated by the installation of clean energy infrastructure, with some mitigation from methane reduction activities). Top GHG reducing practices for ACEP are riparian forest buffers (CPS code 391), critical area planting (CPS code 342), and intensive grazing (CPS code 528).

⁴⁷ <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

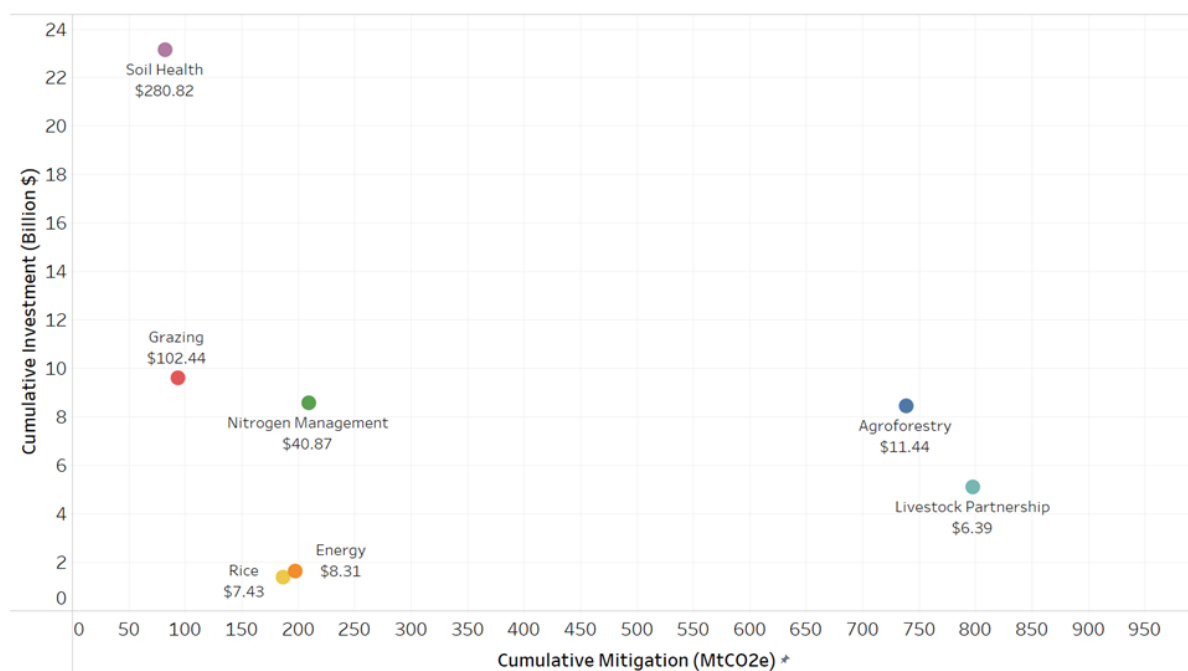
Table 8. Greenhouse Gas Mitigation from Each USDA Program and Cumulative Emissions Changes from Land Use Change (LUC) Across Scenarios (MtCO₂e)

Scenario	Total Mitigation (MtCO ₂ e)	ACEP	REAP	CSP	RCP	EQIP	LUC
Base Farm Bill	1521.3	132.54	205.54	159.82	88.04	934.93	
IRA as Enacted	2134.6	179.65	217.59	315.95	174.54	1394.37	-148.02
Reinvest IRA Without Climate Focus	1893.7	141.30	258.62	275.70	161.83	1166.88	-111.13
Reinvest IRA with Climate Focus	2306.4	169.75	292.61	399.95	269.37	1443.34	-269.02
Reinvest Non-CO ₂ Focus	2574.7	137.57	209.17	402.94	448.57	1350.44	25.55

Cost of Mitigation

Assessing the cost of emissions reduction is important when looking at alternative funding futures. This modeling framework allows for the comparison of changing budgets, as well as shifting portfolios of spending. This allows policymakers to see the impact of increased funding, as well as showing how shifting funding priorities may result in changes in emissions reductions. It is important to note that these NRCS programs are not designed or aimed at emissions reductions, but rather this is a co-benefit associated with conservation activities. That being said, we find evidence that low-cost GHG mitigation is feasible across many of these NRCS programs. On average from 2023 to 2050 under the Reinvest IRA with Climate Focus scenario, we find that livestock partnership, rice, energy, and agroforestry-focused activities all cost below \$12/tCO₂e (**Figure 8**); while nutrient management activities reduce GHGs at a price below \$50; grazing and pasture activities are around \$100/tCO₂e; and soil health practices have the highest average price of around \$280/tCO₂e. This high price is driven by a couple of activities that receive funding but have minimal GHG benefits including mulching and building grassed waterways.

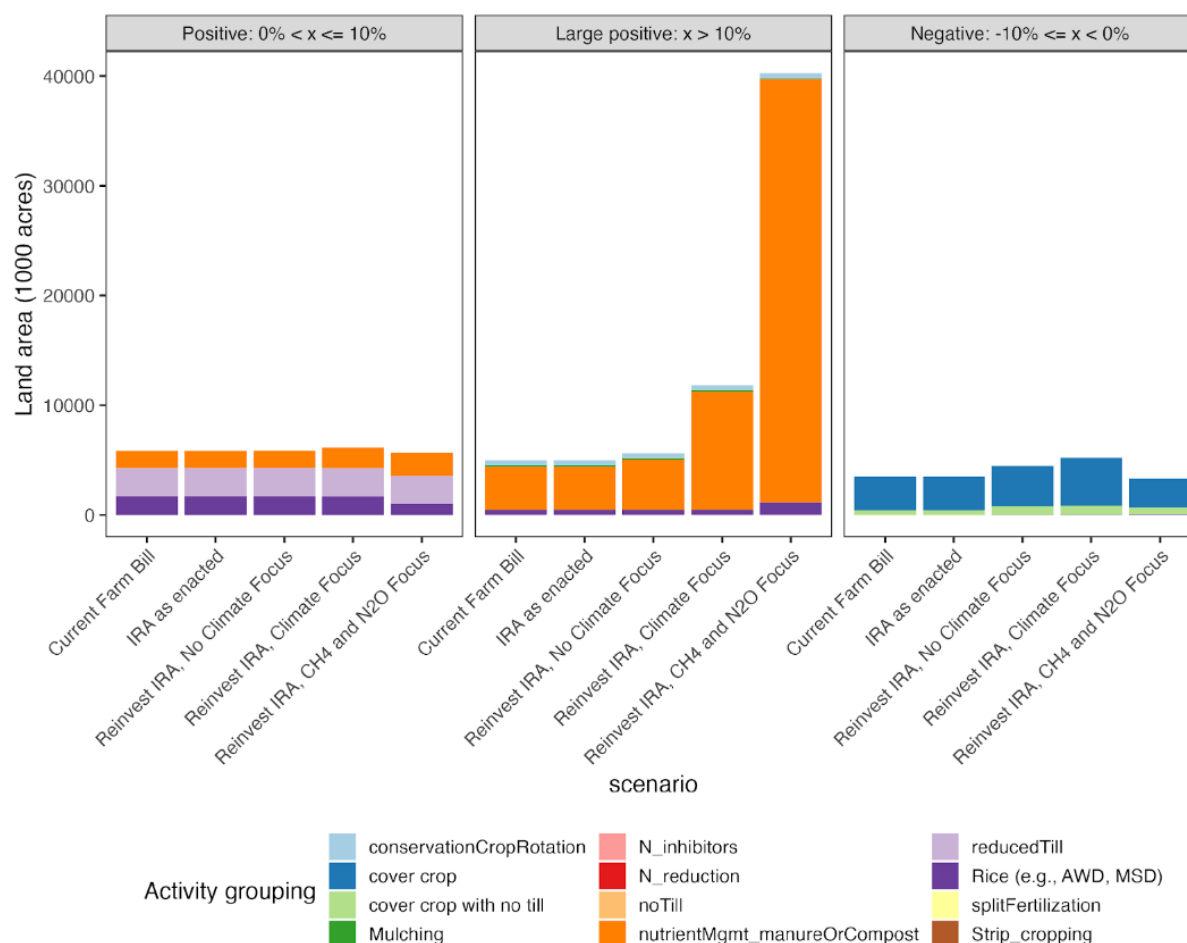
Figure 8. Abatement vs. Total Investment by Mitigation Category under Reinvest IRA, with Climate Focus



Direct and Indirect Land Use Change and Indirect Emissions

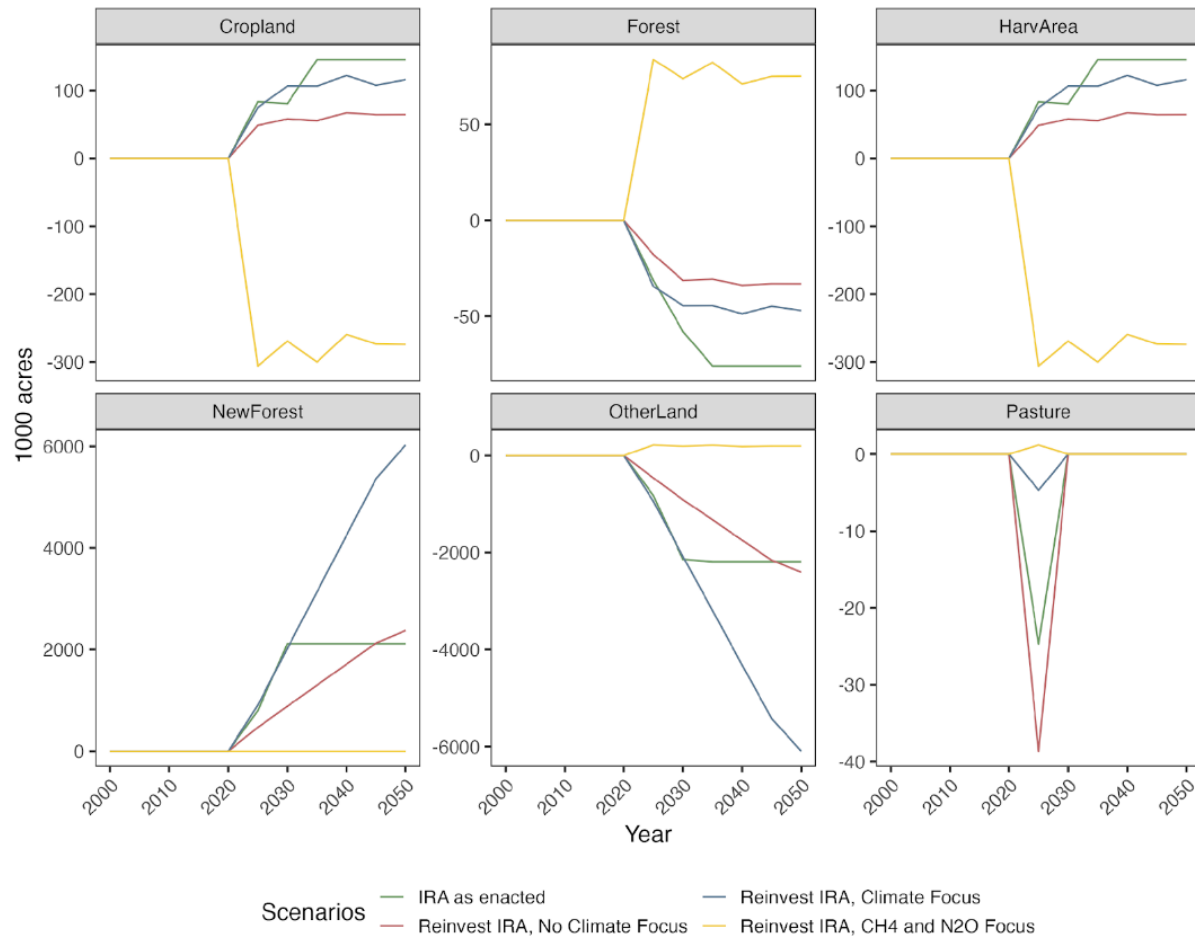
Cropland acres enrolled in certain CSAF practices such as windbreaks, conservation cover, and contour buffer strips, will no longer be available for crop production. Cropland expansion into other land use and land cover types, including forests, compensates for this loss of productive cropland due to CSAF practices. Additionally, some CSAF practices such as cover cropping may result in lower yields ([Figure 9](#)) in the short to medium term, which also drives cropland expansion to compensate for this reduced crop production. However, improved productivity impacts of other CSAF practices offsets some cropland expansion ([Figure 9](#)). About 60–75% of all enrolled acres may experience positive productivity benefits from CSAF practices across most alternative budget scenarios. Specifically, the Reinvest IRA, Climate Focus and the Reinvest IRA, CH₄ and N₂O Focus scenarios have disproportionately higher enrollment in practices with large positive productivity impacts. Nutrient management that replaces synthetic fertilizer with manure or compost has the largest positive yield impacts and also sees the highest enrollment in the Reinvest, CH₄ and N₂O Focus scenario.

Figure 9. Land Area Enrolled in CSAF Activities Grouped by Productivity Impacts Category (Positive, Large Positive, and Negative Yield Impacts)



The overall impact of a CSAF funding scenario on land use and land cover change will depend on the relative balance of CSAF practices that result in direct or indirect land use change via crop yield impacts. We find that alternative budget scenarios result in less than 0.2% change in cropland (<150,000 acres), pasture (<40,000 acres), and forests (<100,000) with most conversions occurring in the first decade following implementation (Figure 10). Other land types experience the greatest losses of up to 4% (2.5–6 million acres) due to conversion to forests and cropland (Figure 10). Because many of the CH₄- and N₂O-focused CSAF investments result in positive yield impacts, the Reinvest IRA, CH₄ and N₂O Focus scenario results in slightly reduced cropland requirements and thus free up land for other uses that increase carbon sequestration ("positive leakage").

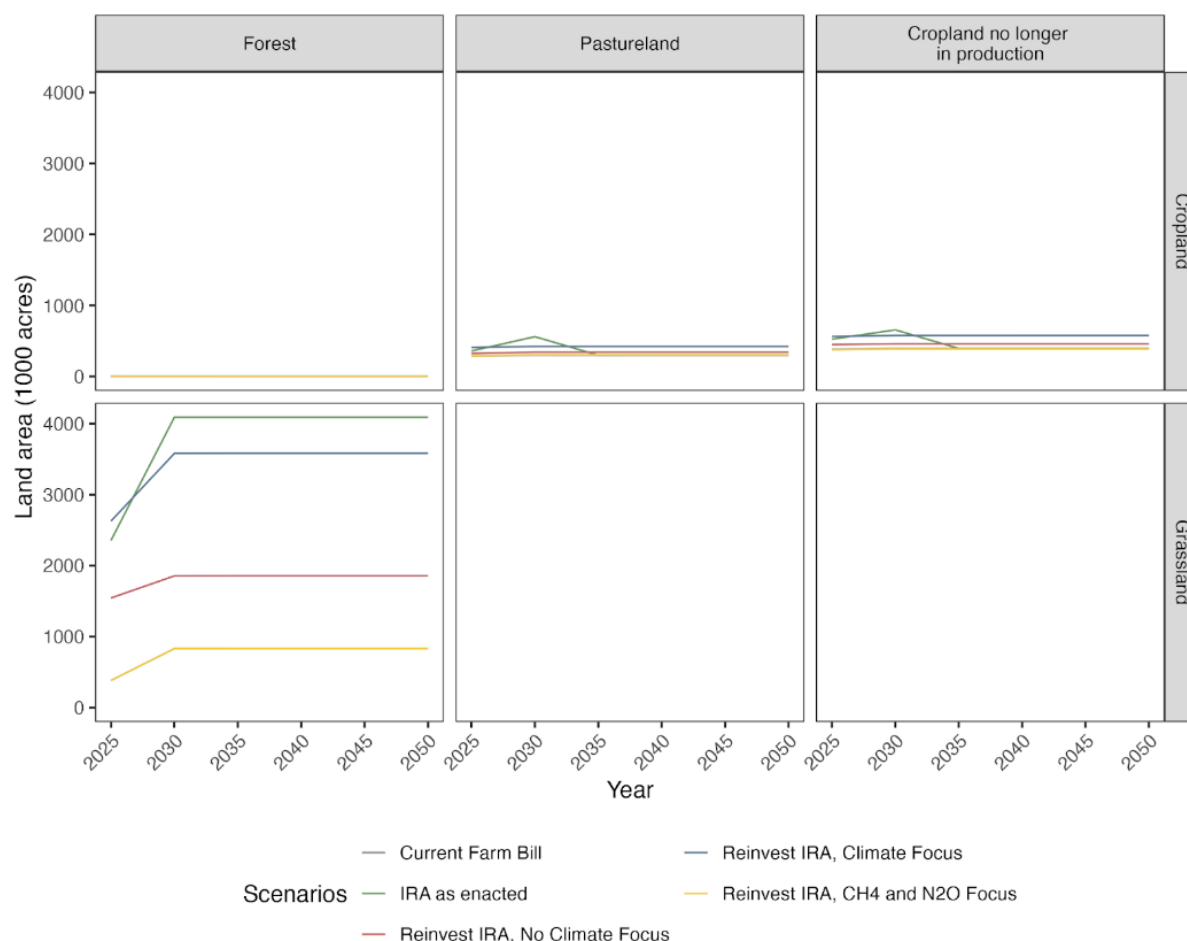
Figure 10. Induced Land Use and Land Cover Change Due to Adopted CSAF Practices in Alternative Budget Scenarios



Note: The y-axis shows the difference in acres from the Current Farm Bill scenario.

Less than 1 million acres (about the area of Rhode Island) of cropland are taken out of production (converted to the “cropland no longer in production” category) or converted to pastureland ([Figure 11](#)), with very slight differences in overall converted acres between scenarios. However, up to 4 million acres (about the area of Connecticut) of grassland (treated as “otherland” in the FABLE Calculator) will be converted to forest due to tree establishment practice adoption in the Reinvest, IRA as Enacted scenario, with the CH₄ and N₂O Focus scenario showing the least amount of reforestation at around 800,000 acres ([Figure 11](#)).

Figure 11. Acres of Direct Land Conversion Due to Enrolled CSAF Practices across Alternative Budget Scenarios

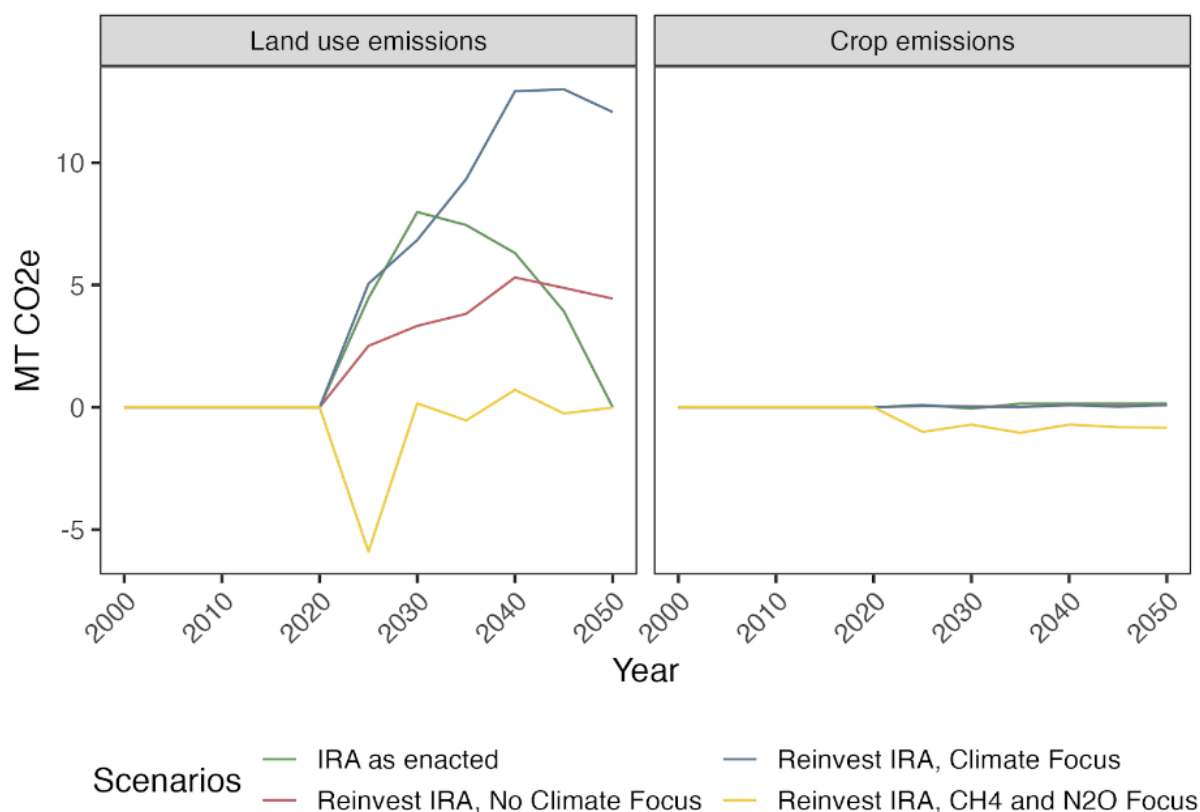


Note: Rows (cropland and grassland) indicate the initial land use and land cover categories, and the columns (forest, pastureland, and cropland no longer in production) indicate the resulting land use and land cover categories due to CSAF practice adoption. Values indicate the total (cumulative) conversion in any given year.

In this study, we account for indirect emissions from land use change from two sources: (1) the loss of land carbon when the initial land use or land cover is converted due to direct land use change from CSAF practice adoption (e.g., carbon loss from grasslands when converted to forest in tree establishment), and (2) the loss of land carbon due to indirect land use change resulting from CSAF practice adoption (e.g., cropland expansion due to reduced yields or taking cropland out of production). Indirect emissions in the alternative budget scenarios are dominated by the first source of emissions—loss of carbon from other land types, largely unproductive marginal or edge of field cropland, when trees are planted due to adoption of tree establishment CSAF practices. Carbon sequestration from tree planting is accounted for in the MACC model results. Annual indirect land use emissions range from -6 MT CO₂e in the Reinvest IRA, CH₄ and N₂O Focus scenario to 13.5 MT CO₂e in the Reinvest IRA, Climate Focus scenario (Figure 12). The negative indirect emissions are due to the carbon sequestration resulting from cropland contraction or the conversion of cropland to other land

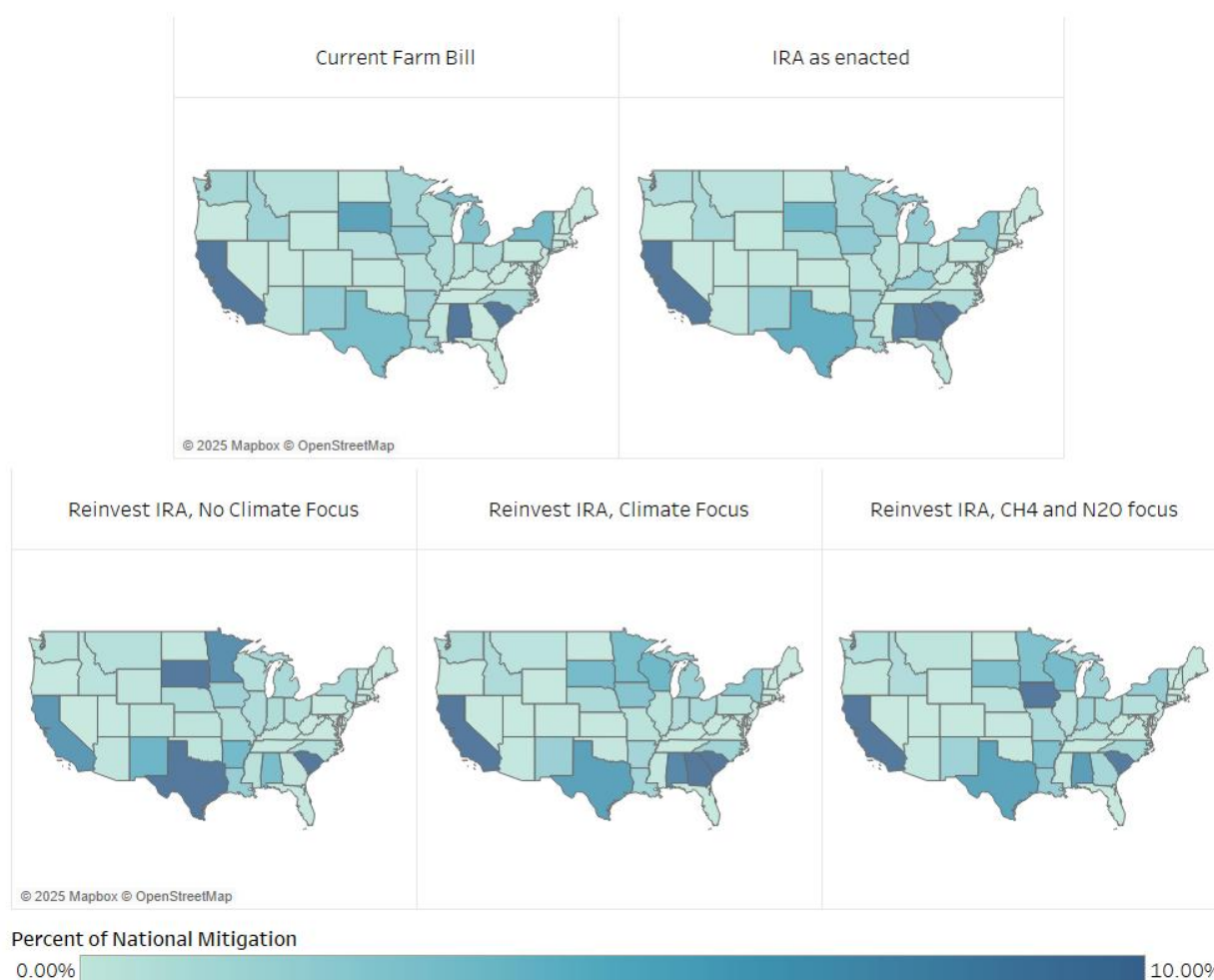
and forests, both of which store more carbon. The slight (approximately 1 MT CO₂e) reduction in crop emissions in the Reinvest IRA, CH₄ and N₂O Focus scenario is mostly due to the reduction in synthetic fertilizer application from cropland contraction (**Figure 12**).

Figure 12. Induced Land Use Change Emissions and Indirect Crop Emissions: Difference from Current Farm Bill Scenario



State and Regional Results

Full state and regional results are shown in the Summary Appendix and References document, Table A. Across all scenarios, we find that states in the Southeast (South Carolina, Georgia, and Alabama), the Corn Belt (Minnesota, Iowa, Nebraska, and South Dakota), and California contribute most of the mitigation achieved (**Figure 13**). These three separate regions achieve mitigation through different practices though, with the southeast focusing on agroforestry practices, while the Corn Belt focuses on nutrient management, conservation and no-till, and conservation crop rotation. California achieves most of its mitigation through livestock partnership activities. Under the CH₄ and N₂O Focus scenario, the share of mitigation achieved in the Southeast declines as agroforestry activities receive less funding relative to nutrient management, rice practices, and livestock partnership.

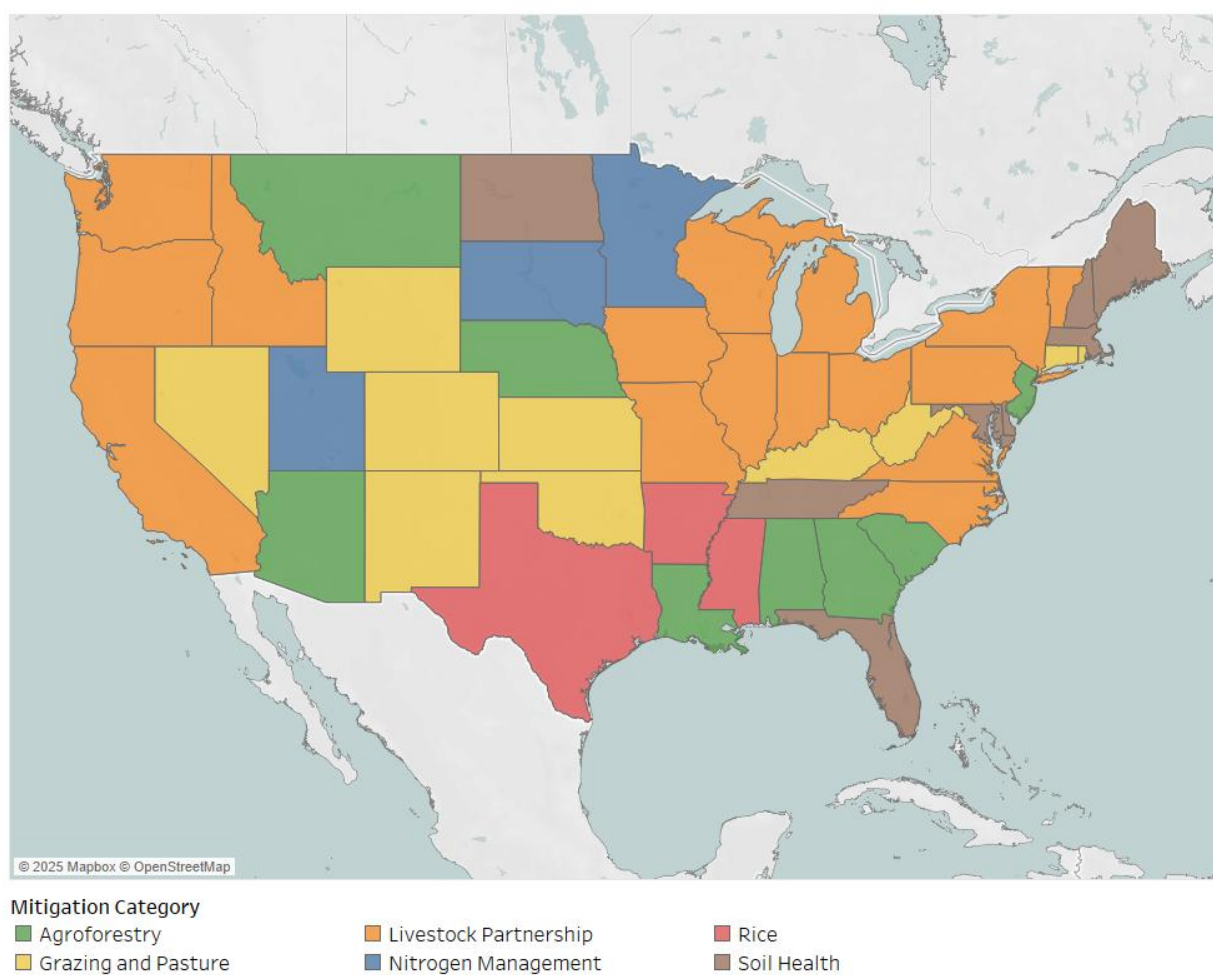
Figure 13. Share of National Mitigation by State across Scenarios (2023-2050)

We also find differences in the key CSAF activities adopted across the country (**Figure 14**):

- Agroforestry drives mitigation in the Southeast and in a few large midwestern and western states. Specifically, tree and shrub establishment is utilized in South Carolina, Georgia, Florida, and Alabama; silvopasture is the leading practice in Louisiana.
- Nebraska, Montana, and Arizona achieve mitigation through critical area planting.
- Livestock partnership drives large amounts of mitigation along the mid-Atlantic and into the northeast, as well as in the Lake States, Corn Belt, and states along the West Coast. Roofs and covers specifically have high utilization in these states due to their lower cost relative to other manure management activities.
- Nutrient management is the leading mitigation category in large crop-producing states such as Iowa, Minnesota, and South Dakota, as well as in Utah.
- Rice practices dominate in many of the states along the lower Mississippi River and in Texas.

- Grazing and pasture practices dominate in the great plains, as well as in some eastern states such as Kentucky, West Virginia, Massachusetts, and Rhode Island, but note that Massachusetts and Rhode Island result in very low overall estimates of mitigation due to relatively small amounts of agricultural activity.
- Soil health practices drive mitigation in the Northeast and mid-Atlantic as well as in Tennessee, and North Dakota. The specific practices driving these reductions vary, with Maine, Maryland, and Tennessee utilizing conservation cover, while North Dakota, Massachusetts, and Delaware adopt reduced tillage strategies; and New Hampshire implements conservation crop rotations.

Figure 14. Top Mitigation Category in Each State under the Reinvest IRA with Climate Focus Scenario (2023-2050)



Conclusions

Our analysis demonstrates that sustained and strategically optimized funding for climate-smart agricultural practices under NRCS conservation programs can significantly mitigate greenhouse gas emissions from U.S. agriculture through 2050. The total mitigation potential is strongly linked to the level of financial investment, with greater funding enabling broader adoption of effective conservation practices. Additionally, optimizing expenditures based on cost-effectiveness ensures that the greatest possible emissions reductions are achieved within the available budget. These findings underscore the importance of maintaining and expanding climate-focused NRCS investments to meet national and global climate goals while supporting agricultural sustainability.

However, our results also highlight the persistent gap between available funding and the full adoption potential of climate-smart practices. Even with increased financial support, many practices remain underutilized, suggesting that additional barriers—such as technical assistance, farmer outreach, or policy incentives—may need to be addressed to unlock their full mitigation potential. Future policy decisions should consider not only the scale of funding but also mechanisms for improving accessibility and effectiveness of conservation programs. By doing so, USDA NRCS programs can play a pivotal role in reducing agricultural emissions, enhancing carbon sequestration, and ensuring the long-term resilience of U.S. farming systems in the face of climate change.