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Harnessing the Land Sector to Achieve U.S. Climate Goals

An all-of-society approach to meeting our climate goals and bolstering the carbon sink by 2035

AMERICA IS ALL IN

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Glossary

- All-of-society: refers to the combination of bottom-up climate action from states, cities, and businesses with the federal government (Zhao et al., 2022).
- Afforestation: planting of new forests on lands which, historically, have not contained forests ("Climate Change 2022," 2022).
- Biodiversity: the variability among living organisms from all sources; this includes diversity within species, between species, and of ecosystems ("Climate Change 2022," 2022).
- Blue carbon: carbon captured by the world's ocean and coastal ecosystems ("What is Blue Carbon," n.d.)
- Burn rate: fraction of grid cell burned every year.
- Carbon sequestration: the process of capturing and storing atmospheric carbon dioxide ("What is carbon sequestration," n.d.).
- Carbon sequestration rate: The rate at which carbon is stored ("Carbon stocks," 2022).
- Carbon sink: anything that absorbs more carbon from the atmosphere than it releases, i.e. forests and oceans ("Climate Change 2022," 2022).
- Climate-change mitigation: efforts to prevent and reduce greenhouse gas emissions ("Climate Change 2022," 2022).
- Climate-smart agriculture: An approach to agriculture that aims to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate by sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions, where possible ("Climate Change 2022," 2022).
- Climate-smart policies: policies that integrate and prioritize reducing greenhouse gas emissions into their set-up and implementation.
- Climate stabilization: reducing or stabilizing the changing patterns of temperature and precipitation averages, variability, and extremes, often through reducing greenhouse gas emissions ("EnviroAtlas Benefit Category," 2022).
- Commodities: an economic good such as a product of agricultural production or from forests ("Commodity," n.d.).
- Ecosystem health: Ecosystem health is a metaphor used to describe the condition of an ecosystem by analogy with human health ("Climate Change 2022," 2022).
- Enteric fermentation: the digestive process in ruminant animals, such as cows, of converting sugars into simple molecules for absorption into the bloodstream, which produces methane as a by-product ("Which is a bigger methane source," n.d.).
- Land sector: agriculture, forestry, and other land uses (excluding blue carbon ecosystems) (Roe, 2019).
- Net carbon sink: combined emissions reductions from the forestry and agriculture sectors
- Natural disturbances: an event that disrupts an ecosystem or population and causes a pronounced change, i.e. fires, insect outbreaks, disease epidemics, droughts, floods, hurricanes, windstorms, landslides, avalanches, and volcanic eruptions (Sigurdsson et al., 2015).
- Reforestation: establishment of trees on land that had recent tree cover ("Climate Change 2022," 2022).
- Wildfire mitigation: actions taken before a wildfire ignites to reduce its severity and negative impacts ("Wildfire Mitigation," n.d.).

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Key Findings

In 2021, carbon sequestration from the U.S. land use sector reduced greenhouse gas emissions by 12% of total gross emissions—754 $MtCO_2e/yr$—demonstrating the critical contribution and potential of the U.S. carbon sink to help meet the country's ambitious 2030 and 2050 climate goals.

Yet the U.S. carbon sink is threatened by climate change, the effects of land use change, and natural disturbances, such as wildfire. Rapid, near-term actions to improve land sector practices can bolster the carbon sink—providing climate benefits alongside enhanced community resilience, food security, biodiversity, and public health.

An all-of-society or "All-In" U.S. climate strategy will be essential to achieving our national climate goals—meaning integrated action at the federal, state, city, and business levels must prioritize the climate-smart implementation of existing policies all while setting and taking new and ambitious action. With diverse jurisdictions and stakeholders who can benefit from a mutually reinforcing and enhanced All-In approach, the U.S. land sector could realize increased emissions reductions by 2035 and contribute critically toward reaching the U.S. 2050 net zero target.

This multi-model analysis integrates the climate-smart implementation of key policies into economic, physical, and regional considerations, revealing how the U.S. land sector can reverse its declining carbon sink while concurrently acting as a critical component of the country's economy-wide emissions reduction efforts.

Implementing existing policies in the U.S. land sector, encompassing the forestry and agriculture sectors, can deliver 40% less net emissions in 2035 from 2021 levels. This is achieved by increasing the forest carbon sink by over 10 MtCO2e and reducing emissions from agriculture by nearly 50 $MtCO_2e$ in 2035.

Full implementation of existing policies plus new and accelerated actions can increase emissions reductions to over 70% by 2035 from 2021 levels through enhanced carbon sequestration from forests and climate-smart livestock management. Additional investments and policies to help secure the carbon sink heading into mid-century include climate-smart tree planting, wildfire mitigation, and precision agriculture.

Paramount to these reductions is the addition and implementation of enhanced climate-smart, comprehensive federal legislation—such as a renewed Farm Bill.

The U.S. Commitment: Harnessing the Potential of Land Use Mitigation

The United States has set ambitious climate goals to reduce greenhouse gas (GHG) emissions, including its national climate target of reducing net emissions by 50-52% by 2030 from 2005 levels and a 2050 net zero emissions goal ("The Long-Term Strategy," 2021). While much attention is appropriately focused on the energy aspects of this necessary transition—for example, in clean energy, electric vehicle deployment, building retrofits, and more—the land sector remains a major component of the U.S. emissions profile. With enhanced policies and climate-smart implementation, it can play a major role in helping the United States achieve its overall emissions goals. Moreover, a more integrated and enhanced set of land sector policies across forestry, agriculture, and urban areas can provide substantial community resilience, food security, biodiversity, and public health benefits ("Food and Land Use," 2018). This paper offers a first-ever assessment of the potential for how a layered, all-of-society or "all-in" approach, encompassing federal, state, cities, businesses, and more, can enhance near-term emissions reductions from the U.S. land sector by 2035—and how these actions can help reverse the trend of a declining national carbon sink. Through a multi-model analysis, we analyze the impact of a suite of land sector policies—encompassing both the forestry and agriculture sectors—on near-term U.S. climate goals. To understand this near-term potential, this analysis then captures the biophysical characteristics of land and market dynamics at a state-level resolution in the United States.

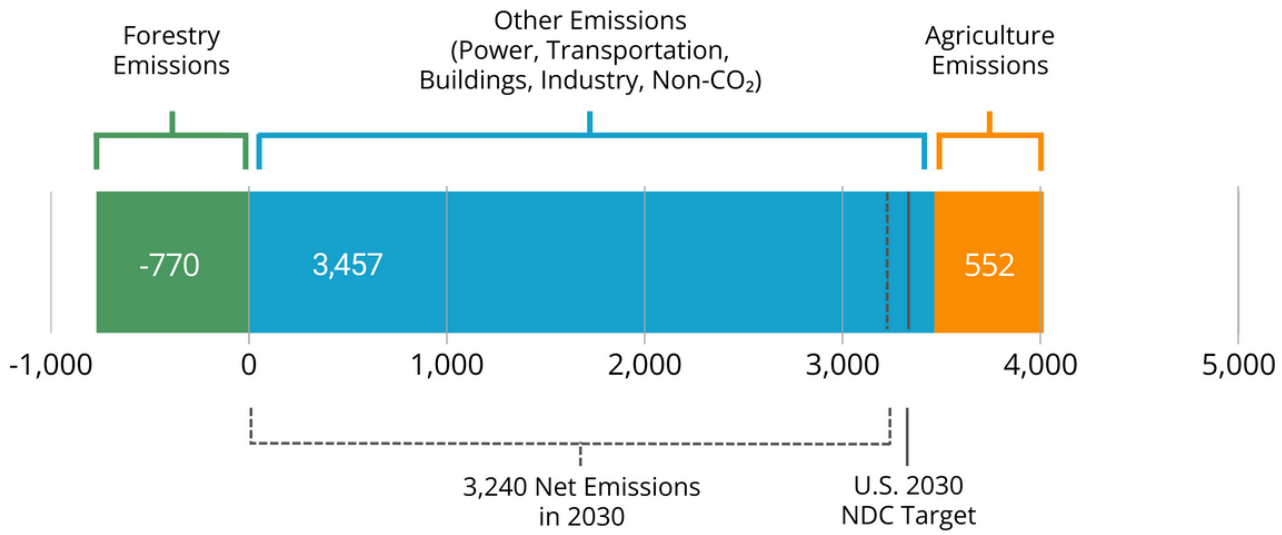

Figure 1: 2030 United States greenhouse gas emissions ($MtCO_2e/yr$) after reductions, featuring the role of agriculture and forestry sector emissions reductions, under an enhanced policy scenario, in helping the United States achieve the 2030 NDC target of 50-52% emissions reductions from 2005 levels by 2030. The net emissions reflect the total emissions in 2030 (other emissions + agriculture emissions + forestry emissions), which accounts for the negative emissions coming from the forestry sector's carbon sequestration activity.

The United States has, in recent decades, had a large and healthy land sector sink that absorbs substantially more carbon than it releases. Lands and land use can generate GHG emissions, particularly carbon, from land clearing, burning, or natural processes—but natural plant growth also absorbs carbon from the atmosphere (Huber, 2018). In any location or even across a country, the balance between the emissions and absorption could be either a "net source" (on balance, emitting carbon or other GHGs) or a "net sink" (on balance, absorbing carbon or other GHGs). The net sink discussed in this report refers to the total land sector emissions reduction potential from the forestry and agriculture sectors. Using the net sink to understand land sector potential in the U.S. can help identify how actions taken in two diverse sectors (forestry, which is currently a carbon sink, and agriculture, which is currently a source of greenhouse gases) can collectively contribute to overall carbon sequestration and help identify where trade-offs in land use management may benefit or hinder that sequestration potential. Historically, the U.S. net carbon sink has re-absorbed an average of 12% of gross U.S. economy-wide GHG emissions annually across all sources (energy, industry, etc.) ("Inventory of U.S.," 2023).

The U.S. carbon sink is generated largely by growth and some expansion in the country's forests and ecosystems (see box one for more information on the history of land use in the United States). Yet, climate-change-induced fires, ecosystem stress or dieback due to droughts and heatwaves, and urban expansion could significantly degrade this sink by the 2030s and beyond. Bolstering and even expanding this carbon sink will, therefore, be important to help the United States achieve its 2030 and 2050 climate goals. Through climate-smart land use policies at all levels of government, combined with effective implementation, the U.S. NDC target is within reach—altogether helping deliver net economy-wide emissions below 3,258 metric tons of carbon dioxide equivalent ($MtCO_2e$) in 2030 or nearly 52% emissions reduction from 2005 levels (Figure 1). However, without strategic planning and innovative policies, the land sector could significantly reduce its net sequestration capacity.

For over a century, the United States has focused on conserving lands through policies like protecting national parks, public land management, and sustainable land use practices ("America's Public Lands," 2023). Such policies also realized additional benefits in supporting a large and enhanced carbon sink. Recently, the federal government has prioritized climate action, especially through the historic Inflation Reduction Act (IRA) of 2022. The IRA allocated funds for various land sector initiatives, including the Agricultural Conservation Easement Program, Environmental Quality Incentives Program, Regional Conservation Partnership Program (RCPP), and Conservation Stewardship Program (Inflation Reduction Act, 2022). Additionally, the IRA and the Bipartisan Infrastructure Law (BIL) funded activities like wildfire resilience, urban forestry, and reforestation (Infrastructure Investment and Jobs Act, n.d.).

Across the United States, there is significant variation between regions and states in the extent to which land sector mitigation policies are implemented. This variation has led to some examples of innovation and good practice that can be adapted and implemented in other regional contexts. Maryland, for example, prioritizes comprehensive land management, exemplified by innovative soil health programs that strengthen carbon sinks and land resilience ("Maryland Healthy Soils," 2017). Urban forestry and tree planting initiatives also serve dual purposes, reducing emissions while aiding community development. Financial incentives, including grants like Minnesota's Soil Health Financial Assistance Grant, encourage sustainable agricultural practices ("Soil Health Financial," n.d.). Policy instruments like action plans and climate targets showcase commitment to the land sector's role, but their efficacy depends on funding allocation. Rhode Island's Forest Action Plan exemplifies this alignment by using organizational tools to analyze the contributions of actionable programs toward broader priorities ("Forest Action Plan," 2023). Another key aspect of full implementation is ensuring equity. An example of addressing the unequal distribution of urban trees is the Urban and Community Forestry Program. Funding directed to low-income and disadvantaged communities under this program can not only help reduce emissions in urban areas but also improve air quality and increase access to shaded areas as extreme heat intensifies ("Urban and Community," n.d.). Federal policies should also target underserved agricultural producers and communities, including rural areas, where investments in these programs can bolster rural economies. These integrative strategies consider regional complexities, stakeholder interests, evolving priorities, and resourceful incentives—shaping the path toward enhanced climate mitigation and resilience in the land sector.

[Box One] A History of the Land Sector Mitigation in the United States

Historically, land use policies in the United States have grappled with a dual mission: conserving natural resources while managing lands for public use ("National Timeline," n.d.). Beyond intrinsic value, conserving public lands is important for protecting their function and storing and sequestering carbon as a carbon sink. As climate change worsens, discussions around enhancing natural carbon sequestration in forests have amplified. Enhancing carbon sequestration and reducing emissions through comprehensive land management policies is a complex challenge, influenced by climate, soil type, forest characteristics, and land practices (Mäkipää et al., 2023). The imperative lies not only in boosting investments in nature-based climate solutions but also in intensifying efforts to measure and monitor the impacts of these interventions (Bossio et al., 2020). There are three primary policy approaches: incentivizing subnational governments and landowners, setting informed targets for agencies at diverse levels, and implementing penalties to discourage detrimental practices.

The vast landscapes of U.S. forests, grasslands, and wetlands already store substantial amounts of carbon and sequester around 754 $MtCO_2e/yr$. In essence, the land sector absorbs emissions equivalent to over 167 million gasoline-powered cars each year. However, land management and agriculture also contribute to emissions, with the agricultural sector alone releasing about 607 $MtCO_2e/yr$. Land-use changes from deforestation, urbanization, and cropland expansion can trigger carbon and GHG releases. Vital strategies such as reforestation, afforestation, and wetland restoration work toward nurturing the carbon sink and fortifying our defense against climate change impacts (Nave et al., 2018). These measures hold the potential not only to bridge the mitigation gap but also provide substantial additional benefits, including ecosystem resilience, biodiversity conservation, and diverse advantages for communities and economies, including water and air purification, waste detoxification, and disturbance regulation such as flood protection ("Opportunities to Accelerate," 2022). Policies such as revolutionizing agricultural practices, safeguarding and revitalizing forests, embracing sustainable urban development, and championing conservation initiatives can support enhanced carbon sequestration even in the face of uncertainty due to a changing climate and growing economy.

Mitigating climate change relies on boosting the land carbon sink and curtailing emissions, especially from agriculture. Precision practices like targeted fertilizer application and livestock feed additives can notably reduce GHG emissions (Shukla et al., 2019). However, the road ahead is not without challenges. The U.S. land sector faces growing vulnerability to climate-related hazards, such as storms, wildfires, and invasive species, which can threaten ecosystems and vital services. Predicting the extent of these threats remains complex due to the varied impact of climate change across regions.

Striking a balance between carbon sequestration, emissions reduction, and various land uses is pivotal. While mitigating climate change and ensuring resilient ecosystems are essential, we must also manage land to sustain food and fiber production, biodiversity, recreation, and cultural values. Achieving this balance hinges on locally informed policies that address the diverse needs of communities, the economy, and the environment.

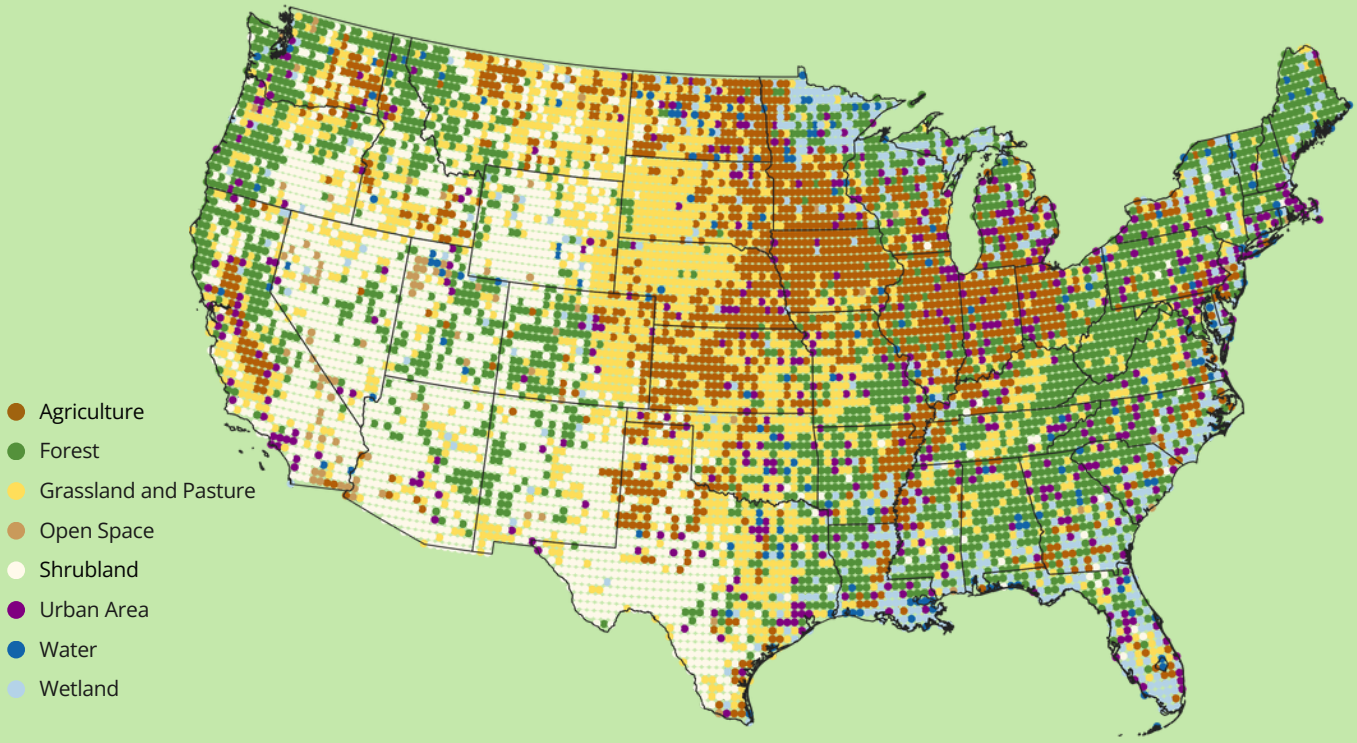

Figure 2: Land use in the United States across a variety of land types, including agriculture, forest, grassland and pastureland, open spaces, shrubland, urban areas, water, and wetlands. *Source: U.S. Geological Survey*

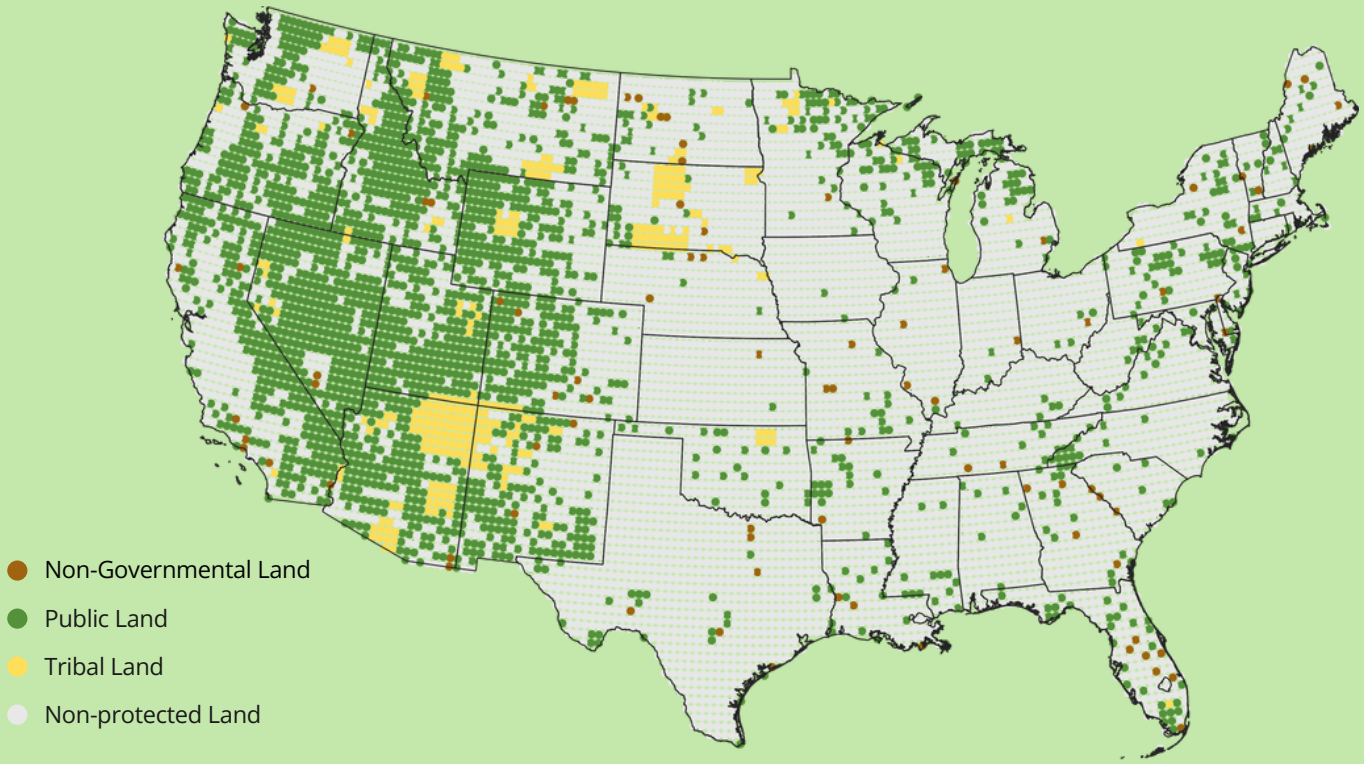

Figure 3: Protected land ownership in the United States, including non-governmental land (private, non-governmental organization, etc.), public land (federal, state, and local government), and Tribal lands. *Source: U.S. Geological Survey*

This new analysis integrates the vision for a comprehensive, "all in" U.S. policy platform with a multi-model approach to assess the opportunities for bolstering and expanding the U.S. carbon sink. An all-of-society or "All-In" U.S. climate strategy will be essential to achieving our national climate goals—meaning integrated action at the federal, state, city, and business levels. This report demonstrates how current and additional action has the potential to help secure and expand the U.S. land sector's net sink—encompassing emissions reductions in the agriculture sector and increased carbon sequestration from forests—by 72% by 2035 relative to 2021—and pave the way toward a sustainable, climate-resilient future.

Bolstering the U.S. land sector sink

Methods: Models

Since 2021, when the United States announced its NDC, new land sector policies have been implemented through Congressional actions, federal regulations, a diverse array of non-federal policies, and actions by subnational actors. The analysis presented here assesses how these policies, coupled with existing and additional policies and actions largely derived from the forestry and agriculture sectors, could influence emissions from the U.S. land sector through 2035 through effective land use management. Increased policy ambition and investment from an "all-in" U.S. climate strategy encompassing states, cities, businesses, and more are also critical to fully realize already on-the-books policies and enhance the impact of these actions.

The land sector is complex, and our approach in this analysis combines three models to assess the impacts of these suites of policy actions on both the forest and agriculture sectors and their contribution to critical near-term U.S. climate goals. This approach captures the biophysical characteristics of land and market dynamics and embeds them in a global framework for all sectors and all gases with state-level resolution in the United States.

The first model, the economy-wide integrated assessment model Global Change Analysis Model (GCAM-U.S.A), provides additional input and contextualizes how the land-sector projections fit into the economy-wide reductions in support of U.S. climate goals. To account for activity in the energy system, we used biofuel production outputs from GCAM's All-In scenario, which has economy-wide policies that demonstrate a pathway to achieving the U.S. 2030 target ("Global Change Assessment Model," n.d.). This includes 1.6, 4.8, and 7.8 billion gallons of biodiesel, cellulosic ethanol, and corn ethanol in 2035, respectively. [Technical appendix to come for more detailed information on these models].

The second model, the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG), assesses the cost-effective combination of different land-based activities that maximize the greenhouse gas mitigation potential of current state- and national-level policies (Adams et al., 2005). This model accounts for opportunity costs as agriculture and forestry commodity markets adjust in response to GHG reduction investments. For example, if afforestation or reforestation activities occur on optimal grazing land, more livestock may need to be produced using centralized feeding operations, increasing emissions from manure management. FASOMGHG also simulates the market impacts and subsequent land use of biomass feedstocks used for both biofuel and bioenergy. FASOMGHG projects subnational land sector dynamics for 11 regions in the contiguous United States (Cornbelt, Great Plains, Lake States, Northeast, Pacific Northwest-east, Pacific Northwest-west, Pacific Southwest, Rocky Mountains, South Central, Southeast, and Southwest - see Figure 6 for the breakdown of the regions) (Segerson et al., n.d.).

The third model, the Ecosystem Demography (ED) model, is used to compare the regional mitigation potential from FASOMGHG with the technical afforestation and reforestation capacities in U.S. forests and to provide geospatial estimates of that potential. This is used to examine the physical potential and risk of natural disturbances of afforestation activities modeled in FASOMGHG. ED is a high-resolution mechanistic forest ecosystem model that quantifies the spatial variation in carbon sequestration rates, accounting for climate and soil patterns, plant growth and mortality, existing land cover, natural disturbances (any event that disrupts an ecosystem or population and causes a pronounced change in an ecosystem), and wildfire burn rates (the fraction of spatial grid cell burned every year, representing the potential risk of fire due to climate conditions and fuel load), to project the total carbon sequestration potential. The ED model has been extensively calibrated and validated with remote sensing observations and field data on forests in the United States and is a component of the NASA Carbon Monitoring System (Hurtt et al 2019; Ma et al., 2021, 2022, and 2023).

Methods: Scenarios

To quantify potential land sector emissions reductions, we use three scenarios under alternative policy assumptions and explore how a suite of policy investments and mitigation activity can inform decision-making based on the potential economic, regional, and physical drivers for carbon sequestration. Deploying the multi-model analysis, three scenarios highlight the impact of existing policies (Existing Policies scenario), the supplementary effects stemming from a suite of potential new policies (Enhanced Ambition scenario), and, in contrast, the results are compared to an "absent climate-smart policies" scenario. Underlying the Existing Policies and Enhanced Ambition scenarios is a set of non-investment socioeconomic conditions outlined by globally recognized pathways for how society, demographics, and economics may shift over the next century in support of other important societal goals (O'Neill et al. 2017, Riahi et al. 2017) (see Wade et al., 2022 for details on FASOMGHG's parameterization for Shared Socioeconomic Pathway (SSP) 1 and other SSPs). These underlying conditions such as increased plant-based diets to the likes of the USDA Healthy Diet Guidelines and focusing urban expansion to areas without existing forest, agriculture, or pastureland impact the potential to realize emissions reductions in these sectors. For example, full implementation of critical federal and state-level policies across all sectors of the economy, like power, transportation, and buildings, is vital for achieving these potential land sector reductions. If other sectors fall behind in achieving their emissions reduction potential, the intensity and frequency of climate change-related natural disturbances will increase the burden on the land sector to remain a carbon sink and not a carbon source. Yet, with increased demand for less carbon-intensive wood products over steel and concrete in the buildings sector, the resilience and robustness of the forestry sector have become more important than ever.

"Absent Climate-Smart Policies" Scenario: Emissions Reductions Potential Without Policy Implementation

The Absent Climate-Smart Policies scenario represents if federal legislation—like the IRA—was repealed today and all states diverted funds away from climate-related policies. This scenario emphasizes the need for full implementation of climate-smart policies already on the books and new and ambitious policies prioritizing securing the national carbon sink. The FASOMGHG model projects how landowners will respond to future demands for crop, livestock, and forestry commodities and maximize the net present value of natural and working lands based on these demands. This results in a baseline scenario in which we can estimate the impact of existing policies to understand the effectiveness of current investments. Additionally, we can value the tradeoffs with market outputs with climate stabilization policies.

"Existing Policies" Scenario: The Foundation

The Existing Policies scenario assumes full implementation of current federal and state policies (see Table 1 for a breakdown of modeled policies) and sets a strong foundation for carbon sequestration in the United States. This includes roughly $42 billion of currently planned federal and state investments in climate-smart agricultural practices, conservation policies across the forestry and agriculture sectors, wildfire mitigation, and afforestation and reforestation efforts.

"Enhanced Ambition" Scenario: Bolstering the Carbon Sink & Reaching U.S. Climate Goals

The Enhanced Ambition scenario assumes that states that are already taking major steps to address climate change, such as California, New York, and Maryland, continue in their high levels of ambition, and a reasonable subset of other climate-leading, fast-mover states follow with their own enhanced climate policies within the forestry and agricultural sectors—as well as additional implementation policies such as blue carbon mitigation, urban land use reform, and wildfire mitigation. Overall, investment in climate-smart policies and incentives increase to $160 billion under this scenario through continued federal and state investments.

Table 1: Breakdown of the key policies included in each scenario driving emissions reductions and their total investment.

Actor	Policy Type	Existing Policies	Enhanced Ambition Policies	Total $
Federal		• Wildfire Emergency Act of 2023, Western Wildfire Support Act, and National Prescribed Fire Act	• Expanded funding to Existing Policies • Funding for Cooperative Fire Protection Program	$63B
		• Forest Stewardship Program, Environmental Quality Incentives Program, Regional Conservation Partnership Program, and Urban and Community Forestry Program	• Expanded funding to Existing Policies • Funding for the Community Forest and Open Space Conservation Program and Urban and Community Forestry Program	$11B
		• Healthy Forests Reserve Program and Landscape Scale Restoration Program	• Expanded funding to Existing Policies • Funding for Forest Health Protection Program	$1B
State		• Colorado: Wildfire Mitigation Incentives for Local Governments, Assistance Landowner Wildfire Mitigation, Increase Wildfire Risk Mitigation Outreach Efforts, Wildfire Mitigation and Recovery, Wildfire Prevention Watershed Restoration Funding • California: Prescribed Fire Liability Pilot Program and Wildfire Resilience Program	• Expanded funding to Existing Policies • Funding for Oregon's Senate Bill 762 for wildfire mitigation and preparation	$16B
		• California: Timberland Conservation and Fire Resiliency Program • Washington: Building Partnerships Competitive Grant Program	• Expanded funding to Existing Policies • Funding for Colorado's Wildfire Prevention Watershed Restoration Funding	$1B
		• Maryland: 5 Million Trees Initiative • New York: Regenerate New York Forestry Cost Share Grant Program • Michigan: DTE Energy Foundation Tree Planting Grant Program and Planting 50 Million Trees in the Great Lakes State • Michigan State University: Forest Carbon and Climate Program	• Expanded funding for Maryland, New York, and Michigan's programs • Funding for regenerative programs adopted by climate-leading states • Funding for Delaware's Tree for every Delawarean Initiative and urban forestry programs adopted by climate-leading states	$57M
		• Minnesota: Conservation Partners Legacy (CPL) Grant Program	• Funding for Louisiana Outdoors Forever Program, New Mexico's Land of Enchantment Legacy Fund, and Washington's Climate Commitment Act and adopted by climate-leading states	$12B
		• Colorado: Updates to State Forest Service Tree Nursery	• Expanded funding to Existing Policies and adoption by climate-leading states	$83M
Federal		• Conservation Stewardship Program, Agricultural Conservation Easement Program, and Conservation Reserve Program	• Expanded funding to Existing Policies	$47B
State		• New Mexico, Minnesota, Colorado, and California's soil health programs	• Expanded funding to Existing Policies • Funding for Pennsylvania's Agriculture Conservation Assistance Program and adoption by climate-leading states	$3B
		• California's Alternative Manure Management Program and Dairy Digester Research and Development Program	• Expanded funding and and adoption by climate-leading states	$528M

Results: Achieving current and future policy potential

The three scenarios quantify potential land sector emissions reductions under alternative policy assumptions and can inform decision-making based on the potential economic, regional, and physical drivers for carbon sequestration. Assuming full implementation of the Existing Policies and Enhanced Ambition scenarios, the modeled policies can achieve substantial emissions reductions in the forestry and agriculture sectors through key provisions in the IRA and increasingly ambitious policies. Yet without full implementation of such policies at the state and local levels, the United States could continue to lose critical sequestered carbon, setting back national sequestration efforts as we aim to reach our ambitious climate goals.

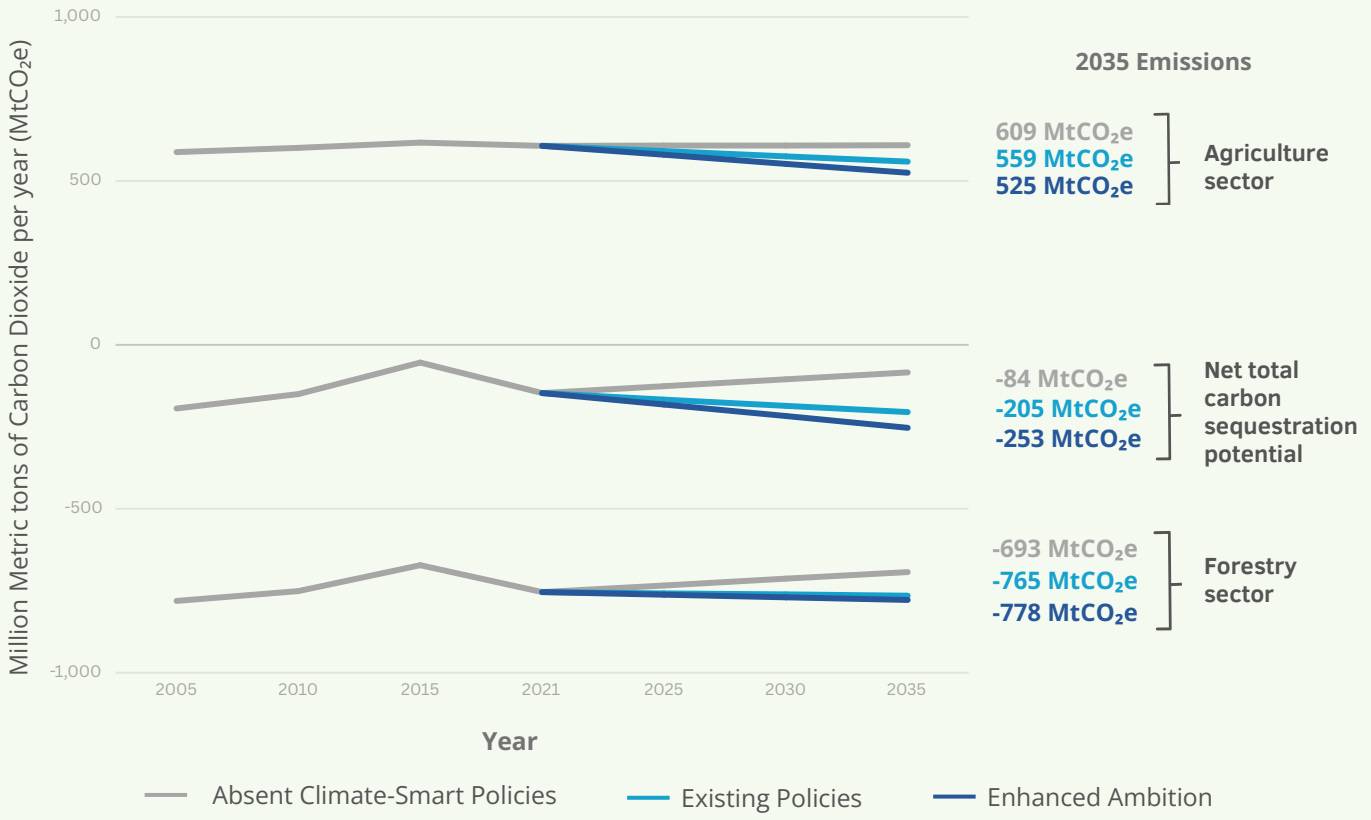

Figure 4: Historical and projected forestry, agriculture, and net annual emissions based on the Existing Policies, Enhanced Ambition, and Absent Climate-Smart Policies scenarios.

"Absent Climate-Smart Policies" Scenario

Under the Absent Climate-Smart Policies scenario, this analysis finds that agricultural emissions from inputs, energy, and other processes will remain at a relatively constant level (609 $MtCO_2e$ in 2035). At the same time, the forest carbon sink maintains a steady decline. Without full climate-smart policy implementation and adoption of Enhanced Ambition policies, the forestry sector will decrease its annual sequestration to 693 $MtCO_2e$ in 2035. Overall, under the Absent Climate-Smart Policies scenario, the net carbon sink provided by the land sector is projected to continuously decrease in the amount of carbon sequestered and is set on a trajectory towards potentially becoming a carbon source, sequestering only 84 $MtCO_2e$/yr by 2035 (Figure 4).

"Existing Policies"

Under the Existing Policies scenario, the land sector, through emissions reductions in the agriculture sector and increased carbon sequestration in the forestry sector, increases net sequestration from the land sector by 58 $MtCO_2e$ in 2035, marking a 40% increase in the net sink compared to today's levels. Existing policies in the forestry sector increase the carbon sequestration potential by 10 $MtCO_2e$ in 2035 compared to 2021 levels, and this is achieved through both intensive and extensive expansion of forests. Afforestation and reforestation contribute to the most carbon sequestration (13% of total reductions) with forest management activities delivering about one-third of the reductions in the forestry sector (5% of total reductions).

Results indicate that critical near-term agricultural emissions decrease by 48 $MtCO_2e$ in 2035 (compared to a net total of 607 $MtCO_2e$/yr in 2021 as reported by the Environmental Protection Agency's (EPA) greenhouse gas inventory (GHGI)) driven by the implementation of climate-smart agricultural practices through federal and state-level policies, such as from IRA and BIL. Critically, this accelerated near-term action from existing policies in the agricultural sector helps deliver a faster rate of reductions and ultimately contributes to a strengthened U.S. carbon sink. Without full implementation, these reductions may not be realized, contributing to a net decrease in the national carbon sink. The majority of emissions reduction potential in the Existing Policies scenario comes from methane reductions in rice production (25% of total reductions), implementation of methane digesters and manure management systems (18% of total reductions), and reduced CO2 from fertilizer production and applications (14% of total reductions).

"Enhanced Ambition"

Through an all-of-society approach, combining existing policies with accelerated actions and enhanced investments, this Enhanced Ambition scenario can enhance the U.S. carbon sink and reduce land emissions by delivering net sequestration of 253 $MtCO_2e$ in 2035—an increase of 72% relative to 2021 (147 $MtCO_2e$). The policies modeled under the Enhanced Ambition scenario can help deliver critical net emissions reductions to achieve the U.S. NDC goal and secure the carbon sink by increasing its levels to 253 $MtCO_2e$/yr by 2035.

Under the Enhanced Ambition scenario, carbon sequestration from forests will increase by 24 $MtCO_2e$ in 2035. This is produced through a range of activities including afforestation and reforestation efforts resulting in a 5% increase in forest area within the continental U.S. on current natural and working lands relative to the current land area by 2035—amounting to over 2 million acres per year due to enhanced and ambitious afforestation policies. Additionally, overall timber harvesting declines slightly relative to the absent-climate policy scenario, but the production of long-lived wood products remains relatively constant, as incentives to replace carbon-intensive building materials expand. At the same time, overall timber harvest is declining as pulp and paper produce demand declines. The Enhanced Ambition scenario results in the U.S. forestry sector increasing as a net sink to levels similar to the early 1990s. This is driven by both forest management activities increasing as well as continued afforestation and reforestation activities on lands ripe for tree growth, such as lands unable to grow or sustain crops and marginal or idled agricultural lands (Figure 5). This approach not only maximizes carbon sequestration potential but also transforms unproductive land into a valuable resource for sustainable growth.

Emissions reduction potential from the agriculture sector increases to 82 $MtCO_2e$ in 2035, a reduction of 13% relative to 2021. The Enhanced Ambition scenario includes an expansion of livestock manure management activities in dairy, beef, and pork production systems, slight reductions in fertilizer usage, and a switch to alternative wet and dry rice production to lower methane emissions. In the Enhanced Ambition scenario, methane reductions from rice fields are still a significant focus, but a greater amount of reductions are tied to livestock mitigation activities such as reduced methane through liquid manure management systems and other methane digester technologies, and reduced enteric fermentation through changes in feed mix, while reduced fertilizer demand continues to reduce emissions, but not as much as under Existing Policies (Figure 5).

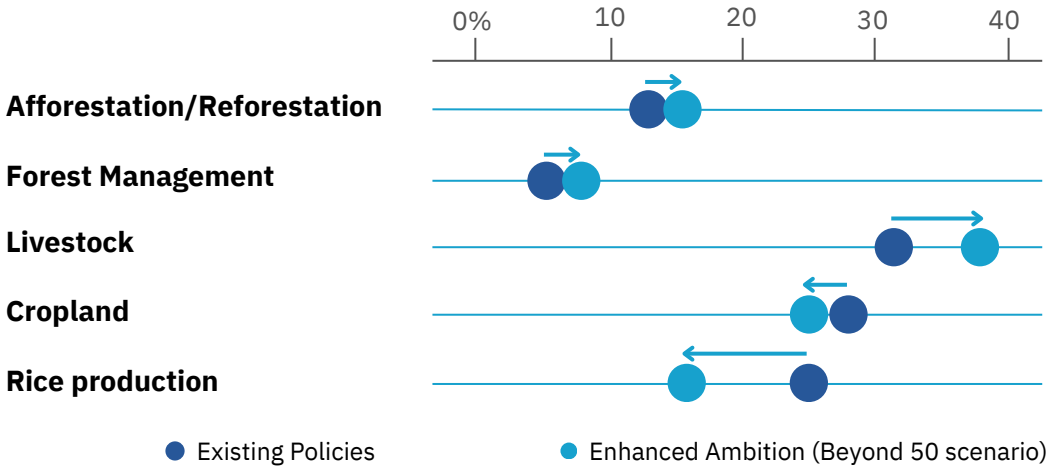

Figure 5: Percent of emissions reductions from key policies under two scenarios: implementing existing climate policies and with enhanced climate ambition at the national- and state-level.

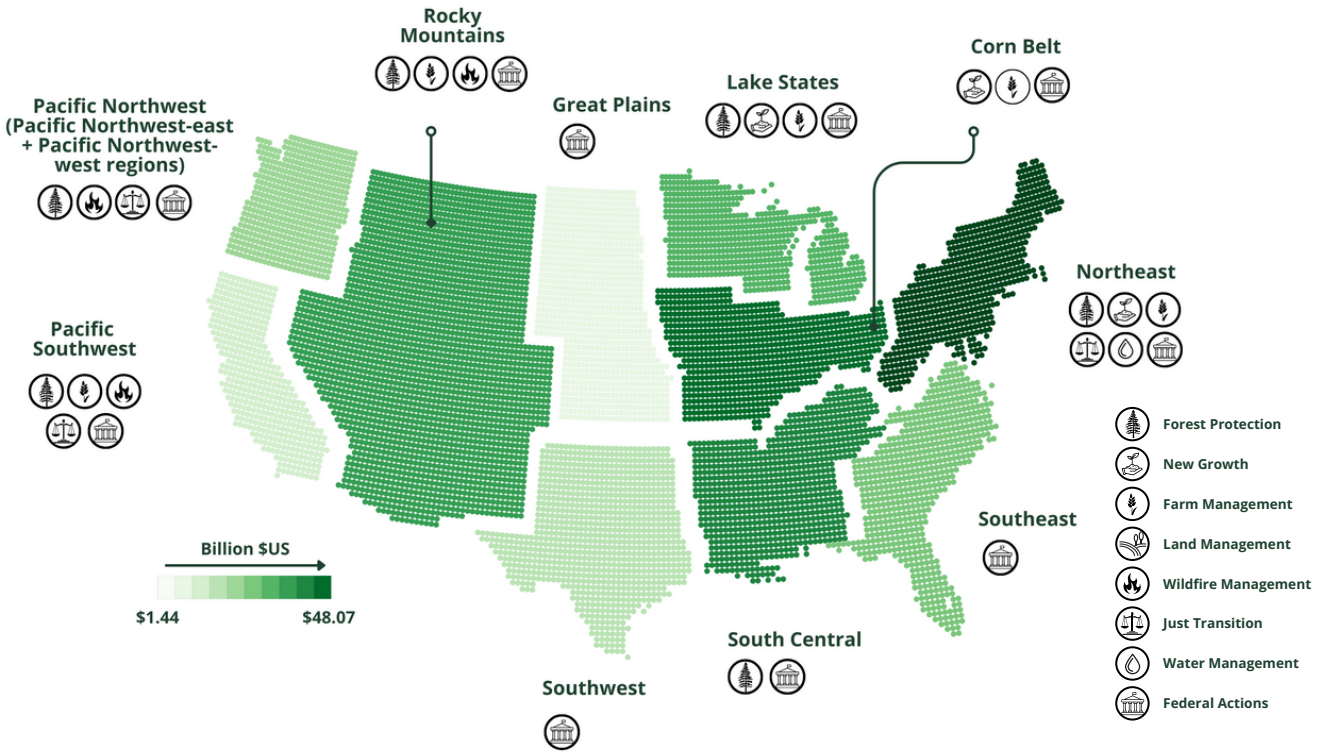

Figure 6: Enhanced Ambition scenario's key policies and funding amounts per region. The model demonstrates the regional significance of different policies, what is most effective, and how funds are distributed. The Northeast and the Corn Belt regions show new growth as key policies and show more return on investment where there is more available land for forests. The Southwest shows only federal action because the region is primarily made up of tier 3 states - slow movers in climate action. Yet there is still some carbon sequestration potential which is why the region is still allocated more funding than the Great Plains, where there is less feasible and productive land to realize emissions reductions.

Key Policy Insights

Land management and regional potential

Climate-smart forest management plays a pivotal role in both enhancing carbon sequestration and fostering multifaceted benefits for communities, landowners, and surrounding ecosystems, such as enhanced food systems and security, alleviated desertification, reversed land degradation, and recreation and spiritual enrichment (Shukla et al., 2019). Distinguishing between standard forest management activities and sustainable, climate-smart approaches is essential to realize these environmental and societal advantages. The key policies in the Enhanced Ambition scenario achieve enhanced carbon sequestration by expanding forested lands by roughly 2 million acres per year, conserving existing forests, and implementing climate-smart forest management practices. These results are substantial in achieving near-term climate goals given currently available and productive land, but they also demonstrate the amount of untapped land area potentially available. Through enhanced land management practices and climate-smart decision-making in the remaining available land, much more carbon sequestration is possible.

Safeguarding existing forests to ensure their perpetuity as carbon reservoirs is important to curtail deforestation and promote forest conservation, thereby maintaining the carbon stocks in these ecosystems. Increasing carbon sinks necessitates increasing forest area through afforestation and reforestation policies and climate-smart forest management techniques that can help optimize carbon storage in existing forests. These practices historically have encompassed sustainable timber harvesting, controlled burns, and selective thinning, among others, to bolster carbon sequestration while concurrently fostering ecosystem resilience and mitigating disturbance-related emissions.

Additional policies exploring how sustainable wood harvesting and timber production can contribute to emissions reductions and support long-term carbon accumulation in forests, such as the Partnership for Climate Smart Commodities Climate Smart Wood Economy program, which brings together Tribes, forest land owners, and wood producers to identify sources of climate-smart

wood. Beyond forests, grasslands and rangelands can also sequester carbon, especially within the Great Plains and Southwest regions. Inappropriate tree planting within grasslands can negatively affect biodiversity, carbon sequestration, and ecosystem functioning. Results do not prioritize afforestation and reforestation in these regions, and consequently, these regions contribute very little to forest carbon sequestration in this analysis. However, Enhanced Ambition assumes these regions take advantage of extended and expanded federal policies such as USDA's Conservation Stewardship Program, which extends to rangelands and can help promote carbon sequestration activities in otherwise unproductive areas.

Future projections utilize intensive forestry practices such as planting or artificial regeneration on recently harvested or non-forest areas. For example, in the Pacific Northwest high carbon sequestration rates per unit land area exceed ecosystem model estimates. This is driven by the expansion of intensively planted Douglas-fir stands, expanding from about 1.2 million acres in 2020 to 1.9 million acres in 2035. These intensively managed forests result in higher growth yields than naturally regenerated forests. Other regions (Great Plains, Pacific Northwest-West, and Pacific Southwest) focus on retaining existing forest carbon stocks through forest management activities and reduced wildfire risk. This finding highlights the important roles that intensive forest planting and management activities can play in reaching climate sequestration targets.

Key agricultural regions such as the Corn Belt, Lake States, and South Central can contribute to both carbon sequestration and emissions reductions in the agriculture sector through enhanced soil management efforts such as nutrient management and conservation tillage. Several states have implemented their own healthy soil programs to promote conservation practices in new and innovative ways that improve soil health, resilience, yield, profitability, and capture carbon (e.g., Maryland Healthy Soils Competitive Fund and Minnesota's Soil Health Financial Assistance Program). In addition to what was modeled, these regions can also implement state-level incentives to adopt optimal land management practices and sequester carbon, such as New Jersey's Natural Climate Solutions Grant program, which earmarks funds for "on-the-ground implementation of projects that create, restore, and enhance New Jersey's natural carbon sinks" ("RGGI Natural Climate Solutions," 2022).

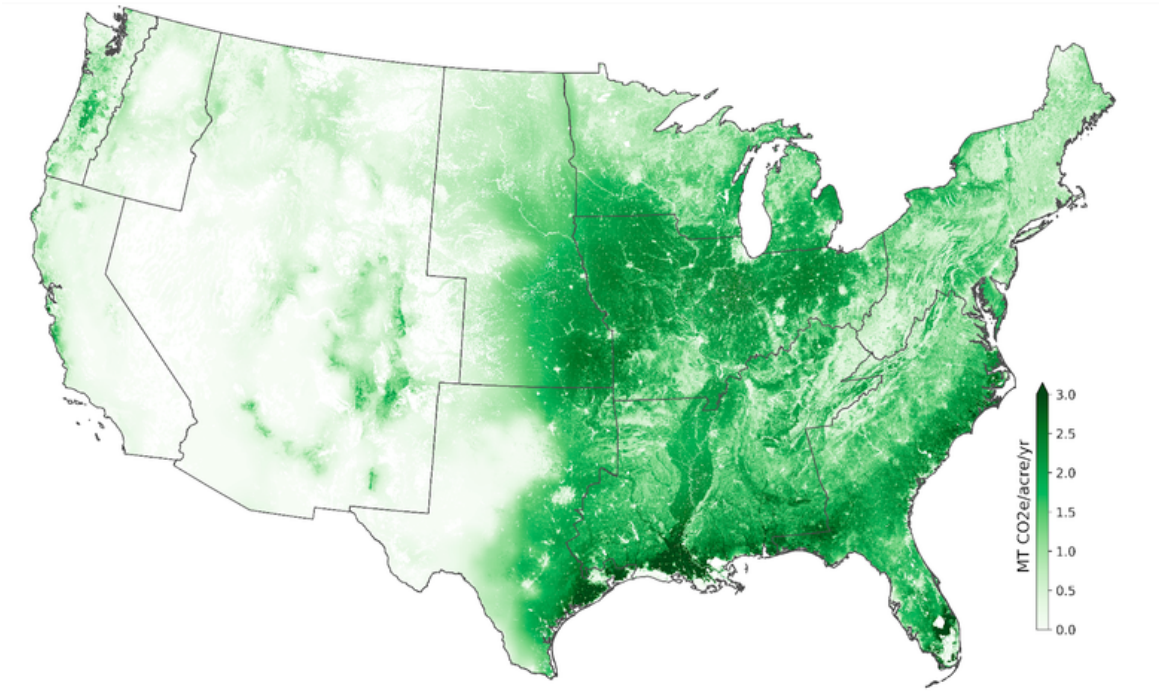

Figure 7: Total (unrestricted) forest carbon sequestration potential in the contiguous United States. This technical potential includes potential forest biomass growth on both existing tree cover and potential new tree cover on all available land including cropland, grassland, shrubland, pastureland, and developed open space.

Yet, the total carbon sequestration potential on land is even greater than what is estimated here. The total unrestricted carbon sequestration potential from afforestation and reforestation is greater than the scope of this analysis and was considered infeasible due to competition with other important land uses such as cropland (Figure 7). To examine the impact of existing and new and additional policies and investments, we model these on a restricted amount of land, excluding cropland and urban areas.

Table 2 shows the emission reductions estimated by FASOMGHG compared to the technical potential from the ED model for the same feasible lands by region. In all cases, the FASOMGHG estimate is within the technical potential for the region estimated by ED. This provides a source of validation, and context that the total sequestration potential could be even higher and at an even faster rate than estimated in this report. This is also true per unit of land area in most regions. In three regions (Rocky Mountains, Pacific Nortwest-east, and Pacific Southwest), the FASOMGHG estimate exceeds the ED estimate per unit area. In these regions enhanced forest management and/or more land area may be required to realize expected carbon gains.

Table 2: Multi-model comparison of carbon sequestration potentials in forest biomass by region on land considered feasible for afforestation/reforestation under the Enhanced Ambition scenario. FASOMGHG projected carbon and land area (column 2). ED maximum forest carbon sequestration potential on the corresponding land area (column 3). ED maximum forest carbon sequestration potential on all available feasible land (column 4). Regions are ranked by other FASOMGHG emissions reduction potential.[1]

FASOMGHG Model Results		ED Model Results	
Regions	**Sequestration potential ($MtCO_2e/yr$) from afforested land area**	**Maximum carbon sequestration potential on FASOMGHG land area ($MtCO_2e/yr$)**	**Maximum sequestration potential on all feasible land ($MtCO_2e/yr$)**
South Central	50 $MtCO_2e/y$ from 25.1 million acres	67	110
Southeast	36 $MtCO_2e/yr$ from 18.0 million acres	47	69
Northeast	12 $MtCO_2e/yr$ from 9.0 million acres	20	41
Cornbelt	8 $MtCO_2e/yr$ from 13.5 million acres	34	76
Lake States	9 $MtCO_2e/yr$ from 9.8 million acres	19	21
Rocky Mountains	7 $MtCO_2e/yr$ from 2.5 million acres	2	54
Pacific Northwest-east	3 $MtCO_2e/yr$ from 1.5 million acres	1	6
Pacific Southwest	2 $MtCO_2e/yr$ from 0.7 million acres	1	6

Wildfire Mitigation & Addressing Other Natural Disasters

As climate change intensifies in the United States, natural disturbances like wildfires, droughts, pests, and flooding pose increasing threats to the land sector. These disruptions challenge efforts to preserve and expand the land carbon sink, often with unpredictable and far-reaching consequences.

Wildfires, in particular, demand significant attention. The federal budget for wildland fire management in 2023 reached $1.77 billion, with a request for an additional $1.94 billion to address the growing severity of the issue (“Budget”, 2023). The USDA has secured $3.5 billion, and the Department of the Interior (DOI) has allocated $1.5 billion over the next five years through the Bureau of Indian Affairs (BIA) Land Improvement Program to bolster wildfire management resources (Infrastructure Investment and Jobs Act, n.d.). Recent historic wildfires across the United States and North America have not only impacted our carbon sink but also air quality. In 2020, wildfires burned more than 10.2 million acres in the United States, and the subsequent emissions contributed to 23% of surface PM2.5 concentration in the air (Li, 2021). These wildfires also threaten homes, businesses, food supply, and more. Home and structure loss due to wildfires has surged by 246% in the western United States over the past two decades (Higuera, 2023). The increase is not solely due to more extensive burns; wildfires have become 160% more destructive in the past decade, with most home and structure loss attributed to unplanned human-related ignitions such as campfires and downed power lines—emphasizing the need for mitigation and human-centered adaptive policies (Higuera, 2023).

[1] Three regions in the FASOMGHG are projected to have no afforestation between 2021 and 2035. This includes the Southwest, Great Plains, and Pacific Northwest-West. This is due to limits on the productivity of tree growth within these regions, as well as, market-driven factors such as demand for livestock products, of which, the Southwest and Great Plains have comparative advantages in production relative to other regions.

Insect and forest disease disturbances also pose significant threats to sequestering carbon in both the forestry and agriculture sectors. Forests recently impacted by insect invasions sequestered 69% less carbon in live trees on average, and those affected by diseases sequestered 28% less from 2001 to 2019 (Quirion et al., 2021). To safeguard forests' climate mitigation potential, strengthened international trade policies, improved point-of-origin phytosanitary standards, and enhanced forest management are crucial. Research and innovation in preventing insect-related forest diseases are already underway but must be accelerated to protect the existing forest carbon stock. Innovative methods such as new fertilizers and hybrid trees can reduce the threat of insects and diseases (Quirion et al., 2021). These advancements can be researched and deployed in the agriculture sector to replace the historic use of harmful pesticides that negatively impact human health and contribute to methane emissions (Woodcock et al., 2017).

While there is potential to significantly increase the forest carbon sink on land that is feasible for afforestation and reforestation, other factors, including extreme weather, pests, wildfires, and others, are changing across the United States, calling into question the stability of the carbon sink. Figure 8 maps the forest carbon sequestration potential from afforestation and reforestation (green scale) on feasible land, excluding agricultural land and urban areas, together with potential wildfire burn rates (red scale). These results depict locations of high potential carbon sequestration (green) and locations of high risk of loss from fire (red). Though afforestation and reforestation are key policies to enhance sequestration, this is not always possible or advisable in fire-prone regions like the Southwest. In such areas, directing funds to mitigate the severity of wildfires before they start, suppressing fire where needed, and reforestation after wildfire can sustain sequestration (Peeler et al., 2023). Even regions with lower or no historical wildfire risks can benefit from proactive wildfire mitigation due to climate change's increasing intensity and hard-to-predict impact on our lands (Modaresi Rad et al., 2023). In addition, by investing in conserving existing carbon stocks, states can simultaneously pursue policy strategies like afforestation to accelerate sequestration. Based on the spatial depiction of potential burn areas, policymakers can identify where forest regrowth could be most productive.

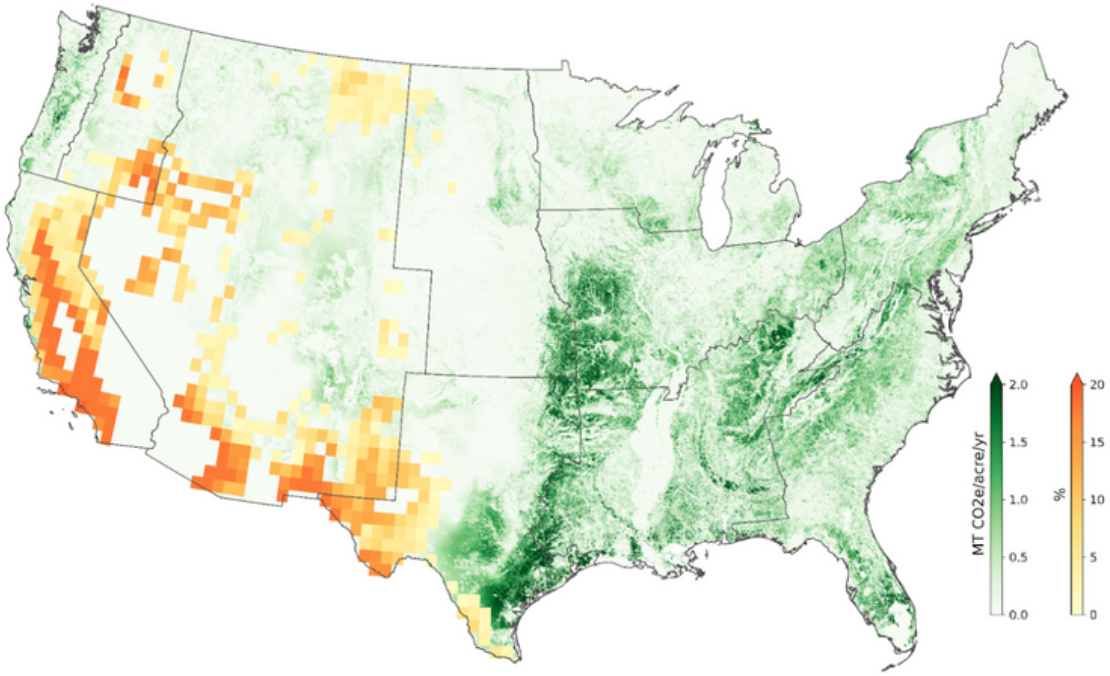

Figure 8: Enhanced Ambition scenario's sequestration potential rate in forest biomass from afforestation/reforestation (green) and projected fire risk (red). The map is restricted to land outside of cropland and urban areas and growth potential is on shrubland, pastureland, and developed open space.

Livestock Mitigation & Reduced Methane

Methane is a primary contributor to emissions in the agricultural sector, and substantial reductions in methane emissions from livestock and rice cultivation. Policies in the Enhanced Ambition scenario contribute to nearly 70% in methane emissions reductions by 2035. Key policies that deliver the highest emissions reductions include implementing methane digesters and liquid manure management systems to capture methane emissions from manure and convert them into usable energy or prevent their release into the atmosphere. Financial incentives, tax credits, and subsidies can promote the adoption of liquid manure management technologies among livestock producers and deliver the largest emissions reductions under the Enhanced Ambition

scenario—30% emissions reduction potential by 2035. Adjusting the composition of livestock diets by changing the feed mix and incorporating additives can also reduce methane emissions from enteric fermentation.

To realize even more emissions reductions, an extended federal methane fee of $1,500/tCH4 could incentivize livestock and rice producers to implement economically feasible emission reduction actions. Even a lower methane fee of $250/tCH4 ($10/tCO2e) could deliver substantial emissions reductions in the agriculture sector—previous analysis projected over 30 MtCO2e emissions reductions by 2030 alone (Zhao et al., 2022). States can also take action to address livestock emissions, as seen in California's anaerobic digester and manure management programs. In addition to supporting state-level climate goals, the more state-level programs there are, the better-equipped state officials will be to ease the capacity constraints of applying for voluntary programs. Several corporations have implemented their own emission reduction goals, e.g. Smithfield Foods and McDonald's, but achieving them requires action throughout the supply chain including from agricultural producers ("Climate Action" n.d.; "Environmental Stewardship," n.d.). Large multinational food corporations can work with their producers to provide them with the tools they need to implement climate-smart agricultural practices.

Blue Carbon Sequestration

Blue carbon ecosystems are increasingly recognized for their role in mitigating climate change, with growing national and international efforts. These ecosystems, like mangroves and seagrass meadows, store remarkable carbon per area, exceeding terrestrial forests. The United States prioritizes the ocean-climate link, allocating funds for coastal habitat restoration through the BIL. The Our Ocean Conference in Palau marked substantial U.S. financial support, including $161.5 million for coastal resilience and $107.9 million for NASA's coastal ecosystem observations (Kryc, 2022).

Amid evolving blue carbon policies, states are adopting diverse strategies due to limited funding. States repurpose resources into blue carbon conservation, like wetland programs, or incorporate them into broader solutions. Louisiana uses oil spill funds for wetland health tools ("Louisiana Restoration Area," n.d.). New Jersey directs Regional Greenhouse Gas Initiative (RGGI) proceeds to blue carbon, while Maryland's Conservation Finance Act aids wetland restoration and explores pilot blue carbon projects ("RGGI Natural Climate Solutions," 2022; "Conservation Finance Act," 2022). On the federal side, agencies like the Council on Environmental Quality (CEQ), the National Oceanic and Atmospheric Administration (NOAA), and the EPA drive blue carbon research and conservation ("Ocean Climate Action," n.d.). As initiatives progress, blue carbon can help shape climate strategies for a sustainable future.

Accelerated and Effective Implementation through All-of-Society Actions

Numerous opportunities exist to expand climate-smart agriculture and forest management policies at federal, state, and local levels. However, these policies are not always equally accessible. To ensure successful implementation, government officials and strategic partnerships play a critical role in leveraging funding and provisions to secure the carbon sink. Government officials can enhance program effectiveness through outreach, educational programs, technical assistance for eligible groups and individuals, and support for competitive grant programs in collaboration with strategic partners ("U.S. Climate Policy," 2023). These efforts can alleviate capacity constraints and raise program awareness, striving to realize all available funding and policy opportunities.

The federal government faces a critical juncture with the 2024 Farm Bill. Passing the bill is an opportunity to expand funding and eligibility, emphasizing carbon sequestration for enhanced mitigation. In late 2023, Congress passed a one-year extension of the 2018 Farm Bill, allowing continued funding for programs that would have otherwise lost funding. Now, Congress has until September to pass a new Farm Bill, placing the federal government at a critical juncture in its land use mitigation programs as discussions heat up in 2024. This bill is crucial for various conservation, sustainable agriculture, and forestry-related programs primarily overseen by the USDA. These programs are at risk of significant weakening or loss of funding if the 2024 Farm Bill does not reaffirm them (Owens, 2023). Simultaneously, this moment presents a major opportunity to expand funding and eligibility for these programs while emphasizing carbon sequestration to enhance mitigation efforts ("NRCS Climate-Smart," n.d.). A new Farm Bill can play a pivotal role in achieving the robust federal legislation needed to maximize emissions reductions from land use. Enhanced and expanded investments in climate-smart agriculture lead to rapid emissions reductions. This includes federal initiatives such as the USDA's Environmental Quality Incentives Program (EQIP), which offers financial and technical assistance for various conservation initiatives to help agricultural producers and forest landowners integrate conservation practices into their lands. One of these initiatives is the On-Farm Energy Initiative, which aids farmers and ranchers in adopting technologies that enhance energy efficiency and operational improvements ("On-Farm Energy," n.d.). In the ambitious Enhanced Ambition scenario, these programs alone are projected to achieve nearly 10% of the potential agricultural mitigation by 2035.

States are central to directing federal funding, implementing ambitious policies, and addressing livestock emissions, all vital in achieving climate goals. States play a crucial role in directing federal funding towards eligible groups and state agencies, as seen in programs like the Iowa Department of Agriculture and Land Stewardship's efforts to support cattle farmers. Furthermore, states can implement their own ambitious policies, such as Pennsylvania's Agriculture Conservation Assistance Program and Illinois's Soil and Water Conservation District Grants Program. State-level actions, including addressing livestock emissions, are integral in supporting climate goals and reducing capacity constraints for voluntary programs.

Incorporating and learning from U.S. Tribal Lands and Territories is vital, as these communities often face greater vulnerability to climate change impacts. Federal and state policies should actively engage Native nations in decision-making, policy crafting, and environmental initiatives. Partnerships with Tribes can lead to co-stewardship of public lands, grants for conservation endeavors, and initiatives combating emissions and other environmental challenges. Tribal involvement in sustainable agricultural practices is also crucial, with several projects directing funds to Tribal agricultural producers to implement climate-smart policies.

The active involvement of cities, businesses, universities, faith groups, non-profits, and more can amplify and support emissions reductions through policy implementation, political action, and innovation. In cities and urban areas, urban land use reform can drive emissions reductions and other benefits by incentivizing denser, multi-use, and transit-oriented development. These reforms can lead to more affordable and accessible cities, better public transit, vibrant communities, and reduced driving. Initiatives such as eliminating minimum parking requirements and promoting multi-use development have shown positive results in various cities, helping to preserve farmland, forests, and green spaces in urban environments.

Universities, businesses, and research institutions can drive research and innovation to improve farming methods, develop pest-resistant crops, and enhance emissions reductions. Scaling the interventions modeled in this analysis requires funding for the necessary infrastructure. The United States currently faces a significant shortage of seeds and seedlings, particularly those adapted to a hotter climate future, making it impossible to meet reforestation needs as natural disasters increase and mature forests continue to age (Fargione et al., 2021). Expanded investment in tree nurseries, research, and workforce development can increase seedling inventories and enhance seed stock diversity (Fargione et al., 2021). Additional research in the agriculture sector can lower costs and improve the effectiveness of practices such as feed additives to reduce methane emissions from cattle or the development of long-rooted perennial crops that sequester carbon deep in the soil. The widespread adoption of new agricultural practices can be expensive and time-consuming for farmers who are already dealing with a labor shortage in agriculture (Hsu & Bustillo, 2023). While this analysis demonstrates that ambitious land sector policies can help the United States reach its climate goals, achieving this requires a dedicated, all-of-society effort to create jobs, train workers, conduct research, identify and scale impactful strategies regionally, and cultivate the necessary trees and crops to sequester carbon while providing food and fiber for communities.

Conclusion

A healthy and bolstered U.S. land sector will be critical for reducing greenhouse gas emissions to reach U.S. climate goals in the near and long term. Preserving and enhancing the forestry sector will maximize the potential carbon sink and its carbon sequestration potential. For agricultural land, emissions reductions are possible in both crop and livestock production systems, with investment currently being implemented under the IRA and BIL. Expanded funding and enhanced partnerships can enable a greater number of states, cities, and businesses to achieve critical reductions. Yet physical and economic hurdles remain, such as the availability of seedlings, increased wildfire occurrence due to climate change, and curbing economic impacts on landowners. A robust, all-of-society approach can harness the unique regional, economic, and physical capacities of each state, forging a path toward a sustainable and resilient future. Policies, including tax credits, standards, and targets, are critical to achieving key economy-wide measures such as 100% clean electricity, promoting electric vehicle adoption, and advancing building sector efficiency (Zhao et al., 2022). Realizing these reductions across all other key sectors of the economy is essential to ensuring the land sector can secure a strong and resilient U.S. carbon sink.

This initial analysis was the first attempt at integrating economic and ecological models to understand land sector mitigation in the United States at all levels of society. We can understand a great deal given existing and future policies and the current land area available with existing tools. Future analysis will expand the analyses and include additional factors including climate change effects to better inform policymaking and land use management in the United States.

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