Economic Impacts of Investing in Climate Mitigation in New York State Forests and Agriculture:

Afforestation, Reforestation, and Manure Methane Capture

FEBRUARY 2022

NEW YORK STATE OF OPPORTUNITY. | UNITED STATES CLIMATE ALLIANCE | RTI INTERNATIONAL

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List of Acronyms

AFAP	Climate Action Council's Agriculture and Forestry Advisory Panel
CAC	New York State Climate Action Council
CH_4	Methane
Climate Act	New York State Climate Leadership and Community Protection Act
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
FIA	Forest Inventory Analysis
FTE	Full-time equivalent
GHG	Greenhouse gas
GWP	Global warming potential
IO	Input-output
MAC	Marginal Abatement Cost
MT	Metric Ton (MT = 1 Mg = 1,000 kg)
MMT	Million metric tons (MMT=1,000,000,000 kg = 1,000,000 Mg)
MM $	Millions of dollars (Latin numeral convention)
N_2O	Nitrous oxide
NWL	Natural and Working Lands
NYS	New York State
RGGI	Regional Greenhouse Gas Initiative

Executive Summary

New York State was among the first states to act on climate change in the United States. Since the mid-2000s, New York has set emissions reductions goals, established a Climate Action Council (CAC), joined the Regional Greenhouse Gas Initiative (RGGI), set a clean energy standard for electricity, tightened energy efficiency standards, and begun the development of a broad-scale climate scoping plan. New York State was also a leading force in the formation of the United States Climate Alliance.

The State has renewed its commitment to taking broad action to address climate change by setting binding targets for emissions reductions into law under the 2019 Climate Leadership and Community Protection Act (Climate Act). The Climate Act requires economy-wide greenhouse gas (GHG) emissions reductions of 40% below 1990 levels by 2030, 85% below 1990 levels by 2050, and decreased to net neutral by 2050. The CAC's dedicated Agriculture and Forestry Advisory Panel (AFAP) is charged with identifying abatement options for New York's natural and working lands (NWL), the focal point of this report.[1] A summary of the key environmental and economic impact results from this report is shown in Table ES-1.

Table ES-1. **Annual GHG Mitigation and Economic Impacts of three GHG Mitigation Activities in New York State**

	AFFORESTATION	REFORESTATION	DAIRY MANURE MANAGEMENT	TOTAL
Abatement (MMT CO_2e / yr)	7.8	0.8	4.8	**13.4**
Total Wages (MM 2020$)	$133	$43	$13	**$188**
Total Jobs	4,621	1,175	342	**6,138**

NWL activities considered by AFAP included abatement options from land use, soil management, livestock, forest management, and the bioeconomy. This report includes an assessment of the economic impacts of three activities recommended by AFAP:(1) reforestation (a subset of forest management), (2) afforestation, and (3) dairy farm manure management. These activities have been well studied by the council and research community, have significant mitigation potential, and have high potential economic impacts. In total, the three NWL activities covered in this report have the potential to abate 13.4 million metric tons (MMT) carbon dioxide equivalent (CO_2e) per year at or below New York State's lowest "value of carbon" (NYS DEC, 2020), or approximately one fifth of the State's annual nonenergy emissions (NYSERDA, 2018). This climate action can also

1 "Climate Act Advisory Panels," https://climate.ny.gov/Our-Climate-Act/Advisory-Panel

support $188 million in total (i.e., direct, indirect, and induced) annual wages with 6,138 full-time equivalent (FTE) jobs over the coming decade. Table ES-1 shows that, by growing forests on 2.3 million acres of unforested lands, the State can sequester 7.8 MMT of CO_2 per year at $51 per metric ton CO_2 or less and support $133 million in total annual wages with 4,621 FTE jobs over the coming decade. By improving reforestation on an additional 1.1 million acres of poorly stocked forest lands, New York State can sequester 0.8 MMT of CO_2e per year within the same cost per metric ton and support $43 million in wages with 1,175 jobs over the coming decade. By covering dairy manure storage units and flaring methane, the State can reduce emissions by 4.8 MMT of CO_2e per year and support $13 million in annual wages with 342 jobs over the next decade.

Table ES-2. Total Annual Wage Benefits of Three NWL Activities Throughout New York State

REGION	WAGES (MM 2020$)
Capital	$ 19.3
Central	22.7
Finger Lakes	33.1
Mid-Hudson	11.4
Mohawk Valley	20.8
North Country	32.0
Southern Tier	28.4
Western	20.6
State Total	$ 188.3

The annual wage and job benefits of these activities would be shared across New York State and would occur primarily in rural areas (Table ES-2). Technical trades such as forestry make up most of the afforestation employment, but nearly 20% of New York State businesses' employment in these sectors is comprised of professional occupations. A large fraction of manure cover and flare installation expenditures goes to manufactured goods, where 36% of businesses' employment comprises professional occupations (Bureau of Labor Statistics, 2021).

The NWL activities considered in this study would offer significant contributions to ecosystem health in addition to these economic and GHG mitigation benefits. Forests can help improve air and water quality, reduce flood risk (Cooper et al., 2021), support wildlife habitat, provide timber and renewable energy, and offer places of recreational and cultural significance. Mitigating GHG emissions through afforestation and reforestation offers both intrinsic and quantifiable economic value to New York State residents and those who come to the State to enjoy its natural beauty. Manure cover and flare systems control odor and improve neighbor relations, reduce rainwater management costs and the impact on municipal roads, prevent overflow during extreme precipitation events, and retain nutrients on farms for application at critical times in the growing season.

In mitigating GHG emissions on its NWL, New York State has a clear opportunity to deliver a diverse set of monetary and nonmonetary benefits throughout the State. It's policy community must work to identify and enact supportive policies that will incentivize private landowners to make large-scale investments on their land, whether forest or farm, to deliver the economic and environmental benefits promised by NWL activities.

Climate Action on New York State's Natural and Working Lands

New York State has set ambitious, economy-wide mandates for addressing climate change. Among the State's Climate Action Council's (CAC) seven advisory panels, the Agriculture and Forestry Advisory Panel (AFAP) has organized six subgroups to address more than 15 distinct strategies for mitigating greenhouse gases (GHG) including land conservation, bioenergy, agroforestry, and manure methane management. The climate solutions developed by the CAC AFAP will play a key environmental and economic role in New York State's climate action. Following the guidance of the CAC and with a focus on natural and working lands (NWL) initiatives, this study focused on three of the techniques considered by the AFAP that are well researched by the policy and academic community, have well-established practices, offer significant potential for mitigation, and have substantial economic impact potential (New York Climate Action Council, 2021; J. Wightman & Woodbury, 2020).

1.1 CLIMATE MITIGATION OPPORTUNITIES IN NEW YORK STATE FORESTRY AND BIOECONOMY

Approximately 2.4 million acres of New York State's natural lands could be afforested to support climate action at or below the State's value of carbon guidance (NYS DEC, 2020), while maintaining current production from cropland and pasturelands. Former pasturelands offer more than half the opportunity, with floodplains and biological corridors providing over 325,000 acres of opportunity each (Cook-Patton et al., 2020). Of the 19 million acres of forest in New York State, 1.1 million acres of understocked forests could be reforested (i.e. harvested and replanted) to improve carbon sequestration. This study found that a total of 8.6 million metric tons (MMT) of atmospheric carbon dioxide (CO_2) could be sequestered each year through afforestation and reforestation throughout the State's rural areas.

There are 19 million acres of private and public forestlands throughout the State and millions more of underutilized pasturelands, floodplains, and marginal croplands (NY DEC, 2021a, 2021b). Among these lands are historically forested areas and areas with potential for significant forest growth, either through natural regeneration or reforestation.

Trees are among the most cost-effective options for removing excess CO_2 from the atmosphere.[2] Recent estimates of nationwide sequestration potential from afforestation suggest that as much as 314 million metric tons (MMT) per year of CO_2 could be sequestered by planting trees, including a potential of 13 MMT per year in New York State (Cook-Patton et al., 2020). Further sequestration opportunities can be had through forest management practices, in particular through reforestation (i.e., harvesting and replanting mature forests that remain "understocked" to increase carbon sequestration rates).

Estimates from this study suggest 9.2 million metric tons of annual sequestration could be accomplished for less than $51 per metric ton of carbon dioxide equivalent (CO_2e, see section 2.1). Afforesting non-forested areas and reforesting understocked forest areas, therefore, offer significant, cost-effective mitigation quantities for the State. The CAC AFAP has identified afforestation potential (NY CAC, 2021), and the research community has characterized the afforestation opportunities across land types (Cook-Patton et al., 2020). Table 1 provides an evaluation of the different forestry and bioeconomy strategies considered by AFAP on three criteria (defined in the table) mitigation potential, economic impact, and strategy definition and data availability. This evaluation helped identify a subset of strategies and technologies for study in this report. Economic impacts of the remaining strategies and technologies should be addressed by future studies.

2 Carbon in trees is taken from atmospheric CO_2 (Ciais et al., 2013).

Table 1. Selection Criteria for Afforestation-Related Climate Strategies on New York State's Natural and Working Lands

SUBGROUP	STRATEGY	MITIGATION POTENTIAL	ECONOMIC POTENTIAL	STRATEGY DEFINITION AND DATA
Forestry	Afforestation*	★★★	★★★	★★★
	Forest Management^	★★★	★★	★☆
	Riparian Forest Buffers	★	★	★
	Urban Forestry	★★	★★	★
Bioeconomy	Biofuels (Forest prod.)	★	★★	
	Bioproduct substitution^ (afforestation harvest)	★☆	★★	
Land Use Conversion	No Net forest Loss	★	☆	
	Marginal Land Conversion	★	★	

Notes: *Solid rectangle indicates chosen strategy 1 (afforestation) and ^hashed rectangles strategy 2 (reforestation, a subset of forest management and bioproduct production). Mitigation potential ranked based on quantified emissions potentials from CAC meetings, the Reforestation Hub, and/or Wightman and Woodbury (2020); Economic potential ranked based on costs per metric ton of abatement relative to value of carbon and scale of opportunity. Strategy definition and data ranked based on clearly stated CAC goals and available data to quantify the opportunity. Stars provide an approximate ordinal ranking with hollow stars indicating half a ranking point. Bioproduct substitution includes the use of bioproducts instead of higher-emissions alternatives such as fossil fuels.

1.2 CLIMATE MITIGATION OPPORTUNITIES IN NEW YORK STATE'S AGRICULTURAL SECTOR

Of the agricultural sector strategies considered by the AFAP, dairy farm manure management best satisfies three selection criteria: mitigation potential, economic impact, and strategy definition and data availability (Table 2). Manure management provides one of the highest mitigation potentials for New York State's agricultural sector at over 4 MMT CO_2e per year cost-effectively at less than $10 per metric ton of CO_2e abatement. The CAC AFAP has identified significant potential and specific targets for manure methane emissions abatement on dairy farms (Table 2; Wightman & Woodbury, 2020). Policy makers, philanthropic organizations, the private sector, and the public (e.g., through carbon markets, government incentives) have an opportunity to reduce an important source of GHG emissions and support New York State's dairy farmers by financing dairy manure storage cover and flare systems to reduce manure methane.

https://cals.cornell.edu/news/dairy-farm-manure-cover-and-flare-systems-reduce-odors-and-methane

It is common for dairy farmers to store manure in liquid storage units until the manure can be applied to a growing field where crops can incorporate the nutrients. Doing so improves water quality by minimizing harmful nutrient runoff. But storing manure in this way produces noxious odors for New York State's farmers and their neighbors, while releasing highly potent GHGs, principally methane (CH_4).[3]

Table 2. Selection Criteria for Climate Strategies for New York State's Agricultural Sector

SUBGROUP	STRATEGY	MITIGATION POTENTIAL	ECONOMIC POTENTIAL	STRATEGY DEFINITION AND DATA
Dairy Livestock	Enteric Fermentation	✶		✶✶✶
	Manure Management*	✶✶✶	✶✶✶	✶✶✶
Soil Management	Nutrient Management	✶		✶✶✶
	Soil Best Mgmt. Practices			✶✶✶
Agroforestry	Silvopasture	✶✶	✶✶	✶
	Alley Cropping	✶	✶	✶
Bioeconomy	Biofuels (Manure CH_4)	✶✶	✶☆	✶✶

Notes: *Solid rectangle indicates chosen strategy (manure management). Mitigation potential ranked based on quantified emissions potentials from CAC meetings, the Reforestation Hub, and/or Wightman and Woodbury (2020); Economic potential ranked based on costs per ton of abatement relative to value of carbon and scale of opportunity. Strategy definition and data ranked based on clearly stated CAC goals and available data to quantify the opportunity. Stars provide an approximate ordinal ranking with hollow stars indicating half a ranking point.

Manure produced on State dairy farms contributes 4.9 MMT of carbon dioxide equivalent (CO_2e) gases per year, about half that is produced in the Finger Lakes and North Country regions, followed by central New York State (see Table 3).[4] GHG emissions can be estimated based on the number of cows, their average daily manure production, and chemical conversion rates that relate the manure's "volatile solids" to converted methane depending on storage conditions. Stored liquid-only manure methane can be well controlled by covering the stored liquid manure with a thick, synthetic rubber cover to trap the methane emissions or by constructing anaerobic digestion tanks that enhance methane production. Combusting the methane, either through simple flaring or for productive energy use (e.g., heat, electricity), converts the methane from a highly potent GHG to the much less potent CO_2, greatly reducing the climate impact. While there are other ways of storing manure and capturing emissions (e.g., anaerobic digesters), this report studies cover and flare technology only.

Table 3. Methane Emissions (Metric Tons CO_2e) from Dairy Cattle Manure in New York State

REGION	EMISSIONS
TOTAL EMISSIONS	4,941,116
Capital	439,012
Central	894,090
Finger Lakes	1,406,437
Mid-Hudson	24,206
Mohawk Valley	287,288
North Country	1,047,523
Southern Tier	406,859
Western NY	435,700

3 Relatively small quantities of the hyper-potent nitrous oxide (N_2O) are also produced from manure storage.

4 This study follows GWP policy guidance from New York State to convert 1 ton of CH_4 to 84 tons of CO_2e (i.e., the 20-year forcing minus feedback).

1.3 NONMARKET BENEFITS OF INVESTING IN FORESTS AND MANURE MANAGEMENT

Though the focal benefit of this study is mitigating GHG emissions, sustainable land management practices also support many vital ecosystem services that have value but often lack markets where those services can be purchased. Ecosystems provide regulating services (e.g., air quality, erosion control, pollination), provisioning services (e.g., food, fuel), cultural services (e.g., recreation, cultural values), and supporting services (e.g., nutrient cycling, biodiversity protection). Though many of these services are imprecisely measured and challenging to value, recognition of their value has grown in recent years (Binder, S. H., Haight, R. G., Polasky, S., Warziniack, T., Mockrin, M. H., Deal, 2017). Table 4 provides a high-level summary of the association between non-market benefits and the activities considered in this study as summarized in this section.

Cover and flare of dairy manure improves air quality by reducing odors (Pogue et al., 2018)

Table 4. **Mitigation Activity and Co-benefits**

BENEFIT CATEGORY	AFFORESTATION	DAIRY MANURE MANAGEMENT
Provisioning		
Food	●	
Wildlife habitat	●	
Biodiversity	○	
Supporting		
Erosion control	●	○
Soil stability	●	●
Nutrient management	●	●
Fire resilience	●	
Cultural		
Recreation	●	●
Heritage	●	
Aesthetics	●	
Regulating		
Climate	●	○
Nutrient cycling	●	●
Flooding and water flow	●	●
Temperature	●	
Pests	●	

Notes: Solid dots indicate a robust relationship between activity and benefit. Hollow dots indicate a weak connection or a context-dependent benefit.

and ammonia emissions, which react with atmospheric gases to form particulate air pollution. New York State has long promoted manure management for water quality reasons. Poor manure management can reduce infiltration of water into soil, contribute to soil compaction and erosion, and reduce vegetation and litter cover (Pogue, 2018). Improved manure management can lead to improved water quality of nearby bodies of water and reduce runoff of pathogens, natural hormones, veterinary growth promoters, antimicrobials, and excess nutrients, benefitting watershed services (Pogue, 2018).

Organic material on forest floors from tree cover can absorb and decompose pollutants (N. Smith et al., 2011). Upstream forest management can benefit waterways by filtering nutrients, purifying water, and regulating the local climate (Biber et al., 2015; Deal, Cochran, & LaRocco, 2012). Afforestation efforts can decrease annual water treatment costs because forests provide important regulating services for nutrient management, reduced sediment runoff, and water purification (Biber, 2015; Deal, 2012). For example, Postel and Thompson (2005) estimated treatment costs for water in watersheds with only 10% forest cover of $0.03/m^3 compared with $0.01/m^3 for a watershed with 60% forest cover. Forests not only improve water quality, but they also regulate flow (Biber, 2015). If these ecosystem services become degraded or are eliminated, then replacing natural services with physical infrastructure can be expensive. For example, New York City spent $1.5 billion on watershed protection over 10 years to avoid over $6 billion in capital costs and $300 million in annual operating costs for filtration plants (Postel, 2005). Watershed protection programs continue to avoid filtration costs today. In dense urban environments like New York City, increasing tree cover can help mitigate the urban heat island effect, lowering heat exposure and energy costs through lower cooling requirements.[5]

Forest management can also promote biodiversity through improved forest connectivity (Biber et al., 2015; Creighton, Baumgartner, & Blatner, 2002; Duncker et al., 2012; Pukkala, 2016). Forest canopy shade regulates water, air, and soil temperatures supporting habitats and biodiversity (Deal et al., 2012; Duncker et al., 2012; Moomaw, Masino, & Faison, 2019). Forest management can promote biodiversity, but it is worth noting that biodiversity impacts depend on management intensity, the type of forest, and other regional characteristics (Biber, 2015).

Last, forests provide cultural value, including tourism, hunting, and aesthetic value (Biber, 2015; Pukkula, 2016). Landscapes are part of cultural identity and provide recreational opportunities for locals and visitors alike. Private landowners value aesthetic beauty, recreation, biodiversity of land, and preservation of land for future generations, and these values are preserved with effective forest management (Creighton, 2002).

The exact value of the ecosystem benefits depends on many factors, including, for example, regional forest types, land opportunity costs, tree species, forest age, environmental factors, and discount rates (Biber et al., 2015; Buotte, Law, Ripple, & Berner, 2020; Deal et al., 2012; Duncker et al., 2012; Pukkala, 2016). Not all benefits are additive. There are trade-offs and synergies among services that influence the net ecosystem service values derived from a given intervention. These interactions underscore the importance of holistic land management practices that use multiple criteria (Buotte et al., 2020).

5 See for example "Mapping Urban Heat Islands Leads NYC Council Data Team to Landsat," https://www.usgs.gov/news/mapping-urban-heat-islands-leads-nyc-council-data-team-landsat, accessed October 27, 2021.

New York State Lands and the Economy

2.1 HOW MUCH CLIMATE ACTION SHOULD NEW YORK STATE TAKE?

Economists apply the logic of supply and demand to identify the optimal amount of environmental quality, as they would with any other good. By supply-demand logic, society should continue paying for environmental quality up to the point its marginal cost is more than the value of the marginal benefits gained. Although the benefits of climate action are challenging to quantify, New York State (and other governments and researchers) has provided explicit guidance on the value of reducing greenhouse gases for consideration in research and policy making (NYS DEC, 2020).

Estimates of the value of GHG mitigation range from tens to thousands of dollars per metric ton of CO_2e. New York State has issued its own "value of carbon" guidance for policy analysis. This analysis applied the 2020 value discounted at 3%, or $51 per metric ton of CO_2, which is the most conservative of the available estimates from the perspective of economic impacts.[6] This value of carbon suggests that acting on opportunities to keep a metric ton of CO_2 out of the atmosphere that costs less than or equal to $51 per metric ton would return a higher value of climate benefits. Some GHG emissions are more potent than others. For example, New York State values methane as 84 times more potent than CO_2 for planning purposes (i.e., at its 20-year GWP). Also, abating certain tons of GHGs can directly save society money – a clear win-win – while other tons can cost upwards of a thousand dollars. Costs vary based on where in the environment and economy emissions are generated or sequestered.

A firm understanding of what drives the cost of GHG abatement opportunities helps us reap the most benefit for our climate action efforts. Economists analyze these costs to construct "marginal abatement cost" (MAC) curves. A MAC curve indicates how much it will cost to abate each ton of GHG between zero and the full potential, often for a given sector of the economy or abatement strategy. When the costs run higher than the value of the GHGs abated, climate action efforts are better spent in other sectors where abatement remains less expensive.

2.2 WHAT ARE THE ECONOMIC BENEFITS OF CLIMATE ACTION?

Whether from the private or public sector, dollars spent reforesting New York State and capturing manure methane from dairy farms will support jobs and wages for New York residents. Input-output (IO) methods are a common way to measure how economic activity such as project expenditures in one part of the economy contributes to activity in other parts of the economy. IO tables track the flow of value from labor and capital, through intermediate production and exchange, to final consumption and investment by households and government. IO methods employ linear algebra techniques to trace value flows from new sources of demand for goods and services back through their supporting supply chains to the income generated for those who make them. Economic impacts in an IO framework are typically divided into direct (the impact in the sector of interest), indirect (the impact in that sector's supply chain), and induced (the impact from spending the direct and indirect incomes earned).

IO methods help provide an appreciation for the greater economic impact our expenditures can have through the use of economic impact

6 New York's value of carbon guidance was revised in June 2021. The analysis here included a sensitivity on the original 2% value of $125 and found that, because of the "steepness" in the marginal abatement cost curve for afforestation, a relatively small amount of additional abatement was selected at the higher value. Given the wide range in available afforestation cost estimates, policy planning would benefit from sensitivity analyses on costs and values of carbon.
See "DEC Announces Finalization of 'Value of Carbon' Guidance to Help Measure Impacts of Greenhouse Gas Emissions," https://www.dec.ny.gov/press/122070.html, accessed October 11, 2021. For dairy manure methane, although this analysis converts all emissions to CO_2e (with a GWP of 84 for CH_4) and values them using the value of carbon guidance for CO_2, the guidance does provide separate estimates for CH_4 and N_2O. The approach taken in this analysis implies a less conservative CH_4 value of carbon between the central and high CH_4-specific 2021 values of carbon; however, the costs per ton for dairy manure methane control were sufficiently low that either value of carbon would imply the same economic levels of abatement.

ECONOMIC IMPACTS

Direct	***Income generated by the businesses implementing the activity.***
Indirect	***Income generated by suppliers in the implementing firms' supply chain.***
Induced	***Income generated by wage earners spending their income in the economy***

"multipliers." Calculated impacts should not be interpreted as necessarily new employment or income, though at least some of the impacts are likely to be. IO methods do not account for opportunity costs that may arise from scarcity in labor or capital, and results must be compared against prevailing market outcomes to gauge to what extent the impacts are likely to be truly additional to the economy (see Appendix 5.1 for additional limitations provided by IO data provider IMPLAN). The economic multipliers for this study were calculated for eight of New York State's economic development regions plus a combination of the New York City and Long Island regions based on county-level IMPLAN 2018 data for the State. The results shown below report impacts accruing throughout the State based on activities performed in the identified regions.

2.3 SEQUESTERING CARBON IN NEW YORK STATE FORESTS

2.3.1 How Many Acres of Trees Should New York State Plant?

This study is based on a county-level assessment of afforestation and reforestation activities across a range of land types identified as able to support tree cover. We followed four steps to identify an efficient amount of afforestation and reforestation activities to undertake and the costs to expend on these efforts.

Step 1: Establish the area of afforestation opportunity by location and land type

Cook-Patton et al. (2020) mapped county-level acreage and carbon accumulation potential nationally from natural forest growth.[7] They identified nearly 4 million acres of potential land for afforestation in New York State, across a range of current land use types with more than half in pasturelands.[8] Cook-Patton et al. (2020) have mapped county-level acreage and carbon accumulation potential nationally from natural forest growth.[9]

To reduce the chance of double counting mitigation potential (across forestry and livestock mitigation activities), approximately 575,000 acres of pastureland supporting the State's rural production economy are not included in this analysis.[10] Additionally, New York State has 987,000 acres of pasture supporting its horse and mule populations that were excluded.[11] In total, conserving productive pasturelands excludes 1.2 million acres from consideration, leaving 2.8 million acres of afforestation opportunity spread broadly across the State (Table 5), not all of which provides economical abatement opportunities. In addition to afforestation, understocked, existing forests also offer sequestration opportunities. Drawing on statewide forest plot surveys from the U.S. Forest Service's Forest Inventory Analysis (FIA) program, there are an additional 1.1 million acres of sequestration opportunity in unstocked, poorly stocked, and medium stocked forests 40 years of age or older throughout New York State following the approach of Sohngen, Walker, Grimland, & and Brown (2007).

7 See "Reforestation Hub," https://www.reforestationhub.org/

8 Cook-Patton and coauthors' acreage estimates were not mutually exclusive. Acres for all land classes were adjusted by the same ratio to match the estimated acreage totals.

9 See "Reforestation Hub," https://www.reforestationhub.org/

10 See "USDA Agricultural Census," https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/New_York/nyv1.pdf

11 See "New York Equine Survey 2005," https://www.reginfo.gov/public/do/DownloadDocument?objectID=19961501

Table 5. **Afforestation and Reforestation Potential in New York State (thousands of acres)**

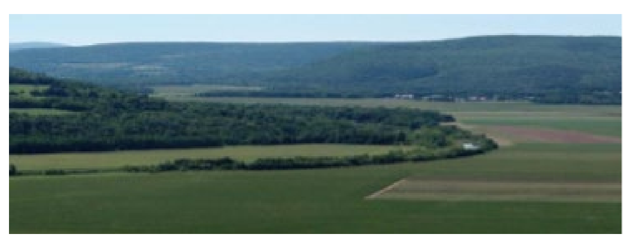
		CAPITAL	CENTRAL	FINGER LAKES	MID-HUDSON	MOHAWK VALLEY	NORTH COUNTRY	SOUTHERN TIER	WESTERN	TOTAL
Afforestation	Pasture	137.5	191.1	285.5	61.6	185.7	160.3	248.1	180.6	1,450.4
	Bio-Corridors	23.5	29.0	77.0	11.4	36.9	54.7	80.8	37.5	350.9
	Floodplains	28.5	37.0	74.2	20.5	35.4	31.4	49.4	51.0	331.4
	Cropland	10.5	16.4	28.2	13.1	17.2	10.8	17.2	11.4	125.8
	All Other	51.3	56.6	103.6	64.8	54.1	39.6	70.3	80.2	566.0
Reforestation		106.0	87.5	49.2	146.4	182.3	346.6	126.4	89.8	1,146.3
TOTAL		357	418	618	318	512	643	592	451	3,971

Step 2: Estimate the carbon sequestration potential on afforested and reforested lands

To estimate the mitigation potential of afforestation activities in New York State, annual sequestration rates of afforested forests use estimates from Smith et al. (2006). Specifically, the annual sequestration rate is based on the weighted average growth rate for afforested lands using the three main forest types in the State over the first 30 years of forest growth (J. E. Smith, Heath, Skog, & Birdsey, 2006). This weighted average results in an estimated average annual sequestration rate of 0.51 metric tons of carbon (or 1.89 metric tons of CO_2e) per acre per year. To estimate the marginal benefit from reforesting activities on currently understocked forests, this study identifies mature forests that contain less than half the carbon per acre relative to fully stocked acres (Sohngen et al., 2007), leaving significant sequestration potential to reforest these acres and support their growth to full potential. This potential may be limited by a variety of factors such as soil suitability, owner preferences, or competing uses.

Step 3: Estimate the costs associated with afforesting and reforesting

Afforestation requires removing acres from use for other purposes, preparing the land, and planting seedlings. Land "opportunity cost" is the value one would need to pay a landowner to compensate them for lost revenues of current use after converting to forest. Opportunity costs may be zero for many natural lands; that is, land owners could be indifferent or prefer their land be forested and would not require compensation beyond the cost of establishing and maintaining tree cover (this is a similar approach as used by Cook-Patton et al. 2020). This assumption is made to reflect that land cover does not provide current or expected market value to the landowners, but afforestation could impact important nonmarket benefits positively (e.g., increased water quality) or negatively (e.g. lost viewshed). Lost nonmarket benefits from afforestation and requirements that landowners leave forest undisturbed for many decades may well require compensation. Other lands that offer



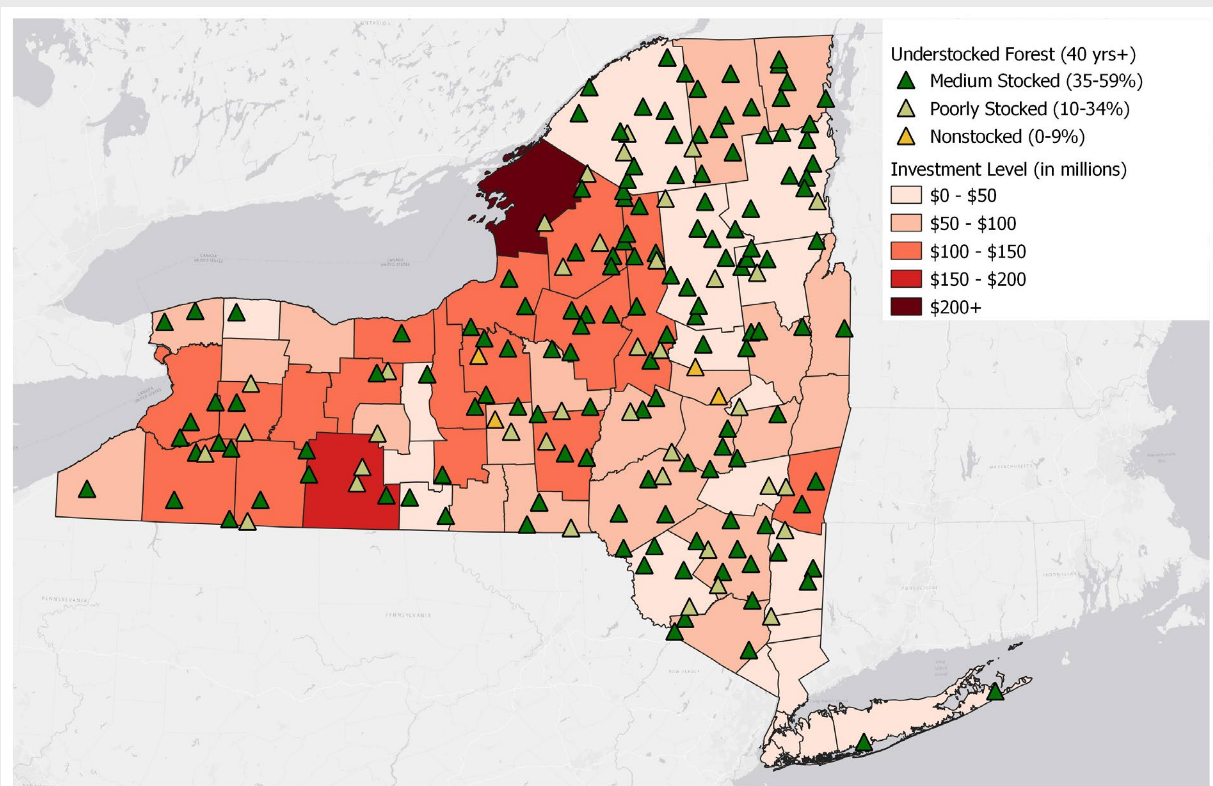
NYS Soil and Water Conservation Committee (NYS SWCC)

competing opportunities for agricultural use or future development would require compensation, for example, from State policies designed to incentivize climate action on private lands. This analysis includes no opportunity costs for natural lands but does include opportunity costs from Nielsen and coauthors (2014) for agricultural lands and costs from Federal Housing Finance Agency data (following Cook-Patton et al., 2020) for urban and developed areas (all costs were in 2020 dollars).

Costs to establish and protect forests – preparing land, planting seedlings, fencing in areas with high deer populations – vary widely, from about $300 (Nielsen et al., 2014) to several thousand dollars per acre (Woodbury, 2021). Noting these outer bounds and certain limitations in each, this study relied on recent establishment cost estimates from Fargione et al. (2021). Fargione et al. (2021) relied on surveys of nursery owners and foresters across the country to estimate the methods and associate costs of afforestation and reforestation practices. These estimates reflect planting of native species in each of the three regions included in the analysis with the eastern United States having the highest average costs due to the high prevalence of hardwoods (Fargione et al. 2021). The median cost estimate for the Eastern United States is $720 per acre (including site preparation, planting, and post-planting costs) with county-level cost variation introduced using data from Nielsen and coauthors (2014).[12] The maximum cost per acre for New York State that satisfies the cost per metric ton threshold of $51 chosen for this study is $3,587, with a median value of $867.[13]

Site preparation costs for understocked forests also include the cost to harvest low-grade pulpwood material from the landscape. Although the revenue from the harvest might not be enough to motivate the harvest on its own, it

Figure 1. New York State Afforestation and Reforestation Costs with Forest Inventory Plots



12 To satisfy criteria other than emissions mitigation, lands with higher opportunity costs or more expensive tree species (e.g., hardwoods) might be selected. Selection on these criteria could lead to costs per ton that are higher than the value of carbon. To motivate this afforestation and reforestation would require valuing the nonclimate benefits of planting in this way. Fargione et al. (2021) include post-planting costs in their surveys (e.g., tree shelters, deer fencing, vegetation management). Costs associated with public programs to administer and monitor planting efforts are not considered but would lead to additional economic impacts for the acres selected.

does partially offset the harvest costs. FIA data allow for estimates of harvest volume from New York State's understocked forests throughout the State (see Figure 1).[13] Estimated afforestation and reforestation costs in this study are conservative in that they do not include policy administration, implementation, or evaluation costs, which would lead to larger economic impacts.[14]

***Step 4:** Plot a MAC curve to identify the optimal quantity of abatement*

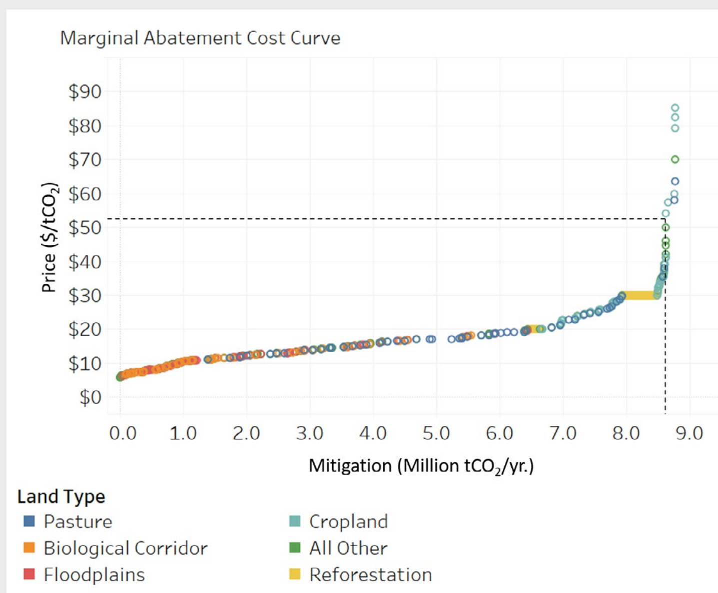
The cost of afforesting New York State's land varies by county and the type of land to be afforested. Marginal costs rise as more mitigation is undertaken, especially after land with zero opportunity cost is afforested. Croplands and urban areas are among the most expensive to forest for this reason. This study's projections show 7.8 MMT yr-1 CO_2 can be abated from afforestation activities at investment levels of $51 per metric ton of CO_2. This projection includes afforesting roughly 2.4 million acres of currently nonforested lands. All understocked forests can be restocked at $30 per metric ton or less, providing a net increase of 0.8 million metric tons of abatement per year. The afforestation and reforestation scenarios result in a total 8.6 MMT of abatement (Figure 2).[15]

Reaching these mitigation levels of 8.6 MMT CO_2 from the forest will cost an estimated $3.3 billion. These expenditures would be distributed throughout the State. Figure 1 shows the county-level distribution of costs of afforestation and reforestation. Investing in New York State's forest carbon stocks will produce jobs and incomes throughout the State, and the $3.3 billion in expenditures on climate action identified here will be offset by the associated climate mitigation benefits valued under New York State's value of carbon guidance (NYS DEC, 2020). Healthy forests also offer a variety of other nonmarket benefits as discussed in Section 1.3.

2.3.2 What Are the Economic Benefits of Planting this Much?

These afforestation and reforestation activities are estimated to generate several thousand jobs in New York State's forestry and supporting services industries and in the supply chain for seedlings, equipment, and materials to harvest low-grade timber, prepare land, and plant seedlings. Low-grade timber produced during reforestation would also provide raw material to New York's pulp mills at competitive rates, depending on policy incentives. As a demonstration of the potential "bioeconomy" benefits of climate action on the state's NWL, this study also assessed the economic benefits of increased pulp mill activity in New York, which is modest relative to the reforestation activities considered.

Figure 2. Total Cost of Afforestation and Reforestation in New York State



13 The median cost for acres with positive opportunity costs is $1,700 per acre.

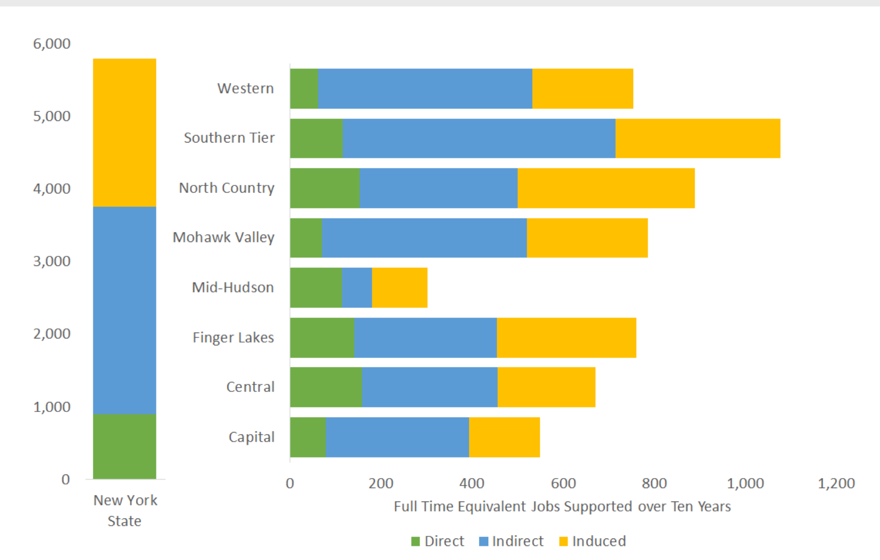
14 Economic benefits from harvesting understocked forests may be limited by local pulp mill capacity.

15 Note that Figure 2 omits some observations with very high costs per ton, which occur in areas with high opportunity costs (e.g., urban areas).

The total number of jobs required for afforesting and reforesting lands in New York State exceeds current employment in the agriculture and forestry support services sectors. This capacity constraint, and the physical constraint of foresting millions of acres, suggests climate action will need to span many years to accomplish its afforestation and reforestation sequestration objectives and suggests that these ambitious climate goals are likely to support growth and new jobs in in these industries.

Completing afforestation and reforestion work over the next 10 years would mean sustaining approximately 15 to 20% more jobs in forestry and support services over that period than are currently active. Sustained effort to reforest New York State in this way would support 896 jobs in these sectors over the coming decade and 5,796 jobs inclusive of those in the implementation and consumption supply chains (i.e., plus indirect and induced jobs; see Figure 3). Afforestation and reforestation activities in the Southern Tier and North Country regions support the largest number of jobs while the Mid-Hudson, one of the State's smaller and more densely settled regions, supports the least.

Figure 3. Direct, Indirect, and Induced Jobs from New York State Afforestation and Reforestation Activities



Approximately 20% of the workforce in New York State's forestry and supporting sectors, in which direct jobs occur, are in professional occupations including administration, education, management, and sales. Annual expenditures on afforestation and reforestation activities to support these employment levels would total $310 million, leading to $176 million in annual wages to New York State residents over 10 years, with the rest of the investment covering capital costs and intermediate inputs (Table 6). Approximately $26 million of these wages would be paid directly to forestry and supporting sectors annually. Like the jobs that generate them, these wages are supported by activity throughout New York State, particularly in its more rural regions where forest opportunities are greatest.

Table 6. Annual Wage Benefits of Afforestation and Reforestation (MM 2020$ / yr.)

	DIRECT	INDIRECT	INDUCED	TOTAL
Capital	$ 4.1	$ 6.7	$ 7.3	**$ 18.1**
Central	2.6	9.6	8.3	**20.6**
Finger Lakes	3.9	13.3	12.3	**29.4**
Mid-Hudson	3.3	3.6	4.4	**11.3**
Mohawk Valley	2.3	8.8	9.0	**20.1**
North Country	4.1	12.9	12.8	**29.8**
Southern Tier	4.9	9.7	12.5	**27.1**
Western	0.7	10.2	8.6	**19.5**
State Total	$ 25.8	$ 74.8	$ 75.2	**$ 175.7**

2.4 REDUCING METHANE EMISSIONS FROM DAIRY MANURE

2.4.1 How Much Manure Methane Should New York State Dairy Farmers Capture?

New York State has over 3,800 dairy farms producing 15 billion pounds of milk annually and supporting a wide network for suppliers and service providers (McCarthy, Canter, & Cogliano, 2019). It is the fourth largest dairy-producing

Table 7. Annual Costs of Covering Dairy Farm Manure over 10 Years (MM 2020$ / yr.)

REGION	COVERING COSTS
Capital	$2.5
Central NY	4.2
Finger Lakes	6.8
Mid-Hudson	0.2
Mohawk Valley	1.4
North Country	4.7
Southern Tier	2.3
Western	2.2
State Total	**$24.4**

state in the country, so its dairy farmers are both a prominent part of the State's rural economy and key allies in tackling methane emissions.

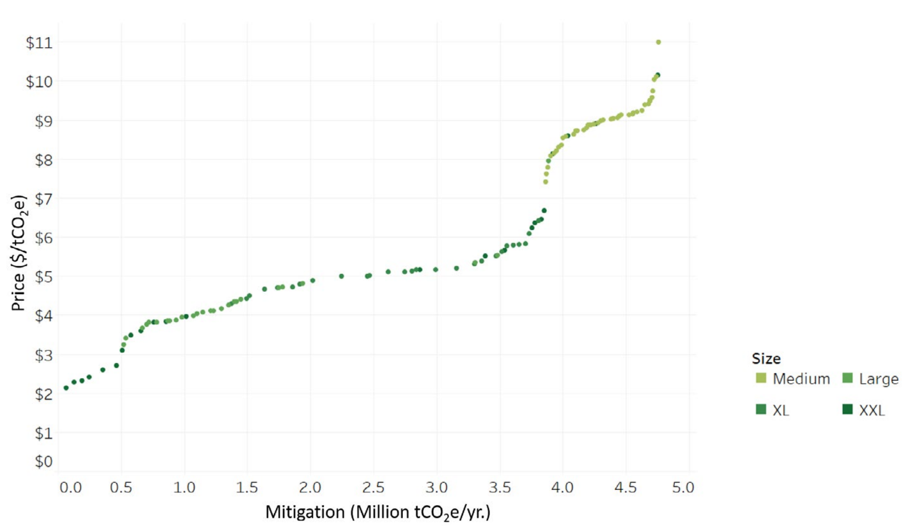
Manure from New York State's dairy cows and heifers produces 4.9 MMT of CO_2e per year with most coming from large farms with 1,000 or more dairy cows. The cost of covering and flaring methane emissions varies by the number of cows on the farm. Nearly all of these emissions can be abated at costs well below the value of carbon guidance threshholds. Covering liquid manure storages and adding a flare requires labor, equipment, and materials. A typical installation costs $270,000 to $380,000, depending on the size of the cover and number of installations (J. L. Wightman & Woodbury, 2016). To cover all of New York State's medium-sized (i.e., 200 to 499 cows) and larger (>500 cows) dairy farms' liquid manure storage units would cost approximately $200 million, or $24.4 million annually over 10 years (Table 7).

Collecting dairy cow manure and flaring methane is one of New York State's most cost-effective abatement opportunities. Abatement costs ranging from $2 to $11 per metric ton of CO_2e for nearly all farms. Smaller farms generally face higher abatement costs because there is a threshold minimum size, and cover and flare systems on these farms do not reach economies of scale. All dairy farms with 200 cows or more can cover and flare emissions at less than $51 per metric ton, but farmers need financial support to do so.

2.4.2 What Are the Economic Benefits of Capturing Dairy Manure Methane?

New York State's climate actions could lead to several hundred jobs supporting the installation of manure storage unit cover and flare systems and production of the equipment and supplies to build them.

Figure 4. Marginal Abatement Cost Curve for Dairy Manure Methane Emissions Mitigation



Dairy farms offer New York State some of its most cost-effective GHG abatement options.

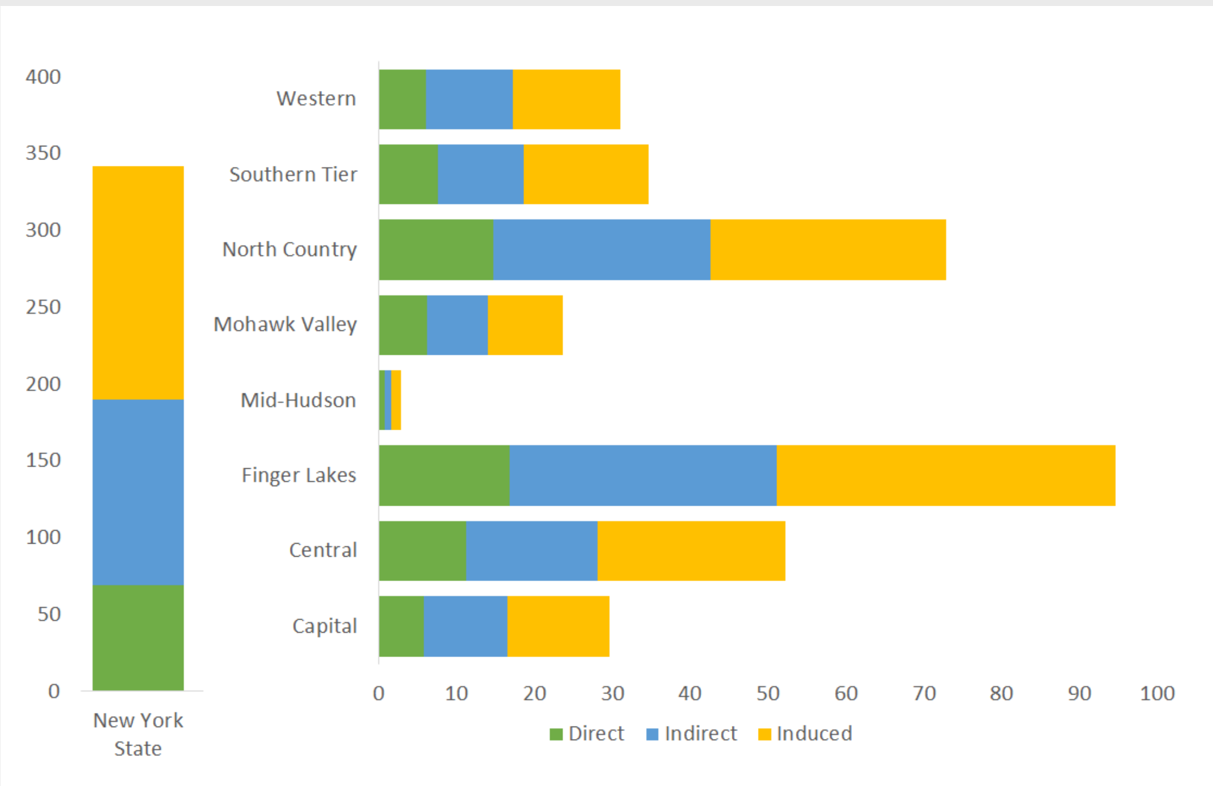
Accelerating the pace of installation would lead to higher levels of employment over a shorter period. Thirty-six percent of the jobs in the State's equipment manufacturing sectors that would provide manure storage covers and separators are in professional occupations such as administration, education, management, and sales.

Installing cover-and-flare technology at all medium and large dairy farms over the next 10 years could support 342 jobs (Figure 5). The greatest opportunities for climate action are in the Finger Lakes and North Country regions. Annual expenditures of $24.4 million to abate manure methane could yield $12.6 million in wages for New York State residents over the next 10 years (Table 8).

Table 8. Annual Wage Benefits from Abating Manure Methane on New York State's Dairy Farms (MM 2020$ / yr.)

	DIRECT	INDIRECT	INDUCED	TOTAL
Capital	$ 0.2	$ 0.4	$ 0.6	$ 1.3
Central	0.4	0.8	0.9	2.1
Finger Lakes	0.6	1.3	1.7	3.7
Mid-Hudson	0.0	0.0	0.0	0.1
Mohawk Valley	0.1	0.3	0.3	0.7
North Country	0.4	0.8	1.0	2.2
Southern Tier	0.2	0.5	0.6	1.3
Western	0.2	0.4	0.5	1.2
State Total	$ 2.2	$ 4.6	$ 5.8	$ 12.6

Figure 5. Job Impacts of Abating Methane Emissions from New York State's Dairy Cow Manure Storage Units



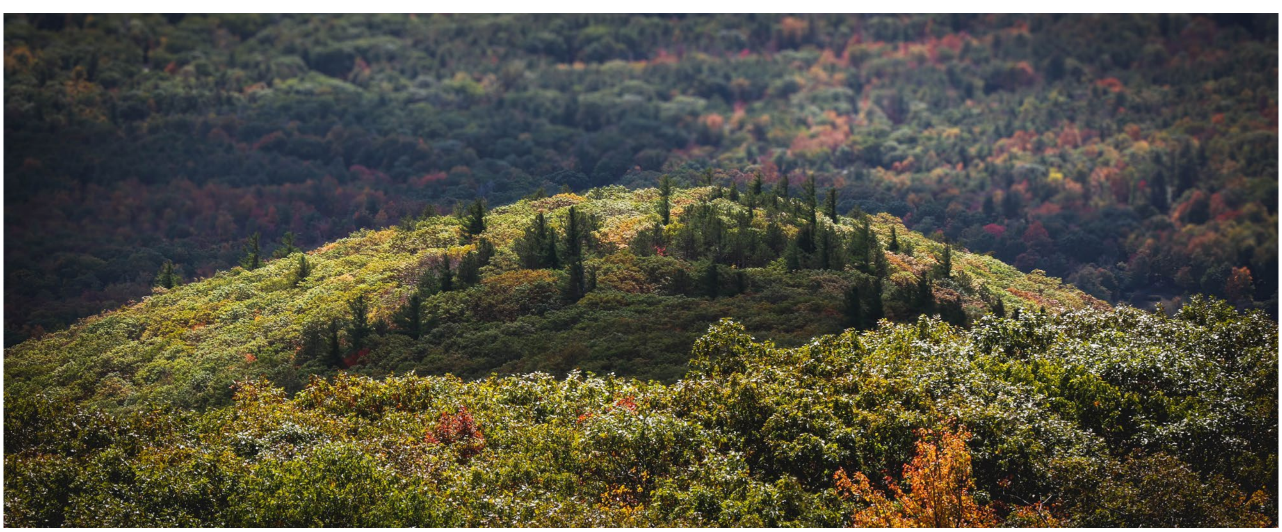
Conclusion: Realizing the Benefits of New York State's Climate Action Opportunities

New York State has set ambitious goals for mitigating GHGs throughout its economy. Its natural and working lands offer significant mitigation opportunities that can provide both environmental and economic benefits. The urgent need for climate action warrants large-scale investments in mitigating emissions. Emissions mitigation offers clear opportunities for investing in the State's rural economies to promote economic development, support the health of the environment, and address climate change. Approximately $3.3 billion in emissions mitigation efforts on natural and working lands in the coming years could be invested and return larger climate and economic benefits plus substantial nonmarket benefits.

The cost estimates in this study are conservative with respect to their implications for estimated economic impacts in several respects. First, the lowest value of carbon ($51 per metric ton) is used to identify the quantity of mitigation activity to be analyzed, meaning fewer acres (and economic impacts) of afforestation were included than would be at a higher value of carbon. Second, uncertainty in afforestation costs means that afforestation and reforestation costs and economic impacts could be higher due, for example, to factors such as selective planting of hardwood species or higher actual opportunity and/or postplanting costs. Third, although no explicit policies were considered in this study, realizing the full identified mitigation opportunity is likely to require policy administration, implementation, and evaluation costs that would raise total costs and economic impacts.

This report identifies 3.5 million acres and approximately 450 farms with climate action opportunities below $51 per metric ton of CO_2 in New York State. Much of the NWL mitigation opportunity in the State is on private lands. Policy action can help fund public investments or facilitate markets for third-party investments in private lands to support GHG mitigation. This substantial opportunity for GHG mitigation suggests a strong role for policy incentives that will spur private action.

New York State's continued leadership on climate action can help match landowners with funders in the private and public sectors, facilitating the financial support needed to effect climate action. To start, the State is setting clear goals and developing supportive policies that can catalyze investments in afforestation, reforestion, and manure methane management over the coming decade with the potential to support thousands of jobs and nearly $200 million in annual wages. Beyond these activities, New York State's active development of many other mitigation options are likely to provide even greater environmental and economic climate action benefits.



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Appendices

5.1 IMPLAN DISCLAIMER

The following disclaimer is provided and recommended by IMPLAN Group, LLC, who provided the underlying data for our study.[16] The multipliers used in our study were independently calculated (see Miller & Blair, 2009) from underlying IMPLAN data, not exported from the IMPLAN software.

IMPLAN is a regional economic analysis software application that is designed to estimate the impact or ripple effect (specifically backward linkages) of a given economic activity within a specific geographic area through the implementation of its Input-Output model. Studies, results, and reports that rely on IMPLAN data or applications are limited by the researcher's assumptions concerning the subject or event being modeled. Studies such as this one are in no way endorsed or verified by IMPLAN Group, LLC unless otherwise stated by a representative of IMPLAN.

IMPLAN provides the estimated Indirect and Induced Effects of the given economic activity as defined by the user's inputs. Some Direct Effects may be estimated by IMPLAN when such information is not specified by the user. While IMPLAN is an excellent tool for its designed purposes, it is the responsibility of analysts using IMPLAN to be sure inputs are defined appropriately and to be aware of the following assumptions within any I-O Model:

- Constant returns to scale
- No supply constraints
- Fixed input structure
- Industry technology assumption
- Constant byproducts coefficients
- The model is static

By design, the following key limitations apply to Input-Output Models such as IMPLAN and should be considered by analysts using the tool:

- **Feasibility**: The assumption that there are no supply constraints and there is fixed input structure means that even if input resources required are scarce, IMPLAN will assume it will still only require the same portion of production value to acquire that input, unless otherwise specified by the user. The assumption of no supply constraints also applies to human resources, so there is assumed to be no constraint on the talent pool from which a business or organization can draw. Analysts should evaluate the logistical feasibility of a business outside of IMPLAN. Similarly, IMPLAN cannot determine whether a given business venture being analyzed will be financially successful.
- **Backward-linked and Static model**: I-O models do not account for forward linkages, nor do I-O models account for offsetting effects such as cannibalization of other existing businesses, diverting funds used for the project from other potential or existing projects, etc. It falls upon the analyst to take such possible countervailing or offsetting effects into account or to note the omission of such possible effects from the analysis.
- **Like the model, prices are also static**: Price changes cannot be modeled in IMPLAN directly; instead, the final demand effects of a price change must be estimated by the analyst before modeling them in IMPLAN to estimate the additional economic impacts of such changes.

16 See "IMPLAN Citation Guidelines," https://implan.com/citation-guidelines/#section3

5.2 TECHNICAL APPENDIX

This technical appendix details the methodology used to project the mitigation and investment potential across natural working lands in New York State based on the techno-economic feasibility of afforestation, reforestation, and manure management activities.

5.2.1 Forestry

Marginal abatement cost (MAC) curves for afforestation across a range of land covers and reforestation on current forest area formed the basis of the economic mitigation potential and impact of climate action in this sector. MAC curves provide an estimate of the "break-even" price and mitigation quantity at which the present value of benefits and costs for mitigation options are equal. The methodology produced a curve where each point reflects the unit (per acre) cost and mitigation potential of a specific county and land type group (for afforestation potential), or forest plot (for reforestation activities). The benefit of the mitigation achieved by afforestation and reforestation is set according to guidance from New York State Department of Environmental Conservation's value of carbon guidance (NYS DEC, 2020). A low value a $51 per metric ton of CO_2 provides a conservative level of investment in GHG mitigation relative to other possible values of carbon.[17] These mitigation estimates are calculated relative to a baseline and are presented in terms of absolute reductions of atmospheric CO_2.

5.2.2 Afforestation Potential

This section describes analysis conducted to estimate the cost and mitigation potential of afforestation efforts across New York State. This analysis looks at a range of land types identified as able to support tree cover aggregated to the county level. A stepwise approach was used to estimate afforestation potential and costs of afforestation: (1) calculate land opportunity projections, (2) calculate carbon storage on afforested lands, and (3) estimate costs associated with afforestation.

Land Availability

Initial land availability estimates are based on findings from the Reforestation Hub (with state level results presented at https://www.reforestationhub.org/), which maps the carbon accumulation potential from natural forest growth at a county level for all of the US. Cook-Patton et al. (2020) estimate nearly 4 million acres of potential land for afforestation within New York State, with more than half the land currently identified as pasture. These results were presented as a total land availability estimate and broken out by non-exclusive land types. To account for heterogeneity in carbon storage, and afforestation costs across land types, the analysis in this report relies

17 An additional mitigation price of $125/tCO_2e$ was considered, per the New York State Department of Environmental Conservation, however due to the shape of the marginal abatement cost of afforestation, mitigation at this price was only marginally higher than at $51/tCO_2e$. New York State has revised its value of carbon guidance since the analysis of this report to $51 and $121/tCO_2e$.

on the individual land types presented in Cook-Patton et al. (2020) but with estimated acres adjusted such that the sum of the individual land types equals the total opportunity measured by Cook-Patton et al. (2020). The adjustment is based on county-level factors equal to the *Total Opportunity* value divided by the sum of individual land classes, which is then multiplied by each individual land classification opportunity area. For example, according to Cook-Patton et al. (2020) Albany County has a total of 34,700 acres of land available for afforestation. However, summing across each of the individual land categories results in 38,750 acres (the sum of available acres for biological corridors, floodplains, forest, marginal croplands, grassy areas, post-burn areas, shrub, streamside buffers, and urban open space). This represents almost 12% more than reported in the total, so each individual land category is multiplied by 1/1.12 making the summation across categories match the reported total.

Table A-1. Calculated Land Area (acres) Available for Afforestation by New York State Economic Development Regions (Acres)

ROW LABELS	CAPITAL REGION	CENTRAL NY	FINGER LAKES	MID-HUDSON	MOHAWK VALLEY	NORTH COUNTRY	NYC LONG ISLAND	SOUTHERN TIER	WESTERN NY	GRAND TOTAL
Pasture	137,473	191,124	285,525	61,555	185,701	160,271		248,109	180,646	1,450,404
Urban	39,642	41,005	71,346	51,985	36,636	24,243	43,313	47,574	62,340	418,084
Biological Corridor	23,524	29,045	77,026	11,364	36,894	54,707		80,829	37,531	350,919
Floodplains	28,546	36,956	74,217	20,543	35,409	31,395	3,925	49,397	51,021	331,409
Cropland	10,492	16,397	28,219	13,135	17,237	10,759	970	17,166	11,398	125,772
Streamside	4,610	14,020	30,312	4,714	14,870	11,092	264	18,267	15,864	114,012
Forest	4,552	517	710	4,822	1,258	903	1,291	3,048	1,240	18,340
Post-Burn	247	410	738	2,258	245	2,055	244	240	503	6,939
Shrub	1,750	380	333	710	535	616	169	714	141	5,349
Range	492	234	119	358	515	715	282	432	94	3,241
Grand Total	**251,328**	**330,087**	**568,543**	**171,444**	**329,300**	**296,755**	**50,458**	**465,774**	**360,778**	**2,824,468**

United States Department of Agriculture (USDA)-identified pastureland (about 575,000 acres) is excluded from consideration to account for pastureland currently being used for livestock production. These acres were removed to preserve current livestock activities, especially those related to cattle farming. Mitigation efforts such as via silvopasture may already be underway on many of these acres. The pasture estimates in the analysis for this report are pasture estimates from Cook-Patton et al. (2020) less county-level pasture estimates from USDA Agricultural Census.[18] Pasture

18 https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_2_County_Level/New_York/nyv1.pdf

lands are further reduced by estimated land area used for horses from the New York Equine Survey 2005[19] (987,000 acres), as USDA pasture estimates do not account for pastureland used for horses and mules. Land area used for raising equine were estimated at the district level, requiring district level estimates to be downscaled to the county level by assuming that horse acres are proportionately distributed across each county within a district using Cook-Patton et al.'s (2020) estimated pastureland availability. In total, these actions reduced total land availability from 4.0 million to 2.8 million acres (land availability by land type is show in Table A-1).

Carbon Storage

The second step to estimating the mitigation potential from afforestation is to estimate the amount of carbon that could be stored across land types. In their analysis, Cook-Patton et al. (2020) also estimate the carbon storage potential across land types and counties. These estimates are annual carbon storage rates for the first 10 years after planting. We are also interested in mitigation potential over a 30-year time horizon. Estimates from Smith (2006) provide average annual mitigation over a 30 year time horizon using methods for estimating yield for reforestation and afforestation on non-forest lands. The analysis for this report uses an average annual carbon storage per acre for afforestation activities calculated using a weighted average across the three main forest types in the State.[20] According to estimates from Smith (2006), average annual mitigation over the first 10 years prior to afforestation is 1.14 tC/acre/yr. increasing to 1.27 tC/acre/yr. over the first 30 years after afforestation in northeastern U.S. forests. The ratio of these two values is used to adjust carbon storage estimates from Cook-Patton et al. (2020) to be representative of a 30-year commitment. Selective planting of hardwoods would likely reduce the sequestration rate and change afforestation costs.

Cost and Mitigation Potential

There are several different types of costs associated with land-use change and afforestation activities including costs of establishing a new land cover and the opportunity costs of transitioning away from the current land use. Opportunity costs for agricultural lands (cropland, pasture, and rangelands) are derived from Nielsen et al. (2014), who use an empirical approach to estimate the capitalized returns to future development in addition to returns from current agricultural production. The Nielsen et al. (2014) data have been applied in other recent modeling assessments of U.S. GHG mitigation potential from forestry and agriculture (e.g., Cai et al., 2018; Wade et al., 2022). Cook-Patton et al. (2020) use data from the Federal Housing Finance Agency[21] to account for county level average parcel prices in urban and developed areas. Opportunity costs for the remaining land types

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19 https://www.reginfo.gov/public/do/DownloadDocument?objectID=19961501

20 Maple/beech/birch, oak/hickory, and elm/ash/cottonwood represent nearly 80% of total forestland in New York. With Maple/beech/birch covering 55% of total, oak/hickory covering 17%, and elm/ash/cottonwood covering 7%. https://www.fs.fed.us/nrs/pubs/rb/rb_nrs121.pdf

21 https://www.fhfa.gov/PolicyProgramsResearch/Research/PaperDocuments/wp1901-1028.pdf

(biological corridors, floodplains, forest, post-burn, shrub, and streamside) are not accounted for in the estimate. Though Cook-Patton et al. (2020) and the analysis in this report assigns no economic opportunity cost to afforesting these land types, landowners may still hold preferences on land cover unrelated to economic opportunity (e.g. agriculture, development). For example, landowners may prefer the viewshed offered by unforested streamsides and be only willing to accept afforesting it in exchange for some payment.

There is uncertainty in forest establishment costs across the US. Estimates for establishing forest cover in the northeast range from about $300/acre according to Nielsen et al. (2014), to in excess of $4000/acre according to (Woodbury, 2021). Estimates in the low and middle of the range may include afforestation that requires less follow-up maintenance and protection from animals (e.g. deer pose a significant threat to seedlings, particularly in New York State). Certain estimates in the high end of the range may include administration and monitoring costs not considered by other studies. They may also include selective planting of certain species (e.g. hardwoods) that are more expensive and provide slower carbon sequestration rates, both driving up costs per ton. Higher cost estimates can also include planting on lands with higher opportunity costs. For example, the range of estimates identified in the analysis for this report included high opportunity cost acres whose dollar-per-acre estimates were greater than $10,000/acre in more densely settled areas. High property values in urban areas may not be appropriate for marginal areas for planting (e.g. medians, wetlands) that would not be otherwise developed; however, these opportunities would still have high labor costs and would not likely scale to significant sequestration quantities. Last, higher opportunity costs may well be justified for benefits other than climate mitigation such as those laid out in the nonmarket benefits section. These values are not considered in the analysis in this report.

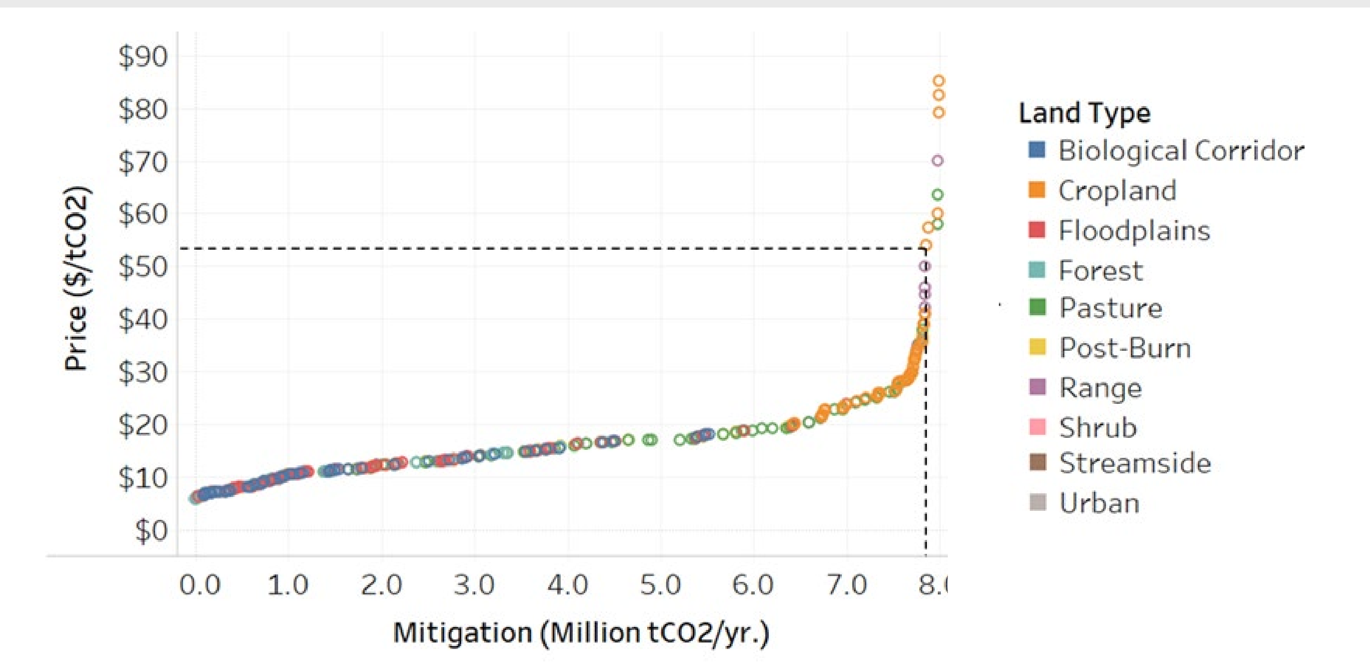
Median establishment cost estimates for the eastern U.S. from Fargione et al. (2021), which includes cost of seedlings ($250/acre), site prep ($120/acre), planting ($250/acre), and post-planting costs ($100/acre; e.g., fencing, vegetation management). Nielsen et al. (2014) also present tree cover establishment costs from data collected from 1986-1993 that were available at the county level. To account for spatial heterogeneity in planting costs, Fargione et al. (2021) costs used in the analysis for this report are scaled by the relative county-level establishment costs from Nielsen et al. (2014). The authors' survey results indicated 543 seedlings planted per acre, not all of which will survive to maturity and contribute to mitigation. In the afforestation scenario, 543 seedlings per acre across 2.3 million acres would result in planting approximately 1.25 billion seedlings planted over 10 years.

Figure A-1 presents the resulting MAC curve. Average annual mitigation from afforestation activities under a carbon price of $51/tCO$_2$e, is 7.8 MtCO$_2$e/yr. This is at a total investment cost of $2.69 billion. These costs can further be broken down by activity, which is presented in Table A-2. At this investment price, 2.36 million acres of afforestation could occur economically, providing for an almost 13% increase in forest area.[22]

Table A-2. Estimated Costs of Afforestation (Million $)

COST TYPE	COST
Seedlings	664.1
Site Prep	318.8
Planting	664.1
Post Planting	265.6
Opportunity	775.3
Total	2,687.9

Figure A-1. Marginal Abatement Cost Curve for Afforestation with $51/tCO_2e Value of Carbon and Implied Mitigation



22 Importantly, our estimates do not account for transactions costs (Galik, Cooley, & Baker, 2012) or landowner hurdle coststhat might limit afforestation (see Baker et al. (2020) for additional discussion).

5.2.3 Reforestation Potential

Reforestation – removal of existing tree cover and intensive replanting – has potential to increase carbon storage over time in the State. Methods for estimating the reforestation potential were derived from Sohngen et al. (2007), who looked at reforestation potential across the Northeast. Estimating the mitigation potential and cost of mitigation from reforestation activities includes: (1) identifying candidate forest plots which would benefit from reforestation, (2) estimating the cost to harvest current biomass and plant new tree cover, (3) estimate the revenue from selling the harvested biomass, and (4) estimating the marginal gain in carbon storage over time from reforestation efforts relative to persistently understocked forests.

Land Availability

The US Forest Service Forest Inventory and Analysis (FIA)[23] identifies forest plots that are nonstocked (0-9% of average stocking rate), poorly stocked (10-34% of average stocking rate), and medium stocked (35-59% of average stocking rate). The analysis in this report is restricted to plots that are currently 40 years old or greater to avoid reforesting areas that might otherwise reach full potential on their own. Poorly and non-stocked forest plots older than 40 years constitute about 221,000 and 21,000 acres respectively, while medium stocked forest represent a large portion of forest area in New York State (slightly more than 903,000 acres) but have less mitigation potential per acre. Figure 2 (above) presents the location of each of these plots.

Costs

Costs associated with reforesting current forests includes harvesting of standing timber, site preparation activities such as competition suppression, animal management, site management plans, and the costs of seedlings. Sohngen et al (2007) include cost estimates for each of these activities for the Northeast. Harvest costs are estimated to be $27.32/m^3, seedlings are estimated at $328.96/acre for a rate of 486 seedlings/acre, and site management costs are estimated at $189.44/acre, for a total reestablishment cost of $518.40/acre. In addition to the costs of reestablishing forest cover post-harvest, landowners would receive payment for the current biomass harvested from their lands. Estimates of current levels of standing biomass are included in the FIA database, including estimates for merchantable biomass, and volume in the sawlog portion of sawtimber trees. We combined these estimates with historical prices received for forest biomass and sawtimber to estimate the value of merchantable wood currently on understocked forest plots. Stumpage prices were collected from the New York State Timber Harvest Statistics[24], averaging the "low price range" across species and regions. This resulted in an estimate

Table A-3. Estimated Cost and Revenue (Negative Costs) from Reforestation Activities (MM 2020$)

COST TYPE	COST
Seedlings	$377.08
Other Planting Expenses	$217.15
Harvesting Current Timber	$1.00
Sawtimber Value	$-0.01
Biomass Value	$-1.11
Net Cost	**$594.1**

23 https://apps.fs.usda.gov/fia/datamart/datamart.html

24 https://www.dec.ny.gov/docs/lands_forests_pdf/stumpagewinter21.pdf

of \$263.82/MBF. Value for forest biomass was assigned from the average import price of pulpwood into the U.S. from the USDA's Foreign Agricultural Service from January 2016 to February 2021, resulting in a price of \$30.50/ m^3.

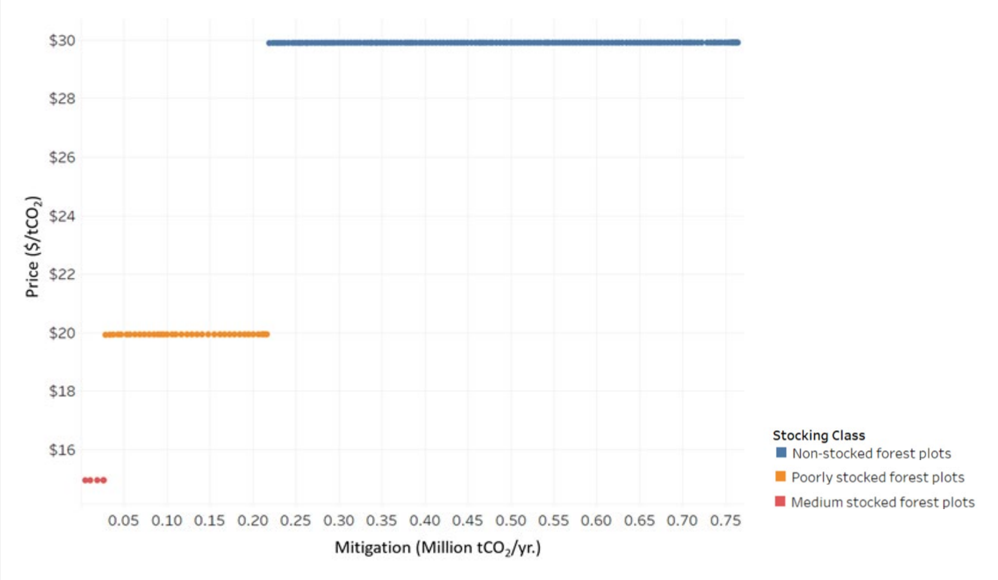
Carbon Storage

Sohngen et al. (2007) found that current under- and poorly stocked forests contain about 17 tC/acre as opposed to 37 tC/acre for current fully stocked forests. This ratio of carbon storage in under- and poorly stocked forest relative to fully stocked forests is the basis for adjusting the average annual sequestration rate presented above (1.27 tC/yr.) to estimate the marginal benefit from replanting forests. By assumption, the analysis in this report assigns nonstocked forest the full marginal benefit from replanting, poorly stocked forests 75% of the marginal benefit, and medium stocked forests 50% of the marginal benefit.

Cost and Mitigation Potential

Combining land availability projections, costs of reforestation, and potential greenhouse gas mitigation, mitigation of 0.8 $MtCO_2$/yr. over 30 years or about 23.3 $MtCO_2$ of additional carbon can be stored in understocked New York State forests at a total net cost of \$0.59 billion. Table A-3 presents the costs of individual activities involved in reforesting and the potential value of harvested timber currently in understocked stands. The estimates are also presented in a MAC curve, showing the cost and mitigation potential of each eligible forest plot (Figure A-2). The resulting MAC follows a step-wise pattern, with little variation in cost between plots within a similar stocking class. This pattern is driven by the limited amount of merchantable forest biomass on these plots, along with similar amounts of standing biomass on the landscape leading to consistent harvest costs and consistent sequestration potential per acre.

Figure A-2. Marginal Abatement Cost Curve for Reforestation



5.2.4 Livestock

This section focuses on the methods used to estimate the potential reduction of methane emissions from dairy cow manure, which can be abated by cover and flare practices. Dairy farming contributes both methane and nitrous oxide from cow manure. Covering and flaring manure methane use anaerobic storage to separate liquid and solid waste then capture and burn the methane emitted from the liquid waste, converting it to CO_2, which has a much lower global warming potential than methane. While nitrous oxide emissions from manure are still present in cover and flare systems, they are a relatively small portion of total GHG emissions and are not accounted for in the analysis for this report. Baseline emissions and abatement potential methodology come from Wightman & Woodbury (2016) and supporting literature. Total baseline methane emissions are a function of the waste excreted from the cattle population and the waste management storage (WMS) type.

Data and assumptions

Population data of dairy cattle and heifers are from USDA's National Agricultural Statistics Service (NASS) and are available at the county level and by farm size. Based on these data, farms are categorized as small (<200 cows), medium (200 to 499 cows), large (500-999 cows), XL (1,000 to 2,499 cows), and XXL (≥2,500 cows). Data and assumptions on WMS type and cost information for covers come from Wightman & Woodbury (2016). Manure can be managed by daily spread, solids storage, liquid-slurry, and a combination of solids and liquids managed separately. Each WMS has a different methane conversion factor (MCF); the most relevant MCF here is liquid slurry (0.24).[25] By 2022, Wightman and Woodbury (2016) project 70% of all New York State dairy manure will be stored as liquid slurry, 17% as solids, and the remaining 13% daily spread. Medium sized farms and larger are assumed to use liquid slurry WMS in compliance with CAFO standards for dairy farms.[26] The remaining manure from daily spread and solids storage is assigned to small farms as a weighted share.

Farms can adopt medium or large covers, depending on the size of the farm. Only farms with 200 or more cows are considered eligible for adopting cover and flares as this is the cost-effective threshold size. The costs concerning covers are based on a 10-year lifespan, though this is conservative as cover and flare systems are expected to work for as much as twice that time.

Mitigation Potential

Kilograms of manure, multiplied by the MCF specific to that farm's WMS and environmental constants, converts manure to methane emissions. Based on these calculations, an estimated 4.9 million tons of CO_2e are emitted annually from all dairy manure farms in New York State (Table A-4). Most of these emissions come from farms of 1,000 or more cows.

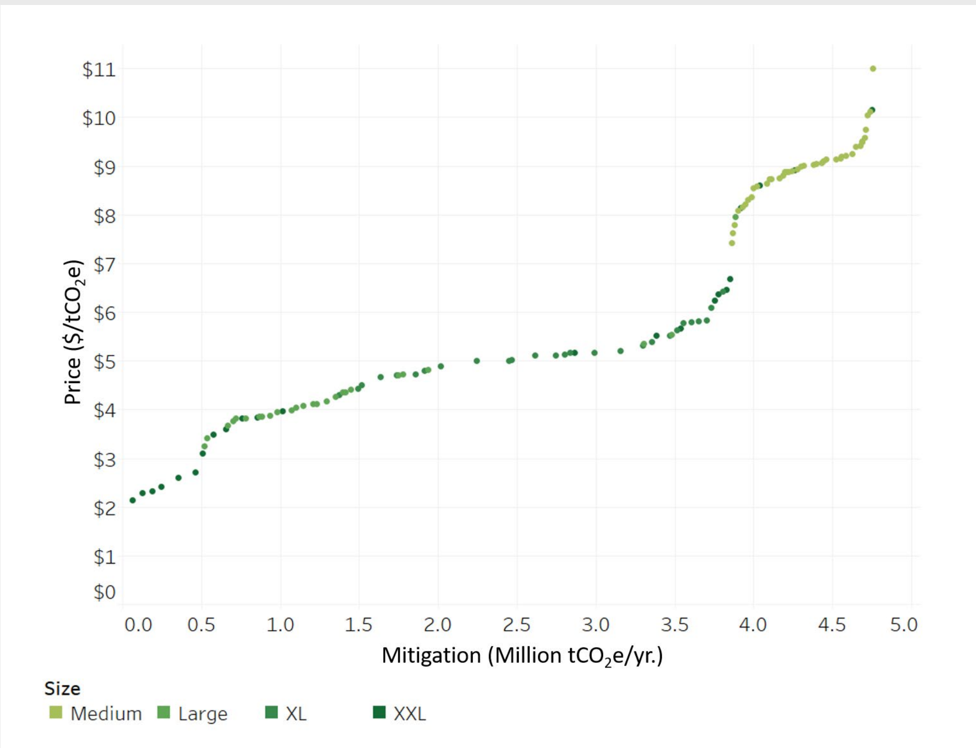
25 As climate change continues to increase average temperatures, the MCF for liquid slurry is expected to increase.

26 https://www.dec.ny.gov/docs/water_pdf/wastestoragefacility.pdf

Table A-4. Methane Emissions from Dairy Farms (Metric Tons CO_2e)

REGION	TOTAL	SMALL	MEDIUM	LARGE	XL	XXL
State Total	**4,941,116**	**141,202**	**838,608**	**742,051**	**2,175,271**	**1,043,984**
Capital Region	**439,012**	4,872	121,663	51,197	177,548	83,731
Central NY	**894,090**	15,691	112,762	140,969	421,217	203,452
Finger Lakes	**1,406,437**	37,598	179,307	191,501	669,092	328,940
Mid-Hudson	**24,206**	2,108	22,098			
Mohawk Valley	**287,288**	21,303	76,991	43,117	99,300	46,577
North Country	**1,047,523**	25,582	86,720	195,976	503,119	236,126
Southern Tier	**406,859**	18,171	137,906	60,757	129,691	60,335
Western NY	**435,700**	15,876	101,161	58,535	175,304	84,824

Figure A-3. Marginal Abatement Cost Curve for Dairy Manure Methane Emissions Mitigation



To calculate abatement, an updated MCF for anaerobic storage and estimates of methane emissions that are not captured and combusted are needed. There are three ways in which methane is not combusted in a cover and flare system: (1) vented methane, accounted for by the 81% annual flare effectiveness (AFE), (2) from solids stored separately, and (3) punctured covers that would require repair. More methane is produced in anaerobic environments for the same volume of waste; the MCF increases from 0.24 to 0.68 in the State (Wightman & Woodbury 2016). This means that the total amount of methane being combusted in cover systems is greater than the counterfactual emissions from the same farm using liquid slurry. To calculate how much methane has been abated using covers and flares, we calculate the unflared portion (1-81% annual flare effectiveness) of the covered liquids and calculate the methane generated from the solids portion stored elsewhere. Deducting these two emission sources demonstrates emissions abatement potential (Eqn 1). Table A-5 shows the total tons of abated methane with the use of cover and flare.

Eqn. 1

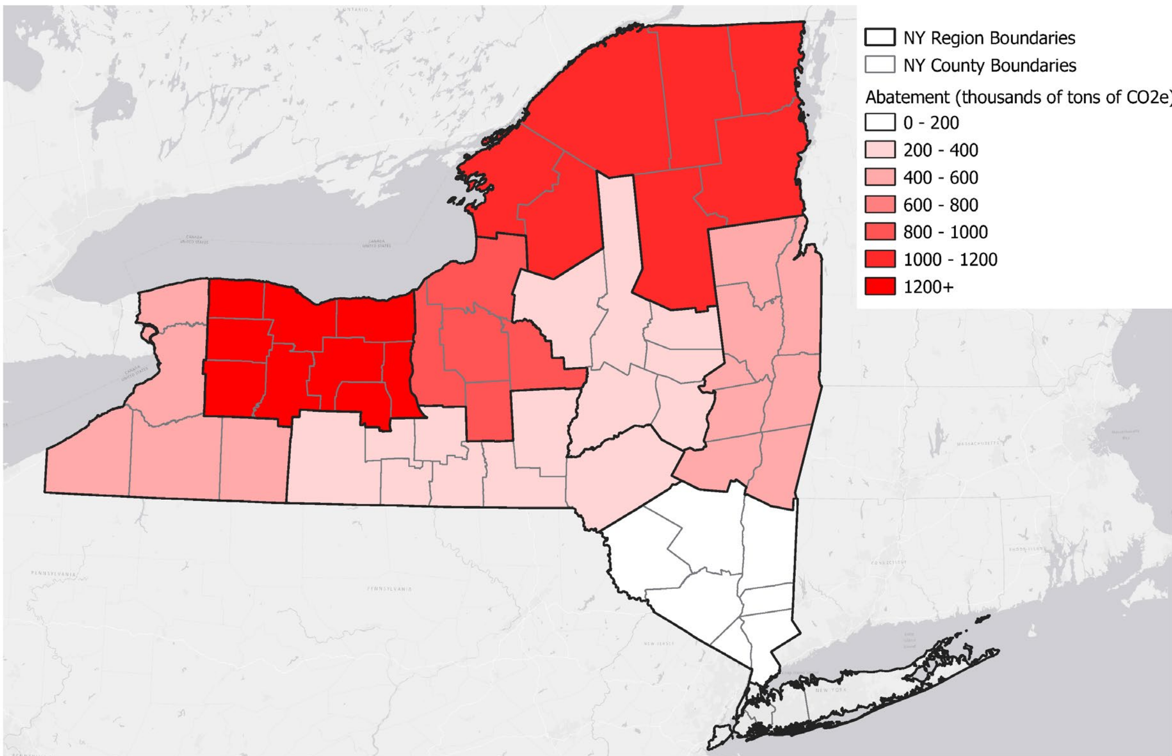
$$\text{Abatement} = \text{emissions}_{MCF_b} - \text{escape}_{MCF_p} - \text{remaining solids}_{MCF_s}$$

To calculate costs, the number of farms were estimated by taking historical cattle population data and extrapolating to 2022 and dividing by the median value for each category size (or 4,250 in the case of the largest farms). From there, the number of total covers were estimated by multiplying the farms by a multiplier depending on the size of the farm, as larger farms require more covers. Cost estimates exist for medium and large covers. Costs are determined at the county level, taking the cost of each component of covers (e.g., personnel, equipment, contracts, etc.) and multiplying by the number of covers estimated for each category of farm size. Combining the costs and mitigation potential, a marginal abatement cost curve can be derived. Figure A-4 shows the projected marginal cost of abatement from cover and flare applications in New York State, organized from least to most expensive per ton abatement. Figure A-6 shows total tons of abatement by geographic region.

Table A-5. Methane Abated (Metric Tons CO_2e)

REGION	TOTAL	MEDIUM	LARGE	XL	XXL
State Total	**4,770,510**	**833,471**	**737,506**	**2,161,945**	**1,037,589**
Capital Region	431,480	120,918	50,884	176,460	83,218
Central NY	873,018	112,071	140,105	418,636	202,205
Finger Lakes	1,360,454	178,208	190,328	664,993	326,925
Mid-Hudson	21,963	21,963			
Mohawk Valley	264,355	76,519	42,853	98,692	46,291
North Country	1,015,680	86,188	194,775	500,037	234,679
Southern Tier	386,307	137,062	60,384	128,896	59,965
Western NY	417,253	100,542	58,176	174,230	84,304

Figure A-4. **Emissions Abatement by Region from Manure Methane Cover and Flare**



5.2.5 Economic Impacts

Multiplier Calculations

County-level IMPLAN 2018 data for the State form the basis of economic impact multipliers for afforestation, reforestation, and manure methane capture and flaring. The analysis for this study based multipliers on county-level data aggregated to New York State's ten economic development regions and 35 sectors including (1) agriculture and forestry support services (NAICS 115); (2) forestry, forest products, and timber tract production (NAICS 113110, 113210) for afforestation costs, and (3) commercial logging (NAICS 113310) for the harvesting component of reforestation. Manure methane cover and flare cost categories included plastics materials for the cover (NAICS 326111, 326112, 326113) in addition to construction and commercial sectors for installation and materials.

Afforestation opportunity costs are modeled as induced impacts from payments to landowners to allow afforestation of their lands (for acres with opportunity costs). Forestry and support services are modeled as direct activities with indirect and induced impacts. Milling activity for reforestation generates indirect and induced impacts only. Only construction and personnel costs for dairy manure methane installations contribute direct impacts and all non-direct personnel impacts are counted as induced.

The analysis for this report includes independently calculated direct, indirect, and induced multipliers using regional purchase coefficients (RPCs) based on IMPLAN's interstate and international trade estimates by sector for the State. RPCs are a standard way of isolating the economic impact on a given region, excluding the impacts on regions outside the study area. The analysis used multipliers for all 35 sectors across the ten New York State regions. Reported impacts are on the entire State from activity originated in the analysis regions (differences between regional and state-wide impacts were modest). IMPLAN employee compensation and job counts are reported as wages and full-time equivalent jobs respectively using conversion tables from IMPLAN. Economic impacts from the bioeconomy component of the reforestation scenario (i.e., harvested pulpwood) are driven by the non-pulpwood purchases of the pulp mill sector only to avoid double counting and indicate the economic benefit of local pulp mills that would be more active processing output from reforestation harvesting. Suitable mills may not exist in all regions of New York State to process these forest products, however.

Labor Force Assessments

Occupational data were compiled for the State from the Bureau of Labor Statistics' Occupation, Employment, and Wage Statistics (OES) data at a 2-digit NAICS-code level (Standard Occupational Classification (SOC) System codes 43-0000 and 11-0000, respectively).[27] Iterative proportional fitting techniques were used to estimate the number of people employed in New York State, in a given industry, and in a given occupation from OES data.

27 See "Occupational Employment and Wage Statistics." https://www.bls.gov/oes/#data

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Afforestation, Reforestation, and Manure Methane Capture